European Commission

SET PLAN TASK FORCE RECOMMENDATIONS

Task Force 1: Circularity and Materials Substitution

Cross-cutting recommendations on tools and methods to make SET Plan technologies more sustainable and resilient

JUNE 2026

CONTENTS

Abbreviations 3

Executive summary 6

1. Introduction 10

2. Key EU policies and initiatives 13

3. Recommendations 14

3.1 Recommendation 1: Generate circular principles and design criteria for energy technologies 15

3.2 Recommendation 2: Create guidelines for Life Cycle Assessments of energy technologies 18

3.3 Recommendation 3: Develop EU-level indicators and targets expressing different circularity strategies 23

3.4 Recommendation 4. Accelerate material substitution for SET Plan Technologies through targeted research and development, and cross-sector collaboration 27

3.5 Recommendation 5: Strengthen the supply of circular materials for SET Plan Technologies through targeted recycling R&D and infrastructure development 31

3.6 Recommendation 6: Stimulate demand for circular materials and components in SET Plan Technologies 35

4. Annexes 39

Annex 1: Participants of the Task Force 39

Annex 2: Methodology of the Task Force 40

ABBREVIATIONS

Abbreviation	Definition
AI	Artificial Intelligence
CCSU	Carbon Capture and Utilisation
CE	Circular Economy
CEAP	Circular Economy Action Plan
CEN	European Committee for Standardisation
CENELEC	European Committee for Electrotechnical Standardisation
CETP	Clean Energy Transition Partnership
CIIP	Common Implementation and Investment Plan
CRMA	Critical Raw Materials Act
CRM	Critical Raw Material
CSRD	Corporate Sustainability Reporting Directive
DG ENER	Directorate-General for Energy
DG GROW	Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs
DG RTD	Directorate-General for Research and Innovation
DPP	Digital Product Passport
DUT	Driving Urban Transition
EC	European Commission
ECRMB	European Critical Raw Materials Board
EDF	Électricité de France
EEA	European Environment Agency
EF	Environmental Footprint
EIB	European Investment Bank
EIP	European Innovation Partnerships
EIT	European Institute of Innovation and Technology
EERA	European Energy Research Alliance
ERMA	European Raw Materials Alliance
ESPR	Ecodesign for Sustainable Products Regulation
ETIP	European Technology and Innovation Platform
ETIP BAT	Batteries
ETIP BIO	Bioenergy
ETIP GEO	Geothermal
ETIP HYDRO	Hydropower
ETIP OCEAN	Ocean Energy
ETIP PV	Solar Photovoltaics
ETIP RHC	Renewable Heating and Cooling
ETIP SNET	Smart Networks for Energy Transition

Abbreviation	Definition
ETIP SNETP	Sustainable Nuclear Energy Technology Platform
ETIP WIND	Wind energy
ETIP ZEP	Zero Emissions Platform
EU	European Union
FCH JU	Fuel Cells and Hydrogen Joint Undertaking
GEOTHERMICA	Geothermal ERA NET Cofund
GHG	Greenhouse Gas
GPP	Green Public Procurement
H2	Hydrogen
IEA	International Energy Agency
ILCD	International Reference Life Cycle Data System
IP	Implementation Plan
ISO	International Organisation for Standardisation
IWG	Implementation Working Group
IWG CCS-U	Carbon Capture, Storage, and Utilisation
IWG DCT	Direct Current Technologies
IWG EEB	Energy and Resource Efficiency in Buildings
IWG GEO	Geothermal Energy
IWG H2	Hydrogen
IWG ES	Energy Systems
IWG IND	Sustainable and Efficient Energy Use in Industry
IWG NS	Nuclear safety
IWG OCEAN	Ocean energy
IWG PEDs	Positive Energy Districts
IWG PV	Solar Photovoltaics
IWG RFB	Renewable fuels and bioenergy
IWG CST	Concentrated Solar Thermal
IWG WIND	Wind energy
JRC	Joint Research Centre
KPI	Key Performance Indicator
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LFP	Lithium Iron Phosphate
NZIA	Net-Zero Industry Act
OECD	Organisation for Economic Co-operation and Development
PEF	Product Environmental Footprint

Abbreviation	Definition
PV	Photovoltaics
R&D	Research and Development
SET	Strategic Energy Technologies
SF6	Sulfur Hexafluoride
SME	Small and Medium-sized Enterprise
SRIA	Strategic Research and Innovation Agenda
SSbD	Safe and Sustainable by Design
TF	Task Force
TRL	Technology Readiness Level
WFD	Waste Framework Directive

This document has been prepared for the European Climate, Infrastructure and Environment Executive Agency (CINEA). However, the information and views presented herein reflect those of the members of the SET Plan Task Forces, and the European Commission or European Climate, Infrastructure and Environment Executive Agency (CINEA) are not liable for any consequence stemming from the reuse of this publication.

Contact address: SET-PLAN-SECRETARIAT@ec.europa.eu

EXECUTIVE SUMMARY

The recommendations of the Task Force on 'Circularity and Material Substitution' address two distinct, but often complementary, concepts of 'circularity' and 'material substitution'. The recommendations aim to provide effective tools and methods to **make Strategic Energy Technologies (SETs) more sustainable and resilient, to maximise the use of existing materials, for example through recycling and repair, and to develop advanced high-performance materials that can act as substitutes.**

The Task Force on 'Circularity and Material Substitution' developed **six recommendations**, created by 23 Task Force members, 5 Independent Experts and the Task Force Leader and Facilitator. The European Commission Policy Officers had an observer role in the recommendation development process.

The recommendations specify **why** action is needed, **what** solutions could address the identified challenges, and **how** they could be implemented. These elements are synthesised below for each of the recommendations. The recommendations also identify the target audience (**who**), the proposed timing for implementation (**when**), and the **KPIs** that could be used to track progress.

The Task Force recommendations target key SET Plan stakeholders: primarily the Implementation Working Groups (**IWGs**), and the European Technology and Innovation Platforms (**ETIPs**), but also the European Energy Research Alliance (**EERA**), and the Clean Energy Transition Partnership (**CETP**). The Task Force members, representing the IWGs, ETIPs, EERA and CETP, have expressed strong interest in implementing the recommendations. Implementation is encouraged to commence in 2026 and continue throughout 2027-2030. Progress can be monitored using the proposed KPIs.

Recommendation 1: Generate circular principles and design criteria for energy technologies

Why: A large share of the environmental and resource impacts of SET Plan technologies is determined at the design stage through choices related to materials, durability, repairability, recyclability and energy efficiency. Although EU frameworks such as the Circular Economy Action Plan and the Ecodesign for Sustainable Products Regulation promote circularity, there is still a lack of harmonised, technology-specific guidance. As a result, many energy technologies remain difficult and costly to repair, refurbish or recycle.

What: This recommendation proposes the development of harmonised circular design principles and technology-specific criteria for SET Plan technologies. The criteria should support life extension, reuse, recyclability, modularity, reverse supply chains and reduced energy losses, while being adapted to the specific characteristics of different technologies and value chains.

How: : Implementation should start with a stock-taking exercise to assess existing circularity-by-design practices and identify gaps across SET Plan technologies. Based on this, SET Plan stakeholders should jointly develop practical guidance and design criteria tailored to different technologies. The process should include regular updates, common sustainability terminology and monitoring of implementation through industry feedback and surveys.

Recommendation 2: Create guidelines for Life Cycle Assessments of energy technologies

Why: Current Life Cycle Assessment (LCA) practices for SET Plan technologies are often fragmented, with inconsistent methodologies, limited data availability and low comparability between studies. These gaps make it difficult to assess sustainability, circularity and material substitution impacts in a reliable and harmonised way, and limit informed decision-making for policy, investment and technology development.

What: This recommendation proposes the development of harmonised, energy technology-specific guidelines for conducting LCAs of SET Plan technologies. The guidelines should align with the Product Environmental Footprint framework and emerging EU standards. They should also support assessments of environmental, circularity and material substitution impacts across different technologies and value chains.

How: Implementation should involve cooperation between SET Plan stakeholders, the EC and standardisation bodies to identify data gaps, develop common methodologies and generate technology-specific guidance. Dedicated working groups, targeted research funding and improved life cycle inventory data generation should support the creation of harmonised benchmarks, datasets and assessment tools for SET Plan technologies.

Recommendation 3: Develop EU-level indicators and targets expressing different circularity strategies

Why: The transition to a circular energy system requires reliable ways to measure progress across technologies, value chains and governance levels. Currently, only limited indicators are available for tracking circularity within the EU energy system. Existing metrics often focus mainly on recycling rather than broader circular strategies such as prevention, reuse, repair and remanufacturing. This limits the ability to monitor progress, compare performance and guide policy and investment decisions effectively.

What: This recommendation proposes developing EU-level indicators and targets that capture the full range of circularity strategies within the R framework across SET Plan technologies (e.g. from 'Refuse' to 'Recover'). These indicators should also be specific to different life cycle phases, SET Plan technologies, and implementation levels (e.g. the EU and national levels, companies and households).

How: Implementation should involve a structured and collaborative process bringing together SET Plan stakeholders, EU institutions, industry, researchers and national authorities. Existing frameworks and standards should serve as a basis for developing harmonised methodologies, supported by common data collection systems, pilot testing and integration into SET Plan monitoring and reporting frameworks. Regular reviews and digital tools should ensure indicators remain relevant as technologies and policies evolve.

Recommendation 4: Accelerate material substitution for SET Plan Technologies through targeted research and development, and cross-sector collaboration

Why: Many SET Plan technologies, including batteries, photovoltaics, wind turbines and hydrogen systems, depend on critical and high-risk raw materials that are scarce, geopolitically sensitive or environmentally harmful to extract. Current approaches to material substitution are often fragmented across sectors, increasing supply risks and limiting the EU's ability to scale clean energy technologies sustainably and competitively

What: This recommendation proposes accelerating material substitution across SET Plan technologies through targeted research, innovation and cross-sector collaboration. It focuses on identifying technology-specific substitution priorities, developing sustainable alternative materials, and strengthening cooperation between the energy, materials, chemical and manufacturing sectors to reduce dependence on critical raw materials.

How: Implementation should begin with identifying priority materials for substitution within each technology area, supported by JRC studies and existing EU frameworks such as the Critical Raw Materials Act. Targeted R&D programmes, shared testing and innovation platforms, and dedicated cross-sector working groups should support the development and deployment of alternative materials. In parallel, policy measures, eco-design standards and market incentives should help accelerate industrial uptake and long-term adoption.

Recommendation 5: Strengthen the supply of circular materials for SET Plan Technologies through targeted recycling R&D and infrastructure development

Why: Recycling rates for many critical raw materials used in SET Plan technologies remain low, while limited recycling infrastructure, insufficient recovery systems and fragmented value chains continue to hinder circularity. Valuable materials from batteries, PV modules, wind turbines and hydrogen systems are often lost at end of life, increasing dependence on primary raw materials and creating environmental and supply risks.

What: This recommendation proposes strengthening the supply of circular materials by expanding recycling, remanufacturing, and recovery capacities for SET Plan technologies. It focuses on improved material-flow mapping, targeted R&D for advanced recycling technologies, shared infrastructure, and digital collaboration tools to increase the recovery and reintegration of high-value secondary raw materials.

How: Implementation should start with identifying priority material streams and components with high recovery potential across SET Plan technologies. Targeted R&D, pilot recycling and remanufacturing facilities, and shared testing infrastructure should support the development of scalable recovery solutions. In parallel, digital platforms, training programmes and policy measures promoting recyclability and the use of recycled materials should help strengthen circular value chains and market uptake across the EU.

Recommendation 6: Stimulate demand for circular materials and components in SET Plan Technologies

Why: Despite growing interest in circular economy solutions, the uptake of reused, recycled and renewable materials in energy technologies remains limited. Higher costs, insufficient standards, fragmented value chains and low market confidence continue to restrict demand for circular materials and components across SET Plan technologies.

What: This recommendation proposes measures to stimulate demand for circular materials and components in SET Plan technologies through harmonised standards, certification schemes, incentives and targeted public procurement. The objective is to create a viable single market for circular solutions and strengthen the business case for recycled, remanufactured and renewable materials.

How: Implementation should involve cooperation among SET Plan stakeholders, industry, policymakers and standardisation bodies to develop common standards, certification systems and market incentives. Public procurement criteria, financial support mechanisms and awareness-raising activities should help increase market confidence and encourage wider adoption of circular materials across clean energy value chains.

1. INTRODUCTION

The concepts of 'circularity' and 'material substitution' are distinct and complement each other only under certain conditions. **The common ground between these two concepts is their focus on the use of materials**[1]. In theory, material substitution can, under the right circumstances, contribute to circularity - if the substitution of materials contributes towards (greater implementation of) the R-strategies (see Table 1 below). To align with broader EU policy objectives, it is important to emphasise that both material substitution and circularity should ultimately contribute to sustainability and improved resilience, ensuring positive environmental, social, and economic outcomes. Accordingly, it is acknowledged that increases in the energy efficiency of SET Plan technologies could also influence circularity and material substitution and could therefore be monitored through indicators.

CIRCULARITY

The circular economy is a model of **production and consumption that involves practices such as sharing, leasing, reusing, repairing, refurbishing, and recycling existing materials and products for** as long as possible. In this way, product lifetimes can be extended and waste reduced to a minimum[2].

At the EU level, the Waste Framework Directive (WFD, 2008)[3] refers to **waste as any substance or object that the holder discards, intends to discard, or is required to discard**. The WFD also establishes a hierarchy of preferred practices to promote a circular economy, with 'prevention' as the most favoured strategy and 'disposal' the least (as shown in the figure below).

Figure 1: Waste hierarchy under the Waste Framework Directive. Source: European Commission

Since the introduction of the WFD (2008), new frameworks have been developed to define various strategies for circularity. One example is the 'R-strategies' framework, shown in Table 1 below. These R-strategies can be classified under three categories based on the 'waste loop' they represent. While shorter loops and higher positions on the R-ladder are **generally associated** with greater resource efficiency and circularity, it is important to note that these strategies do not **automatically** lead to sustainability benefits. Their effectiveness depends on the specific context and should be evaluated on a case-by-case basis.

1) **Smarter product manufacturing and use** (R0 Refuse, R1 Rethink, R2 Reduce) in the design phase. This prioritises avoiding unnecessary resource use and optimising product design (e.g., energy technologies) to reduce material inputs and consider the whole life cycle from the design phase onward.

2) **Life extension strategies** (R3 Reuse, R4 Repair, R5 Refurbish, R6 Remanufacture, R7 Re-purpose) in the consumption phase. Extend the lifespan of energy technologies through reuse, repair and refurbishment, maximising the utility of existing components.

1 Specifically, material efficiency (considering to what extent the use of materials in process/products/systems achieve a desired outcome) and material effectiveness (the quality and suitability of the material for a specific function).
2 https://www.europarl.europa.eu/topics/en/article/20151201STO05603/circular-economy-definition-importance-and-benefits
3 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32008L0098

3) **Creative material applications** (R8 Recycle, R9 Recover) at the end-of-life phase. Recycle materials (e.g. from decommissioned energy assets) and recover resources to minimise waste and promote circularity.

Table 1: Overview of 'R-strategies' for circularity

	R-Strategy	Description
Smarter product use and manufacture	R0: Refuse	Make product redundant by abandoning its function or by offering the same function by a radically different (e.g. digital) product or service.
	R1: Rethink	Make product use more intensive (e.g. through product-as-a-service, reuse and sharing models or by putting multi-functional products on the market).
	R2: Reduce	Increase efficiency in product manufacture or use by consuming fewer natural resources and materials, including reducing energy losses. It includes the prevention of food waste across food value chains, including agricultural production, processing, manufacturing, distribution, and consumption.
Life extension strategies	R3: Reuse	Reuse of a product which is still in good condition and fulfils its original function (and is not waste) for the same purpose for which it was conceived.
	R4: Repair	Repair and maintenance of defective products so they can be used with their original function.
	R5: Refurbish	Restore an old product and bring it up to date (to the specified quality level).
	R6: Remanufacture	Use parts of a discarded product in a new product with the same function (and in as-new condition)
	R7: Repurpose	Use a redundant product or its parts in a new product with a different function.
Creative material application	R8: Recycle	Recover materials from waste to be reprocessed into new products, materials or substances, whether for the original or for other purposes. This includes the reprocessing of organic material but does not include energy recovery or reprocessing into materials for use as fuels or for backfilling operations.
	R9: Recovery (of energy)	Recovery of (embodied) energy from waste and residues. From a waste management angle, energy recovery is an environmentally preferable option to landfill disposal in accordance with the waste hierarchy principle. However, the resource-efficiency gains from waste-to-energy and waste-to-fuel strategies are limited compared with other 9Rs, particularly given the loss of value of potentially recyclable materials through combustion [4].

Adapted from: The EIB Circular Economy Guide, European Investment Bank (2020) [5]

4 Hence, the EIB does not consider activities primarily aimed at energy recovery from wastes and residues as substantially contributing to the circular economy.

5 European Investment Bank. (2023). The EIB circular economy guide: Supporting the circular transition. European Investment Bank. https://www.eib.org/attachments/thematic/circular_economy_guide_en.pdf

MATERIAL SUBSTITUTION AND ADVANCED MATERIALS

Below, we define the terms 'Material substitution' and 'Advanced Materials', as well as explore their relationship.

- **Material substitution:** the process of replacing hazardous, scarce, critical or environmentally harmful materials used in products or industrial processes with more sustainable, readily available, or less harmful alternatives.
- **Advanced materials:** materials that are rationally designed to have (i) new or enhanced properties, and/or (ii) targeted or enhanced structural features to achieve specific or improved functional performance. This includes both new emerging manufactured materials (high-tech materials) and materials that are manufactured from traditional materials (low-tech materials) [6].

The material currently used in energy technologies can be substituted with advanced materials. Such material substitution could lead to improved economic or environmental performance. For example, substituting materials with renewable or low-carbon materials can reduce emissions, waste and virgin material demand [7]. Recent developments in EU policy (read further below) place strategic focus on critical raw materials (CRMs), which are economically important and have a high supply risk [8]. As such, EU efforts may now be focused on identifying substitutes for CRM, especially those that are geopolitically sensitive or subject to supply chain vulnerabilities [9].

The main objectives of the Task Force on 'Circularity and Material Substitution' were to:

- Integrate circularity by design across clean energy technologies.
- Standardise EU regulations and metrics for material recycling and sustainable substitution.
- Accelerate the development of advanced substitute materials to reduce CRMs use.
- Expand recycling infrastructure, prioritising strategic and critical materials.
- Simplify Life Cycle Assessment (LCA) tools for widespread industry adoption.
- Enhance funding mechanisms and incentives to scale up circular economy solutions.
- Harness digitalisation to boost material traceability and cross-sector collaboration.

.

6 OECD. (2022). Advanced materials: Working description (OECD Environment, Health and Safety Publications Series on the Safety of Manufactured Nanomaterials No. 104). OECD Publishing. https://one.oecd.org/document/ENV/CBC/MONO(2022)29/en/pdf

7 European Commission. (2023). Circular energy transition: A framework for the future. European Commission. https://circulareconomy.europa.eu/platform/sites/default/files/2023-06/Circular-energy-transition.pdf

8 The Commission reviews the list of critical raw materials for the EU every three years. The list of 2020 includes 30 CRMs: European Commission. (2020). Critical raw materials resilience: Charting a path towards greater security and sustainability (COM(2020) 474 final). European Commission. https://ec.europa.eu/docsroom/documents/42849

9 Joint Research Centre. (2024). Advanced materials for substitution in the clean energy sector. Publications Office of the European Union. https://setis.ec.europa.eu/document/download/1ac68d55-705e-4b28-ad2a-3d681d4ca90d_en?filename=Advanced%20materials%20for%20CRM%20substitution_0.pdf

2. KEY EU POLICIES AND INITIATIVES

The Task Force 'Circularity and Material Substitution' is situated within a complex array of existing legislative documents (e.g. EU directives and regulations), strategic communications, and EU initiatives. Key EU policies are listed in the table below.

Table 2: Key EU policies and initiatives for Task Force 1 (Circularity and Material Substitution

Type of policy	Relevant EU policies and initiatives
Cross-sectoral policies	EU Green Deal [10] (2020), European Green Deal Industrial Plan [11] (2023), Net-Zero Industry Act [12] (NZIA, 2024), European Industrial Strategy [13] (2021), Clean Industry Deal [14] (2025)
Energy policies	Renewable Energy Directive [15] (2023), Energy Efficiency Directive [16] (2023), EU Energy System Integration Strategy [17] (2020)
Circularity policies	Circular Economy Action Plan [18] (CEAP, 2020), Ecodesign for Sustainable Products Regulation [19] (2024), Waste Framework Directive [20] (WFD, 2008), new Batteries Regulation [21] (2023), Directive on End-of-Life Vehicles [22] (2000), Waste Electrical and Electronic Equipment Directive [23] (2012), Circular Economy Act [24] (2025)
Materials substitution policies	Critical Raw Materials Act [25] (CRMA, 2024), Communication on Advanced Materials for Industrial Leadership [26] (2024)
Other relevant policies	Communication on Making Sustainable Products [27] (2022)
EU initiatives	• High-level expert groups: European Critical Raw Materials Board [28] (ECRMB), Technology Council for Advanced Materials [29] • Partnerships: European Innovation Partnerships (EIP) on raw materials [30], the EU's strategic raw materials partnerships with third countries • Stakeholder networks: European Institute of Innovation and Technology (EIT) Raw Materials [31], European Raw Materials Alliance [32] (ERMA) • Platforms: Circular Economy Stakeholder Platform [33], Raw Materials Information System[34]

10 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:52019DC0640
11 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:52023DC0062
12 https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52023PC0161
13 https://single-market-economy.ec.europa.eu/industry/strategy_en
14 https://commission.europa.eu/topics/eu-competitiveness/clean-industrial-deal_en
15 https://energy.ec.europa.eu/topics/renewable-energy/renewable-energy-directive-targets-and-rules/renewable-energy-directive_en
16 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ%3AJOL_2023_231_R_0001&qid=1695186598766
17 https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=COM%3A2020%3A299%3AFIN
18 https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1583933814386&uri=COM:2020:98:FIN
19 https://eur-lex.europa.eu/eli/reg/2024/1781/oj/eng
20 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32008L0098
21 https://eur-lex.europa.eu/eli/reg/2023/1542/oj/eng
22 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32000L0053
23 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02012L0019-20180704
24 https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/14812-Circular-Economy-Act_en
25 https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52023PC0160
26 https://research-and-innovation.ec.europa.eu/document/download/0fcf06ea-c242-44a6-b2cb-daed39584996_en?filename=com_2024_98_1_en_act_part1.pdf
27 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2024%3A98%3AFIN
28 https://single-market-economy.ec.europa.eu/sectors/raw-materials/areas-specific-interest/critical-raw-materials/critical-raw-materials-act/board_en
29 https://research-and-innovation.ec.europa.eu/research-area/industrial-research-and-innovation/chemicals-and-advanced-materials/advanced-materials-industrial-leadership_en
30 https://single-market-economy.ec.europa.eu/sectors/raw-materials/eip_en
31 https://eitrawmaterials.eu/
32 https://erma.eu/
33 https://circulareconomy.europa.eu/platform/en
34 https://rmis.jrc.ec.europa.eu/

3. RECOMMENDATIONS

The Task Force 'Circularity and Materials Substitution' developed **six recommendations.**

Figure 2: The 'Circularity and Material Substitution' Task Force recommendations

The Task Force recommendations target key SET Plan stakeholders: primarily the IWGs and the ETIPs, but also EERA and CETP.

All recommendations include the following elements:

- **Summary** of the key insights
- **Why** action is needed
- **What** solutions are out there to help resolve challenges
- **Who** is interested in implementing the recommendation
- **How** the recommendation can be implemented through various actions
- **When** it is recommended to implement the recommendation
- **Which KPIs** could help track implementation progress

The Task Force included 23 Task Force members, 5 Independent Experts, the Task Force Leader and Facilitator, and European Commission Policy Officers (as observers) (see participants list in Annex 1). The recommendations were created based on Task Force meetings, written feedback and desk research (see methodology in Annex 2).

RECOMMENDATION 1: GENERATE CIRCULAR PRINCIPLES AND DESIGN CRITERIA FOR ENERGY TECHNOLOGIES

Recommendation summary:

A large share of the environmental and resource impacts of SET Plan technologies is determined at the design stage through choices related to materials, durability, repairability, recyclability and energy efficiency. Although EU frameworks such as the Circular Economy Action Plan (CEAP) and the Ecodesign for Sustainable Products Regulation (ESPR) promote circularity, there is still a lack of harmonised, technology-specific guidance. As a result, many energy technologies remain difficult and costly to repair, refurbish or recycle.

This recommendation proposes the development of harmonised circular design principles and technology-specific criteria for SET Plan technologies. The criteria should support life extension, reuse, recyclability, modularity, reverse supply chains and reduced energy losses, while being adapted to the specific characteristics of different technologies and value chains.

Implementation should start with a stock-taking exercise to assess existing circularity-by-design practices and identify gaps across SET Plan technologies. Based on this, SET Plan stakeholders should jointly develop practical guidance and design criteria tailored to different technologies. The process should include regular updates, common sustainability terminology and monitoring of implementation through industry feedback and surveys.

WHY

Challenges identified by TF members and literature review

A large portion of a product's environmental impact is decided at the design stage. This is because design choices influence material selection, durability, recyclability, and potential for reuse, all of which are crucial for achieving circularity. The amount of energy lost, both during the manufacturing process and during operation, is also heavily influenced by the design phase. The EU's CEAP and related strategies highlight the importance of integrating circularity principles from the outset of product development to minimise waste and maximise resource efficiency.

A key issue is the limited existence, awareness of and implementation of circular design principles. The current landscape is fragmented. While high-level EU frameworks such as the CEAP and the ESPR provide strategic direction, there is a significant lack of clear, technology-specific guidelines and criteria for the circular design of energy technologies. Without clear circular design criteria and guidelines, the design of various energy technologies makes repair, refurbishment, remanufacturing, recycling and recovery difficult and expensive

Expected outcomes and contribution to EU priorities

This recommendation supports the European Green Deal, the CEAP and the SET Plan by promoting circular design in energy technologies. By integrating circularity from the design stage, it aims to reduce material use, increase product lifespan, and improve end-of-life recovery – key steps toward resource efficiency and climate neutrality.

It contributes to:

- The CEAP, by enabling sustainable product design and reducing waste.
- The ESPR, by paving the way for future circularity criteria.
- The Raw Materials Strategy, through reduced reliance on critical resources.
- The EU Climate Law, by lowering the environmental footprint (EF) of energy technologies.
- The WFD, by enhancing reuse, repairability, and recyclability.

For the SET Plan, the recommendation strengthens alignment across Common Implementation and Investment Plans (CIIPs), supports Actions 4 and 6, and provides clear, harmonised guidelines that can improve innovation, deployment, and monitoring of circularity in EU energy systems.

WHAT

Generate circular design criteria and guidelines targeted at energy technologies, derived from some common circular principles:

- Design for life extension (e.g. modular components, easy refurbishment)
- Design for recycling and/or re-use (e.g. label components for easy identification and sorting, integrate Digital Product Passports, digital twins).
- Circular business models (i.e. shift from ownership to service-based models – such as energy-as-a-service).
- Reverse Supply Chain Design (e.g. Plan for take-back schemes and reverse logistics).
- Cross-sectoral circularity (link energy technologies with construction, transport, and manufacturing sectors).
- Implementation of energy efficiency and losses reduction as much as feasible.

The ease of implementing circularity principles varies significantly across different energy technologies. Certain technologies, by their very nature, lend themselves more readily to circular practices, while others face substantial technical and economic challenges. Furthermore, the degree to which circularity principles have been integrated into existing efforts varies, as seen in the differing levels of emphasis ETIPs/IWGs place on advancing circularity by design in their existing Implementation Plans (IPs) and Strategic Research and Innovation Agendas (SRIAs).

The goal is to arrive at a general set of design criteria and technology-specific guidelines (harmonised in principle/goals but adapted to the realities of each energy technology) for meeting these criteria. The resulting circular principles for the design of SET Plan technologies would serve as a strong communication tool to inform and support actors across the value chain, with a focus on simple language in a user-friendly format. The criteria and guidelines should break down how the principles apply to different stakeholder groups (e.g. technology users, design teams, manufacturers of SET Plan technologies, Government/ Regulators/Local authorities). Transparency as to the gaps will facilitate the identification of suitable business cases and may highlight necessary changes to the regulatory and infrastructural landscape.

WHO

- **SET Plan stakeholders** (ETIPs, IWGs, EERA, CETP): To take stock of existing design guidelines and circularity practice in SET Plan technologies. Preliminary examples of material relevant for SET Plan technologies include:
  - Buildings: Level(s)[35] include indicators on 'Design for adaptability and renovation' and 'Design for deconstruction, reuse and recycling'.
  - Solar PV: ETIP PV have hosted events on circular strategies[36]
  - Wind: The Circular Wind Guide presents 18 different circular strategies, which go beyond recycling[37].
  - Batteries: The 'Circularity Guidelines on end-of-life battery management'[38] includes some design principles.
- **Joint Research Centre (JRC):** Circular Economy Strategies for the EU's Renewable Electricity Supply (JRC, 2025)[39]
- **Multiple user groups of the guidelines:** For example, technology users, design teams, manufacturers of SET Plan technologies, government, regulators and local authorities.

35 https://green-forum.ec.europa.eu/green-business/levels/quick-introduction-levels_en
36 https://etip-pv.eu/events/working-group-workshops/towards-a-circular-pv-industry-strategies-innovations-in-pv-circularity-intersolar-2024/
37 Veelen-Kallio, N., van Diest, E., Room, J., & Knol, E. (2022). How to facilitate the wind industry to become fully circular. Circular Wind Hub. https://circulairemaakindustrie.nl/app/uploads/2022/02/How-to-facilitate-the-wind-industry-to-become-fully-circular-by-ECHT-2022.pdf
38 Alliance for Rural Electrification. (2024). ProBaMet circularity guidelines on end-of-life battery management. https://www.ruralelec.org/wp-content/uploads/2024/09/ProBaMet-Circularity-Guidelines.pdf
39 Joint Research Centre. (2025). Circular economy strategies for the EU's renewable electricity supply. Publications Office of the European Union. https://publications.jrc.ec.europa.eu/repository/handle/JRC138570

HOW

To chart an effective path forward, a stock-taking exercise is essential to assess the current state of the material on 'circularity by design' for energy technologies. This analysis should differentiate between academic contributions (the plausible), policy objectives (the desirable), and implementation of circularity practices at the design and operational levels (the reality on the ground). Such an exercise would highlight areas where progress has been made, identify gaps in deployment and adoption, and help determine and prioritise actions advancing circularity in energy technologies. This exercise should be repeated at reasonable intervals to maintain a valid overview of the state of circularity of energy technologies.

Based on the insights gained from the stock-taking exercise, circular design criteria and guidelines should be developed to balance general sustainability principles with the unique challenges and opportunities of each energy technology. At a general level, these guidelines should emphasise core principles such as enhancing recyclability, enabling modular design for easier maintenance and upgrades, and reducing resource intensity (including energy losses) throughout the product lifecycle. In addition, these guidelines should adapt to the nuances of specific technologies (e.g., the accessibility of above-ground vs. underground installations, the use of niche materials, and the speed of technological change in different components of the different technologies). Tailoring these criteria to the distinctive characteristics and maturity levels of various energy technologies will ensure that the guidelines are both practical and impactful, driving meaningful progress toward circularity across the energy sector and allowing for periodic updates as the state of circularity, the deployment of the technologies and the technologies themselves advance. A common glossary of sustainability terms ensures transparency and consistency in the terminology used.

The adoption and usefulness of these guidelines should then be monitored through regular surveys of the respective industries, to develop technology-specific 'Protocols' that guide industrial designers and manufacturers in integrating Circularity Criteria to realise 'Circular Products / Solutions'.

WHEN

Short-term (2026-2027):

- Conduct a thorough stock-taking exercise to map the current state of circularity by design in energy technologies (including glossary).
- Develop design criteria and guidelines, prioritising physical assets where circularity can deliver the greatest impact.

Medium-term (2027-2030):

- Implement these criteria and guidelines.

Long-term (post-2030):

- Track adoption and ensuring guidelines remain useful as technology changes and circularity evolves.
- Conduct and evaluate a suitable industry survey.

KEY PERFORMANCE INDICATORS (KPIS)

- Number of stakeholder platforms that have completed the stock-taking assessment. Alternatively, the degree of coverage is based on the market share of the specific energy technologies.
- Number of stakeholder platforms that have produced circularity guidance documents (principles and criteria addressing specific technical and economic challenges as pertinent to the SET Plan technologies) and report on circularity in their activity fiches.
- Degree of implementation of the guidelines/degree of fulfilment of design for circularity criteria.

RECOMMENDATION 2: CREATE GUIDELINES FOR LIFE CYCLE ASSESSMENTS OF ENERGY TECHNOLOGIES

Recommendation summary:

Current LCA practices for SET Plan technologies are often fragmented, with inconsistent methodologies, limited data availability and low comparability between studies. These gaps make it difficult to assess sustainability, circularity and material substitution impacts in a reliable and harmonised way, and limit informed decision-making for policy, investment and technology development.

This recommendation proposes the development of harmonised, energy technology-specific guidelines for conducting LCAs of SET Plan technologies. The guidelines should align with the Product Environmental Footprint framework and emerging EU standards. They should also support assessments of environmental, circularity and material substitution impacts across different technologies and value chains.

Implementation should involve cooperation between SET Plan stakeholders, the EC and standardisation bodies to identify data gaps, develop common methodologies and generate technology-specific guidance. Dedicated working groups, targeted research funding and improved life cycle inventory (LCI) data generation should support the creation of harmonised benchmarks, datasets and assessment tools for SET Plan technologies.

WHY

Challenges identified by TF members and literature review

The energy industry and researchers alike are currently struggling to find new materials and technical solutions that would be able to guarantee the necessary technical performance, meet the various and sometimes conflicting sustainability and circularity goals (staying within the planetary boundaries), while maintaining competitiveness, urging to reach necessary greenhouse gas (GHG) emission reductions and securing the supply of key materials and components. This is particularly challenging for low Technology Readiness level (TRL) solutions, new technologies, and materials, for which data gaps are common across both the studied processes and materials, as well as across different life cycle stages. Studying the potential impacts of different recycling options is difficult if required data on recycling methods are lacking or if it is not known where and how the necessary infrastructure would operate.

In addition to comprehensive datasets, harmonised technology-specific guidelines and robust benchmarks would be required to identify the most sustainable options, enable fair comparisons between alternative solutions, and attract investment. The lack of specific guidelines makes comparing results across studies (with different goals and scopes) challenging, making it difficult to draw more general conclusions for policy-making purposes. Comprehensive sustainability assessments are also needed for developing the circular design criteria, as explained in the previous recommendation. Eventually, they can assist in creating simpler, life-cycle-based design and LCA tools that focus on the aspects and impacts most relevant to each energy technology, without shifting burdens.

Expected outcomes and contribution to EU priorities

This recommendation directly supports key EU strategies, including the CEAP and the Clean Industrial Deal, which call for life-cycle-based approaches. By promoting harmonised sustainability and circularity assessments – especially through the generation of energy technology-specific LCA guidelines – this action will:

- Enable more robust, comparable, and data-driven decision-making across the SET Plan technologies, increasing sustainability and transparency in product value chains in line with the Digital Product Passport (DPP) Initiative.
- Support the development of sustainability and circularity criteria for future policy frameworks (e.g. under the ESPR and the Industrial Decarbonisation Accelerator).
- Strengthen the resilience of energy value chains, supporting the Raw Materials Strategy and helping to reduce dependencies on critical materials.
- Contribute to the climate neutrality targets by 2050 by identifying low-impact solutions and enabling innovation through better data and evaluation tools.

WHAT

LCA is a research method that can support research and investment decision-making towards a sustainable circular economy. It can be used to identify hotspots where the greatest improvement potential exists, to secure the competitiveness of new energy technologies entering the market, and to target efforts where they matter most from both environmental and economic perspectives.

Conducting LCAs requires specific knowledge, tools and data. The different methodological choices, system boundaries, and data sources used in LCA may significantly affect the results, making it difficult to compare results across studies. A lack of technology-specific guidelines and LCI data is a bottleneck identified by several ETIPs and IWGs that currently prevents wide-scale use of LCA in technology and materials development.

The European Commission has produced voluntary methods and frameworks, such as the Product Environmental Footprint (PEF)[40], and the Safe and Sustainable by Design[41] (SSbD). The SSbD framework follows a life cycle approach and provides support in the development of more sustainable products, technologies and materials. Based on the PEF, more detailed PEF Category rules can also be developed to allow fair and robust comparisons between products or technology groups that serve similar functions. Recently, the International Standards Organisation (ISO) released new standards that provide vocabulary[42] and a framework for circularity measurement[43] (ISO59 000 series), and new standards related to data sharing and circular business models are under preparation.

The Eco-design for Sustainable Product Regulation, the Renewable Energy Directive, and the Batteries Directive are examples of policy initiatives and regulations that integrate selected sustainability requirements and calculation rules. New criteria will be developed as part of the Industrial Decarbonisation Accelerator[44]. According to the Clean Industrial Deal, the development of comprehensive life-cycle assessment and GHG accounting methodologies continues to support voluntary and binding target-setting and the generation of sustainability criteria. Release of the updated and more comprehensive Environmental Footprint (EF4.0) method and related EF database[45] is foreseen in the near future. The SET Plan entities could act as both data set providers and data users in the EF database development.

40 https://eur-lex.europa.eu/eli/reco/2021/2279/oj
41 https://data.europa.eu/doi/10.2760/28450
42 https://www.iso.org/standard/80648.html
43 https://www.iso.org/standard/80649.html
44 https://www.europarl.europa.eu/legislative-train/theme-a-new-plan-for-europe-s-sustainable-prosperity-and-competitiveness/file-industrial-decarbonisation-accelerator-act
45 https://data.europa.eu/doi/10.2777/9177918

Implementing all these voluntary and/or compulsory methods and criteria requires good data availability from the value chains of energy technologies. Feedback collected from current SET Plan stakeholders highlights a lack of necessary data, benchmarks, and a shared understanding of how LCAs and other sustainability assessments should be conducted, and how circularity should be assessed alongside other topics. The existence of harmonised, energy-technology-specific guidelines or product-category rules eases the implementation of the practice methods and facilitates comparisons between alternative solutions. Integrating the views and experiences of the ETIPs into such guidelines is important to ensure they serve their purpose and address relevant points for each energy technology and value chain. To go beyond environmental impacts and cover health and safety and relevant social aspects, additional methods and interdisciplinary research to complement LCA studies are required.

WHO

Generating energy technology-specific environmental footprint category rules (or similar guidelines) requires cooperation between various stakeholders, including SET Plan entities and countries, the EC and JRC and the European Standardisation bodies.

- **SET Plan stakeholders** (ETIPs, IWGs, EERA, CETP): To take stock of existing LCA and sustainability guidelines, prepare for data gap analysis and collect technology-specific insights on the most relevant materials, processes, life cycle stages and environmental impact categories. Existing efforts and activities in this direction are already underway within different ETIPs and IWGs. As an example, ETIP SNET has begun activities with stakeholders on smart energy systems, particularly by defining the technical scope for the LCA of smart grid components. The existing RHC SRIA (p. 25) calls for standardisation and valorisation pathways, which should be tailored to solar thermal components such as collectors, tanks, and piping. ETIP Geothermal has identified various needs related to guidelines and data for geothermal-specific flows, set a dedicated R&I topic on the life cycle approach and emission footprint reduction, and dedicated LCA model development, as part of its SRIA (topic 1). IWG H2 is already implementing LCA activities, but the need for more comprehensive analyses that cover broader sustainability aspects (e.g., water, resource use, and CRMs) has been recognised. The SHE2H project (under Fuel Cells and Hydrogen Joint Undertaking – FCH JU) has developed guidelines for the LCA of fuel cells and hydrogen (H2) technologies.[46] The lack of harmonised guidelines and up-to-date datasets has been identified as a bottleneck in evaluating the sustainability of wind power, particularly in tender processes for onshore and future offshore wind farms, as LCAs are increasingly required for environmental impact assessment. The development of a harmonised LCA framework for electricity generation from wind energy is currently underway in International Energy Agency (IEA) Wind Task 60. For nuclear energy production, an LCA study conducted by Électricité de France (EDF) in France (using the ISO14040-44 standards) is available[47].
- **The JRC and the European Commission:** To provide good starting points and to list available methods and relevant sustainability topics to consider, also beyond environmental impacts:
  - Proposal for a sustainability framework for energy technologies (JRC, 2023)[48] also includes safety considerations according to the SSbD.
  - **H2**
    - LCA of H2 and Fuel Cell Technologies (JRC, 2020)[49]
    - Environmental LCA comparison of H2 delivery options within Europe (JRC, 2024)[50]
    - A conceptual framework for assessing and monitoring social risks and impacts related to H2 technologies and their value chains (JRC, 2025)[51]
  - **Batteries:** JRC study in support of developing Carbon Footprint rules for batteries (2025)[52]
  - **Buildings:** Level(s) is based on six macro-objectives that address key sustainability aspects over the building life cycle.[53]

46 https://fc-hyguide.eu/
47 https://www.edf.fr/sites/groupe/files/2022-11/edfgroup_acv-4_plaquette_2022111_en.pdf
48 Joint Research Centre. (2023). Proposal for a sustainability framework for energy technologies. Publications Office of the European Union. https://op.europa.eu/en/publication-detail/-/publication/f10a882e-7d32-11ee-99ba-01aa75ed71a1/language-en
49 https://horizoneuropencpportal.eu/sites/default/files/2023-09/chju-life-cycle-assessment-of-hydrogen-and-fuel-cell-technologies-2020.pdf
50 Joint Research Centre. (2024). Environmental life cycle assessment comparison of hydrogen delivery options within Europe. Publications Office of the European Union. https://publications.jrc.ec.europa.eu/repository/handle/JRC137953
51 Joint Research Centre. (2025). A conceptual framework for assessing and monitoring social risks and impacts related to hydrogen technologies and their value chains. Publications Office of the European Union. https://publications.jrc.ec.europa.eu/repository/handle/JRC138850
52 https://eplca.jrc.ec.europa.eu/EU_BatteryRegulation_Art7.html
53 https://green-forum.ec.europa.eu/green-business/levels/quick-introduction-levels_en

- **Carbon Capture and Utilisation (CCSU):** Guidelines for LCA of carbon capture and utilisation (EC, 2022)[54]
- **Solar:**
  - LCA of Solar Technologies (JRC, 2016)[55]
  - Harmonised rules for the calculation of the carbon footprint of photovoltaic modules in the context of the EU Ecodesign Directive (JRC, 2025)[56]

HOW

Generating the necessary guidelines and filling data gaps requires cooperation among the SET Plan entities, value chain actors, the EC and the JRC, and the European Standardisation bodies (CEN/CENELEC), dedicated research funding, and a clear mandate for the SET Plan to act as a coordinating body.

- Set up a (temporary) working group that focuses on both environmental sustainability and circularity-related data and other technology-specific requirements under each ETIP, or generate shared working groups among ETIPs that share parts of the same value chain.
- Integrate life cycle approach and requirements for comprehensive sustainability assessments as part of all material and technology development projects (including safety aspects when relevant) into the CIIPs and other core documents of the SET Plan stakeholders, with the overall aim of identifying most relevant life cycle stages, processes and environmental impact categories among SET plan technologies, to serve as inputs for generating harmonised technology-specific recommendations, and the necessary benchmark studies. Interdisciplinary research efforts are required to address all relevant environmental aspects (ranging from climate and water to resource depletion, CRMs, and hazardous substances). Complemented with other methods and tools, the energy technology-specific EF category rules and/or LCA studies following the EF method (when available and allowing comparisons) can be used for informing, e.g. the generation of eco-design criteria according to ESPR, non-price sustainability criteria as part of public procurement, tenders, investment decision-making and green funding, creating both regulatory push and market pull.
- Include 'LCI data generation' (related to new technologies, processes, chemicals and materials) as a required outcome of publicly funded research projects related to SET Plan technologies. Create a survey and review existing databases and studies to identify the most pressing data needs and gaps across materials and technologies within each IWG/ETIP (or relevant energy technology value chain). Additional efforts and expertise from the ETIPs and IWGs are needed to develop the data quality matrices and guidelines that ensure the coverage, representativeness, and timeliness of the generated datasets. For this data to be widely used, it should eventually be incorporated into existing LCI databases (e.g., International Reference Life Cycle Data System – ILCD or EF). SET Plan actors could take a leading role as data providers or coordinators, in cooperation with relevant industry associations, other expert organisations and database providers and develop a harmonised database for the participating technologies.
- Target research funding (e.g. Horizon Europe) to entities or projects that can contribute to relevant dataset generation and technology-specific LCA criteria development. Conduct meta-analyses of existing LCA studies or sustainability assessments, including circularity and criticality aspects, and encompass the whole life cycle of energy technologies. Research projects should be able to draw conclusions that can serve as inputs for policy recommendations, more specific sustainability and circularity criteria, and/or standardisation activities. Consider increasing funding rates for projects with stringent sustainability goals and outputs.
- Target funding to research that may foster the development of new materials and materials substitution with the help of AI and modelling tools/databases. Consider establishing dedicated knowledge hubs targeted at Small and medium Enterprises (SMEs) that need support with their LCA activities.
- Involve international cooperation partners in European research projects to address value chains that cross European borders and to achieve the necessary data coverage and representativeness across different technologies/materials.

54 European Commission. (2022). Guidelines for life cycle assessment of carbon capture and utilisation. Publications Office of the European Union. https://op.europa.eu/en/publication-detail/-/publication/d58d8150-2d8e-11ed-975d-01aa75ed71a1/language-en

55 Joint Research Centre. (2016). Life cycle assessment of solar technologies. Publications Office of the European Union. https://publications.jrc.ec.europa.eu/repository/handle/JRC95155

56 Ardente, F., Eynard, U., Leccisi, E., Mathieux, F., & Wolf, K. (2025). Harmonised rules for the calculation of the carbon footprint of photovoltaic modules in the context of the EU Ecodesign Directive. Publications Office of the European Union. https://data.europa.eu/doi/10.2760/4062978

WHEN

Short term (2026-2027):

- Working groups and/or specific experts named for sustainability and circularity topics and (data) gap analysis
- Sustainability, circularity and safety-related assessments integrated in all relevant calls and working program drafts.
- 'LCI data generation' integrated as a required output in all major research projects that receive public funding – an aligned EU-led project might be needed, similar to the Bridge Project.
- Advocacy for an LCA authority at the EU level
- Examples of comprehensive LCA benchmark studies generated in European research projects related to all SET Plan technologies
- Material substitution and sustainability-related goals and targets integrated in CIIPs

Medium term (2027-2030):

- Meta-analyses and recommendations available from research projects, providing input for creating harmonised guidelines for evaluating both sustainability and circularity

Long term (post 2030):

- Sustainability and circularity impact criteria set for SET Plan technologies
- Modelling tools, toolboxes and AI-assistants available for sustainable material development

KEY PERFORMANCE INDICATORS (KPIS)

- Number of dedicated groups/experts established for LCAs of a specific SET Plan technology or value chain.
- Number of LCA benchmark studies and datasets generated in European research projects
- Number of new technology-specific EF Category Rules documents generated and/or in process.

RECOMMENDATION 3: DEVELOP EU-LEVEL INDICATORS AND TARGETS EXPRESSING DIFFERENT CIRCULARITY STRATEGIES

Recommendation summary:

The transition to a circular energy system requires reliable ways to measure progress across technologies, value chains and governance levels. Currently, only limited indicators are available for tracking circularity within the EU energy system. Existing metrics often focus mainly on recycling rather than broader circular strategies such as prevention, reuse, repair and remanufacturing. This limits the ability to monitor progress, compare performance and guide policy and investment decisions effectively.

This recommendation proposes developing EU-level indicators and targets that capture the full range of circularity strategies within the R framework across SET Plan technologies (e.g. from 'Refuse' to 'Recover'). These indicators should also be specific to different life cycle phases, SET Plan technologies, and implementation levels (e.g. the EU and national levels, companies and households).

Implementation should involve a structured and collaborative process bringing together SET Plan stakeholders, EU institutions, industry, researchers and national authorities. Existing frameworks and standards should serve as a basis for developing harmonised methodologies, supported by common data collection systems, pilot testing and integration into SET Plan monitoring and reporting frameworks. Regular reviews and digital tools should ensure indicators remain relevant as technologies and policies evolve.

WHY

Challenges identified by TF members and literature review

The transition to a circular economy needs to occur on multiple levels, from households and individual consumers to national and cross-border ecosystems. Measuring and monitoring the development of this transition is an ambitious task and is ideally supported by indicators relevant to all steps in that process. To make the systemic transition towards a Circular Economy (CE) and society measurable, a robust monitoring system is needed to assess circularity across all its facets.

There are only a limited number of indicators to measure circularity within the EU energy system – so what should actually be measured? Answering this question requires consideration of circularity in absolute terms (to compare actors, technologies/products, territories, etc) but also in terms of progress (relative) to encourage and privilege specific actions, and to measure the impacts/quality of circularity actions, to justify the policy decisions, to motivate CE actors. The EU Circular Economy Monitoring Framework[57] does not provide details on these elements within the energy system.

Circularity targets exist at the EU level; for example, the European Union aims to double the share of recycled materials in the economy's total material use between 2020 and 2030 (CEAP, 2020). Additionally, the anticipated circular economy act (2026) will aim to have 24% of materials circular by 2030[58]. The question to be addressed now is 'how can these targets be translated into measurable indicators for different actors within the SET Plan?' This task might require additional funding, and some SET plan participants suggest allocating a task within the SET plan, since the development of an indicator is (or should be) sector-specific.

57 See: https://ec.europa.eu/eurostat/web/circular-economy/monitoring-framework
58 See: https://ec.europa.eu/commission/presscorner/detail/en/ip_25_550

Expected outcomes and contribution to EU priorities

This recommendation supports the CEAP, European Green Deal, and Clean Industrial Deal by addressing the lack of harmonised, technology-relevant circularity indicators for energy technologies. Developing EU-level circularity KPIs and targets will:

- Enable consistent measurement across technologies and Member States.
- Track progress on resource efficiency, waste reduction, and critical material use.
- Guide policy and investment toward high-value strategies like reuse and remanufacturing.
- Align with EU frameworks such as ISO 59020, Ecodesign, and the Batteries Regulation.
- Integrate social, environmental, and economic dimensions as promoted by the Sustainable Product Initiative.

For the SET Plan, this will:

- Equip CIIPs with actionable metrics.
- Enable technology-specific tracking of circularity progress.
- Improve alignment between R&I, industry, and policy.

It ensures circularity becomes a measurable and strategic part of the EU's clean energy transition.

WHAT

There is a need to develop EU-level indicators/targets (henceforth, targets) that capture different circularity strategies (Rs) beyond recycling—particularly targets for manufacturing and reuse. Indicators and targets should consider the following:

- Levels of implementation: EU, national, regional, local, company, household
- CE strategy: re-use, rethink, reduce, repair, refurbish, etc.
- Theory of change: process, output, outcome, impact
- Type of energy technology and value chain (e.g. % of circular/captured carbon in fuels)
- Life cycle phase: raw material, production, use phase, waste treatment

Different tools and resources have been identified:

- ISO 59020, which provides organisations with guidance to assess their circularity performance within defined economic systems.
- 'Beyond Emission Reductions: Circular Economy Indicators for the Energy Transition of the Power Sector' (2025)[59] applies three indicators: (i) relative material impact, (ii) absolute material impact, and (iii) energy self-sufficiency.
- Battery regulation[60].
- New indicators measuring transition to circularity (EC, 2025)[61].
- A material flow analysis approach centred on the circularity of raw materials used in vehicles[62].

Overall, targets should be flexible so that they can be tailored to different levels of implementation and applied by multiple actors. Specifically, it should segregate the different R-framework strategies metrics into either the individual Rs or the main Narrow, Slow and Close CE narratives. This way, the indicators will capture different R-strategies rather than focusing solely on recycling. It has been reiterated throughout the process that the creation of such indicators should be a co-creation among the involved parties, including industry, policymakers, enforcement entities, and academics. Key aspects include (i) gathering reliable data, (ii) co-creating metrics with stakeholders, and (iii) benchmarking and reporting aided by the enforcement entities.

59 Lérida, A., et al. (2025). Beyond emission reductions: Circular economy indicators for the energy transition of the power sector. Industrial & Engineering Chemistry Research. https://pubs.acs.org/doi/10.1021/acs.iecr.5c00415

60 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ:C_202500214

61 European Commission. (2025). New indicators measuring transition to circularity. Publications Office of the European Union. https://op.europa.eu/en/publication-detail/-/publication/6fc93a19-52fc-11f0-a9d0-01aa75ed71a1

62 Joint Research Centre. (2025). Circularity measures on critical raw materials and e-drive motors in vehicles. Publications Office of the European Union. https://publications.jrc.ec.europa.eu/repository/handle/JRC140892

WHO

- **SET Plan stakeholders:** they should take an active role in coordinating and driving the development of circularity indicators and targets across the energy sector. Their responsibility is to ensure that these indicators are relevant to the technologies and value chains covered by the SET Plan and that they align with EU-level objectives. This involves facilitating collaboration among research organisations, industry actors, and policymakers to co-create metrics that reflect different R-strategies and life-cycle phases. Stakeholders should also support the integration of these indicators into CIIPs, provide technical expertise for defining methodologies, and help establish data collection and reporting systems. Furthermore, they should act as a bridge between EU institutions and national or regional authorities to harmonise approaches, promote adoption among companies, and monitor progress toward agreed targets. By doing so, SET Plan stakeholders will ensure that circularity becomes a measurable and strategic component of the clean energy transition.
- **National governments:** setting CE targets at the national level involves aligning with EU objectives while addressing country-specific challenges and opportunities. This may include setting targets for increasing the use of recycled materials, promoting Ecodesign principles, and investing in circular innovation. Indicators should take existing ones into account and align with, or improve, specific targets for the given EU Member States. Indeed, EU Member States are already required to meet specific targets established by:
  - CRMA (2024): Improve recycling capacity for strategic raw materials.
  - Batteries Regulation (2023): Mandatory minimum levels of recycled content for batteries.
- **Regional authorities:** they can further refine CE targets to reflect local priorities and conditions. This involves identifying regional strengths and weaknesses, engaging stakeholders, and developing targeted initiatives to promote circularity within specific geographic areas. Regional targets may focus on areas such as waste management infrastructure, circular procurement practices and support for circular innovation.
- **Companies:** setting CE targets at the company level involves assessing current resource use, waste generation and environmental impacts, and identifying opportunities for improvement. Targets may include reducing material consumption, increasing product lifespan and implementing circular business models such as product-as-a-service

HOW

The development of EU-level indicators and targets for circularity should follow a structured and collaborative process. First, a multi-stakeholder Task Force should be established, involving EU institutions, Member States, industry, research organisations, and civil society to ensure sector-specific expertise. The next step is to define the scope and framework by aligning with existing EU initiatives and international standards, identifying which R-strategies will be prioritised, and mapping indicators across implementation levels and life-cycle phases. Indicators should then be co-created through consultations and workshops with stakeholders to ensure they capture both absolute performance and relative progress, and integrate the theory of change to link metrics with policy objectives. European Commission and standardisation bodies should formalise the indicators

A robust data infrastructure and methodology must be developed, including harmonised data collection protocols, digital reporting tools, and solutions for confidentiality and interoperability. Pilot testing should follow in selected sectors and Member States to validate feasibility and reliability, and benchmarking should be used to refine indicators. Once validated, indicators should be integrated into policy and monitoring frameworks such as SET Plan Implementation Plans and EU reporting systems, with clear guidance for Member States and companies on target-setting and reporting.

Finally, a mechanism for continuous review should be established to update indicators in line with technological and market developments. Digital dashboards and portals should be developed to enable real-time monitoring and transparency, and advanced analytics can be explored to provide predictive insights into circularity trends. The SET Plan should advocate for the integration of these mature and validated indicators into binding policy instruments, such as the Corporate Sustainability Reporting Directive (CSRD) and Green Public Procurement (GPP) criteria.

WHEN

Short term (2026-2027):

- Propose indicators at the macro, meso and micro levels of implementation - i.e., from international to household or company level, and select those with the potential to provide intelligence on current levels of circularity, progress of those levels over time, and the impacts of circular policies and initiatives. There can be a trade-off between choosing 'ambitious' indicators (to define new areas for circular action) vs. relying on less ambitious indicators where data is more readily available.

Medium-term (2027-2030):

- Establish targets for the defined indicators. Establish data collection infrastructure. Indicators to be used in EU/national/company policies and reports.

Long-term (post-2030):

- Review progress according to targets. Consider new reporting requirements and regulations, and ways to support collection and reporting through enhanced harmonisation and simplification, as well as the development of digital tools and portals.

KEY PERFORMANCE INDICATORS (KPIS)

- Progress (at EU/national/other levels) according to the indicators and targets;
- Uptake of the indicators (e.g. in policy reports, CIIPs, as part of the EU monitoring framework).

RECOMMENDATION 4. ACCELERATE MATERIAL SUBSTITUTION FOR SET PLAN TECHNOLOGIES THROUGH TARGETED RESEARCH AND DEVELOPMENT, AND CROSS-SECTOR COLLABORATION

Recommendation summary:

Many SET Plan technologies, including batteries, photovoltaics, wind turbines and hydrogen systems, depend on critical and high-risk raw materials that are scarce, geopolitically sensitive or environmentally harmful to extract. Current approaches to material substitution are often fragmented across sectors, increasing supply risks and limiting the EU's ability to scale clean energy technologies sustainably and competitively.

This recommendation proposes accelerating material substitution across SET Plan technologies through targeted research, innovation and cross-sector collaboration. It focuses on identifying technology-specific substitution priorities, developing sustainable alternative materials, and strengthening cooperation between the energy, materials, chemical and manufacturing sectors to reduce dependence on CRMs.

Implementation should begin with identifying priority materials for substitution within each technology area, supported by JRC studies and existing EU frameworks such as the CRMA. Targeted Research and Development (R&D) programmes, shared testing and innovation platforms, and dedicated cross-sector working groups should support the development and deployment of alternative materials. In parallel, policy measures, eco-design standards and market incentives should help accelerate industrial uptake and long-term adoption.

WHY

Challenges identified by TF members and literature review

Many of the technologies prioritised under the SET Plan—such as batteries, photovoltaics (PV), wind turbines, H2 systems, and fuel cells—depend on critical and strategic raw materials that are either scarce, geopolitically sensitive, or environmentally damaging to extract[63]. These include cobalt, lithium, silver, rare-earth elements, graphite, and platinum-group metals, as well as fossil carbon used in various components. For example:

- Batteries rely heavily on cobalt and nickel, both of which are largely imported and often associated with high environmental and social risks.
- PV modules use silver and indium, which are expensive and difficult to substitute without performance trade-offs.
- Wind turbines require rare earth magnets (e.g. neodymium, dysprosium), which are almost entirely refined outside the EU.
- Fuel cells and electrolysers depend on platinum and iridium, which are extremely rare and costly.

The CRMA[64] sets targets for domestic extraction, processing, and recycling of strategic raw materials, while the CEAP[65] promotes sustainable product design and circularity in high-impact sectors. The European Green Deal[66] provides the overarching framework for achieving climate neutrality by 2050 and reducing resource dependency.

Despite these policy efforts, material substitution has not yet been systematically addressed across SET Plan sectors. This recommendation focuses on what exactly should be addressed: the identification and replacement of high-risk materials in each technology line, through coordinated R&D and cross-sectoral collaboration. It aims to ensure that clean energy technologies can scale sustainably without being bottlenecked by sourced material scarcity or geopolitical risk.

A conscious approach to transitioning to an economic model driven by demand is required, addressing a self-sustaining market and ecosystem balance through the implementation of sustainable substitution value chains that integrate strong innovation efforts at every stage. The current way of developing clean energy is too fragmented. Each technology (like solar, wind, and electric batteries) operates in its own 'silo,' trying to solve its own material supply problems independently. A 'big picture' approach that prioritises the overall goal of fighting climate change is in demand.

63 https://www.iea.org/topics/critical-minerals
64 https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/green-deal-industrial-plan/european-critical-raw-materials-act_en
65 https://environment.ec.europa.eu/strategy/circular-economy-action-plan_en
66 https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en

Expected outcomes and contribution to EU priorities

This recommendation is expected to contribute to:

- **CEAP:**
  - Helps reduce import dependence and geopolitical risks by identifying and substituting high-risk materials, boosting EU recycling and processing capacity.
  - Aligns with goals for sustainable product design and increased circularity in energy, transport, and digital sectors.
- **European Green Deal:** Promotes a clean energy transition that is not only low-carbon but also resource-resilient and socially responsible.
- **CIIPs:** Embeds material substitution as a strategic R&I priority across all SET Plan technology areas.

Expected outcomes for the SET Plan will be:

- Identification of priority materials for substitution per technology line.
- Pipeline of alternative materials via targeted R&D.
- Cross-sector collaboration and knowledge sharing.
- Reduced use of CRMs.
- Enhanced EU resilience and competitiveness.
- Promotion of substitution through economically driven demand, e.g., cheaper, more efficient, offering better value.
- Facilitation of the creation of joint innovation platforms that bring together the energy sector with the chemical, materials science, and advanced manufacturing sectors

This action ensures the SET Plan advances a climate-neutral energy transition that is also materially sustainable.

WHAT

Advanced materials play a crucial role in the development of clean energy technologies by enhancing technological performance, reducing costs and increasing sustainability. The impact of substituting advanced materials to reduce dependence on CRMs could be greater in sectors such as renewable energy and mobility, where demand is expected to grow or remain high and European production capacity is limited. Material substitution can be accelerated within the SET Plan through:

- **Identification of substitution priorities:** Each ETIP/IWG should identify which critical materials are most urgent to substitute within their technology area. For example: cobalt and nickel in batteries, silver and indium in PV, rare earths in wind turbines, and platinum and iridium in H2/fuel cells.
  - The list of 34 CRMs and 17 strategic raw materials (as defined in the CRMA, 2025) should be taken as a starting point.
  - The study on 'Advanced materials for substitution in the clean energy sector' (JRC, 2025)[67] should serve as a key resource for informing targeted research priorities and identifying viable substitution options.

- **Targeted R&D on alternative materials:** Launch cross-border R&D projects focused on developing and validating alternative materials that are more abundant, sustainable, or recyclable. This includes cobalt-free battery chemistries (e.g., Lithium Iron Phosphate – LFP, sodium-ion), silver-free PV metallisation (e.g., copper-based), rare-earth-free magnets for wind turbines, non-platinum catalysts for H2 systems, and the substitution of fossil carbon with captured carbon in relevant applications. Strategically promote R&D funding on next-generation substitutes.

- **Cross-sector collaboration and knowledge sharing:** Facilitate collaboration between sectors that rely on similar materials to share research, testing infrastructure, and substitution strategies, and estimate EU-wide demand for priority substitute materials while identifying options for their sustainable sourcing. Currently, IWGs and ETIPs are highly effective within their specific technology domains (e.g., ETIP PV for solar, ETIP Wind for wind, IWG on renewables integration). However, the energy transition's biggest challenges are inherently cross-sectoral. In this respect, it is recommended to

67 https://setis.ec.europa.eu/advanced-materials-substitution-clean-energy-sector_en

build a working group or forum that could be called something like the 'System Integration Forum', 'Strategic Forum for Energy System Integration', or 'Cross-Sectoral Energy Transition Platform'. As the energy transition moves from scaling individual technologies to integrating them into a complex system, a dedicated space for cross-sectoral dialogue is essential. It would help transform the excellent but fragmented work of the IWGs and ETIPs into a more coherent and accelerated pathway for the entire European economy. This is precisely the kind of systems thinking that policymakers should be encouraging to ensure a cost-effective, resilient, and socially just energy transition.

- **Policy and market support:** Define substitution targets per technology line and align them with the CEAP and its objectives. Promote eco-design standards and certification schemes to support market uptake of substitute materials. Adapting substitution not as a simple trend, but as a complex systemic shift that requires coordinated action between the market, the government, and all players in a balanced industry ecosystem to move from development to implementation. Achieving this calls for targeted research and development, as well as cross-sector collaboration.

- **Blueprint for future material substitution:** This provides a clear, actionable framework for tackling raw material challenges (e.g., substitutes for copper in conductors, rare earth elements in magnets, or critical minerals in batteries) by, (i) identifying the raw material risk (supply chain, environmental, geopolitical), (ii) creating a clear, long-term regulatory driver, (iii) funding and conducting foundational R&D into alternative materials (iv) developing prototypes and conduct rigorous real-world testing with early adopters, and (v) establishing standards, building manufacturing capacity, and driving widespread deployment through continued policy support. The technical challenges for high-voltage switchgear are exponentially greater, making it a perfect candidate for the next wave of concerted, EU-wide R&I efforts, precisely following the blueprint described. The task now is to institutionalise this model and apply it deliberately to the next set of raw material challenges facing the clean energy transition. The work on durable materials for geothermal technologies under Geothermal ERA NET Cofund (GEOTHERMICA) exemplifies the same collaborative blueprint, but with a different technological focus and specific challenges. The GEOTHERMICA example is immensely valuable. It demonstrates that the collaborative model is not limited to cases with a direct regulatory ban. It is equally critical for overcoming fundamental technical barriers that hinder the deployment of key renewable energy sources. By citing both the Sulfur Hexafluoride (SF6) transition (a market-driven response to regulation) and the GEOTHERMICA raw materials work (a pre-competitive R&D effort to unlock a technology's potential), a compelling and comprehensive case for systematically applying this 'blueprint' across the entire energy system is presented. This strongly reinforces the argument for the structured, EU-wide approach you initially supported

WHO

- **SET Plan stakeholders** (specifically the ETIPs and IWGs) to agree on substitution priorities for individual SET Plan technologies.
- **The JRC and the European Commission** for their work on advanced materials for substitution in the clean energy sector (JRC, 2024)[68] and on supply chain analysis and material demand forecast in strategic technologies and sectors in the EU (JRC, 2023)[69].
- **High-level expert groups** (i.e. ECRMB[70] and the Technology Council for Advanced Materials[71]) to align efforts, avoid duplication, and address regulatory and governance barriers across Member States.
- **Specific partnerships,** including the EIP on raw materials or the EU's strategic raw materials partnerships with third countries.
- **Stakeholder networks,** including the EIT Raw Materials and ERMA.
- **Experts, industry, and research institutions** dealing with materials used in energy, digitalisation and smart grid technologies.

68 https://setis.ec.europa.eu/advanced-materials-substitution-clean-energy-sector_en
69 https://single-market-economy.ec.europa.eu/document/download/a5a7b598-6542-42c3-9b32-ba98b6a959f8_en
70 https://single-market-economy.ec.europa.eu/sectors/raw-materials/areas-specific-interest/critical-raw-materials/critical-raw-materials-act/board_en
71 https://research-and-innovation.ec.europa.eu/news/all-research-and-innovation-news/technology-council-advanced-materials-holds-inaugural-meeting-2024-11-18_en

HOW

The implementation of this recommendation should follow a coordinated, phased approach that integrates research, collaboration, and policy alignment. First, SET Plan stakeholders, including ETIPs and IWGs, need to identify the most critical materials for substitution in each technology area, using existing resources, such as the CRMA and JRC studies, as a baseline. This prioritisation should be based on supply risk, environmental impact, and technological dependency.

Once priorities are clear, targeted research and development programs should be launched to explore and validate alternative materials that are abundant, sustainable, and compatible with performance requirements. These efforts must be supported by cross-sector collaboration, bringing together energy technology developers, material scientists, chemical industries, and advanced manufacturing sectors to share knowledge, infrastructure, and innovation pathways.

A dedicated platform for cross-sector dialogue should be established to ensure that substitution strategies are not developed in isolation but integrated into a systemic approach for the entire energy transition. In parallel, policy frameworks should define substitution targets, embed them into eco-design standards, and create incentives for market uptake of substitute materials. Data sharing and open-access results from R&D projects will accelerate learning and adoption. Finally, the process should include continuous monitoring and adaptation, ensuring that substitution strategies evolve with technological progress and market dynamics. This approach will institutionalise material substitution as a strategic priority, enabling the SET Plan to deliver a clean energy transition that is both climate-neutral and resource-resilient.

WHEN

Short term (2026-2027):

- Identify substitution and circularity priorities;
- Launch pilot R&D projects;
- Initiate cross-sector working groups.

Medium-term (2027-2030):

- Scale up R&D and demonstration projects;
- Publish open-access results;
- Integrate substitution into eco-design frameworks;
- Create a cross-technology Task Force on circularity;
- CIIP and ETIP SNET's action plan.

Long-term (post-2030):

- Mainstream substitute materials in industrial practice;
- Reduce EU dependency on CRMs;
- Promote the inclusion of circularity requirements/standards in existing Certification schemes;
- Develop blueprint for future material substitution.

KEY PERFORMANCE INDICATORS (KPIS)

- Number of substitution-focused R&D projects launched.
- % of circular carbon in products used in SET-Plan technologies
- % of reduction in CRM use per technology.
- % of fossil carbon substituted with captured carbon in relevant SET-Plan technologies.
- Number of substitute materials adopted in commercial applications.
- Number of cross-sector partnerships and Task Forces established on substitution and circularity.
- Number of circularity criteria in well-established product quality and performance certifications.

RECOMMENDATION 5: STRENGTHEN THE SUPPLY OF CIRCULAR MATERIALS FOR SET PLAN TECHNOLOGIES THROUGH TARGETED RECYCLING R&D AND INFRASTRUCTURE DEVELOPMENT

Recommendation summary:

Recycling rates for many CRMs used in SET Plan technologies remain low, while limited recycling infrastructure, insufficient recovery systems and fragmented value chains continue to hinder circularity. Valuable materials from batteries, PV modules, wind turbines and hydrogen systems are often lost at end of life, increasing dependence on primary raw materials and creating environmental and supply risks.

This recommendation proposes strengthening the supply of circular materials by expanding recycling, remanufacturing, and recovery capacities for SET Plan technologies. It focuses on improved material-flow mapping, targeted R&D for advanced recycling technologies, shared infrastructure, and digital collaboration tools to increase the recovery and reintegration of high-value secondary raw materials.

Implementation should start with identifying priority material streams and components with high recovery potential across SET Plan technologies. Targeted R&D, pilot recycling and remanufacturing facilities, and shared testing infrastructure should support the development of scalable recovery solutions. In parallel, digital platforms, training programmes and policy measures promoting recyclability and the use of recycled materials should help strengthen circular value chains and market uptake across the EU.

WHY

Challenges identified by TF members and literature review

Circular materials are renewable and biobased, compostable and biodegradable, reusable, remanufacturable, upcycled, secondary, designed for disassembly, and recycled/recyclable. Many circular materials may not match the performance of primary materials, and production costs are often higher. This is hampered by the lack of facilities for disassembly, repair, or remanufacturing, which, in turn, limits scaling and adoption.

Recycling rates for many CRMs in Europe are low, and there is a lack of appropriate systems and technologies, as well as sufficient end-of-life volumes for recycling. Many critical materials used in batteries, PV modules, wind turbines, and H2 systems are not being recovered at scale, leading to resource loss, environmental harm, and continued reliance on primary raw material imports[72]. For example:

- Lithium and cobalt in batteries are often lost due to inefficient or non-existent recycling systems.
- Silver and silicon in PV modules are difficult to recover due to complex module designs and a lack of disassembly standards.
- Rare earths in wind turbine magnets are rarely recycled because of environmental, technical and economic barriers.
- Platinum group metals in fuel cells are valuable but require advanced recovery technologies.

Besides recycling, aspects of recovery also need to be addressed, e.g. the use of minerals from brine in geothermal plants. In terms of communication along the value-chain, offshore wind companies often operate in silos along the wind farm life cycles, paying little attention to disassembly and recycling at the end of use, while timely communication between decommissioning and recycling is missing[73].

This recommendation addresses the development of efficient, scalable recycling technologies for circular materials tailored to the material profiles of SET Plan technologies, the creation of shared infrastructure, and the establishment of digital tools to support collaboration and knowledge exchange. It focuses on building the supply side of circular materials, especially high-value recycling and remanufacturing, to support a circular, resilient, clean-energy economy.

72 https://www.iea.org/reports/recycling-of-critical-minerals

73 European Commission. (2023). Circular energy transition. European Commission. https://circulareconomy.europa.eu/platform/sites/default/files/2023-06/Circular-energy-transition.pdf

Expected outcomes and contribution to EU priorities

This recommendation supports the CRMA target of recycling 25% of strategic raw materials by 2030 and the CEAP's goal of boosting circularity in high-impact sectors such as batteries, renewables, and electronics. It also supports the SSbD framework[74] and the Advanced Materials Strategy for Industrial Leadership[75] by fostering research, innovation, and deployment of biobased and recyclable materials.

By promoting scalable recycling and solutions enabling circularity (e.g., renewable, reuse, remanufacturing) for SET Plan technologies, it will:

- Strengthen EU supply chain resilience and reduce import dependence.
- Advance the Green Deal by enabling a more resource-efficient, climate-neutral energy system.
- Reinforce the circular economy through the reuse of recovered materials, reducing mining and waste impacts.

Expected outcomes for the SET Plan will be:

- Mapping of critical material flows to guide recovery efforts.
- Shared R&D and infrastructure for advanced recycling, remanufacturing, and reuse.
- Greater use of eco-design for recyclability and disassembly.
- A digital platform to support collaboration and scaling.

This action transforms end-of-life components into strategic resources, positioning circularity as a core enabler of the EU's clean energy transition

WHAT

Actions to enhance the supply of recycled materials include:

- **Mapping of Material Flows and Recycling/Remanufacturing Potential:** Identify which materials and components (e.g. battery packs, PV modules, wind turbine magnets) offer the highest potential for recovery and reintegration into production. Certain materials could be prioritised, based on:
  - Availability (anticipated mass): Steel, aluminium, and copper are commonly used throughout the electricity supply chain. By 2023, the cumulative volume of steel in solar PVs (10,940 tonnes), wind turbines (274,194 tonnes), and decommissioned fossil fuel plants is estimated at 5.9 million tonnes, to which renewables contribute with 285,000 tonnes[76].
  - Economic value: Certain high-grade materials with valuable properties.

- **Targeted R&D on Renewable materials, Recycling and Remanufacturing Technologies:** Launch cross-border R&D projects focused on:
  - Efficient recovery (of lithium, cobalt, graphite, silver, rare earths, and platinum group metals).
  - Advanced recycling methods (e.g. hydrometallurgy, mechanical separation) and remanufacturing.
  - Eco-design approaches that facilitate disassembly and material recovery.
  - Alternative materials derived from renewable sources

- **Infrastructure and Capacity Building:** Invest in shared pilot-scale recycling and remanufacturing facilities, transport of captured carbon and testing labs accessible across Member States. Support training programmes for engineers and technicians in related technologies.

74 https://www.safeandsustainablebydesign.eu/ssbd/
75 https://research-and-innovation.ec.europa.eu/research-area/industrial-research-and-innovation/chemicals-and-advanced-materials/advanced-materials-industrial-leadership_en
76 https://joint-research-centre.ec.europa.eu/jrc-news-and-updates/theres-new-waste-coming-transition-renewables-how-reuse-and-recycle-it-2025-03-11_en

- **Digital Collaboration Platform:** Develop a European platform to support:
  - Matchmaking between recyclers, manufacturers, and researchers.
  - Real-time data on material availability and recycling processes.
  - Open-access case studies and benchmarks.

- **Market development support:** The creation of conditions for a viable, balanced market is needed, providing good conditions for viable players, and which creates an interest in investments. Today, the market (e.g., the battery sector) is immature, and large parts of the value chain are not located in the EU; hence, it is difficult for recycling companies to achieve competitive advantages.

- **Cross-technology cooperation:** Each technology sector (geothermal, solar, wind, hydropower) applies a separate silo approach and conducts its research and development independently. This leads to competition for the same CRMs (like lithium, cobalt, copper, and rare earth elements) without considering the overall system's limitations. Cooperation and R&D funding should be directed towards solutions that benefit the whole system.

WHO

The recommendation is addressed to:

- SET Plan stakeholders – specifically ETIPs and IWGs, since all of them are involved in the market uptake of circular solutions;
- The European Commission (DG RTD, DG GROW, DG ENER, JRC);
- Industry stakeholders (manufacturers, recyclers, technology developers);
- National policymakers and local authorities that are part of the ETIPs to focus on mapping knowledge and capabilities;
- European projects (e.g. Horizon, Interreg);
- Research organisations and universities;
- European Environment Agency (EEA), for its expertise (i.e. investigating Europe's secondary raw material markets (EEA, 2022)[77] and recycling materials from green energy technologies (Signal)[78]);
- Platforms, including the Circular Economy Stakeholder Platform, to support the process. This is particularly relevant for facilitating the expansion of existing infrastructure and the availability of circular materials through sound mapping at the EU level.

HOW

The recommendation should be implemented by first mapping material flows across SET Plan technologies to identify components with the highest recycling potential. Based on this, targeted R&D should develop efficient recovery and advanced recycling methods for critical materials, while integrating eco-design principles to enable easier disassembly. Pilot-scale recycling and remanufacturing facilities should be established to build capacity, with support from training programs and funding. A European digital platform should connect recyclers, manufacturers, and researchers, enabling real-time data exchange and collaboration. Policy measures must create incentives for the use of recycled materials and embed recyclability standards into product design. This coordinated approach will ensure that recycling becomes a scalable and strategic pillar of the EU's clean energy transition

77 European Environment Agency. (2025). Investigating Europe's secondary raw material potential. European Environment Agency. https://www.eea.europa.eu/en/analysis/publications/investigating-europes-secondary-raw-material

78 https://www.eea.europa.eu/en/european-zero-pollution-dashboards/indicators/recycling-from-green-technology

WHEN

Short term (2026-2027):

- Map material flows;
- Launch pilot recycling and remanufacturing projects, including renewable materials;
- Initiate digital platform.

Medium-term (2027-2030):

- Scale up infrastructure;
- Demonstrate closed-loop recycling systems;
- Encourage remanufacturing and the use of renewable materials;
- Publish results.

Long-term (post-2030):

- Mainstream use of recycled materials in clean energy technologies;
- Meet or exceed CRMA recycling targets.

KEY PERFORMANCE INDICATORS (KPIS)

- Volume of recycled materials and remanufactured elements reintegrated into production.
- % of circular carbon and renewable materials in products used in SET-Plan value chains
- % of reduction in primary raw material use.
- Number of recycling/remanufacturing R&D projects and pilot plants launched.
- Number of actors using shared infrastructure and digital tools.

RECOMMENDATION 6: STIMULATE DEMAND FOR CIRCULAR MATERIALS AND COMPONENTS IN SET PLAN TECHNOLOGIES

Recommendation summary:

Despite growing interest in circular economy solutions, the uptake of reused, recycled and renewable materials in energy technologies remains limited. Higher costs, insufficient standards, fragmented value chains and low market confidence continue to restrict demand for circular materials and components across SET Plan technologies.

This recommendation proposes measures to stimulate demand for circular materials and components in SET Plan technologies through harmonised standards, certification schemes, incentives and targeted public procurement. The objective is to create a viable single market for circular solutions and strengthen the business case for recycled, remanufactured and renewable materials.

Implementation should involve cooperation among SET Plan stakeholders, industry, policymakers and standardisation bodies to develop common standards, certification systems and market incentives. Public procurement criteria, financial support mechanisms and awareness-raising activities should help increase market confidence and encourage wider adoption of circular materials across clean energy value chains.

WHY

Challenges identified by TF members and literature review

The demand for circular materials includes materials that are renewable and biobased, compostable and biodegradable, reusable, remanufacturable, upcycled, secondary, designed for disassembly, and recycled/recyclable. Multiple obstacles are preventing the Single Market for this type of material. For most of them (except, e.g., certain metals), renewable and secondary raw materials are more expensive than fossil-fuel and primary raw materials, lack suitable value chains, and recycling/remanufacturing tends to be more expensive than landfilling[79]. A second-hand photovoltaic panel is only 20-40% cheaper than a new one at current prices, but when accounting for dismantling, transportation, and refurbishment costs, second-hand panels are not competitive, and the market remains underdeveloped.

Additionally, practices of unfair subsidies and prolonged market distortion in the net-zero industry abroad further complicate the EU's competitiveness in this sector (China's subsidies on net-zero technologies have long been twice as high[80]), with both direct and indirect impacts on circularity solutions and opportunities for these technologies.

A lack of quality standards hinders the emergence of a second-hand market for energy technologies. The absence of quality or performance guarantee certificates for second-life panels is not conducive to market development[81]. The automotive sector serves as a best-practice example, with a highly mature market for refurbished parts supported by established standards, rigorous inspections, and credible certifications. Moreover, robust standards and credible certifications rely heavily on accurate, traceable data, which is often lacking for circular materials. There are different processes for recycling and remanufacturing, and each type of material has its own specificities:

- **Ensuring a common approach regarding the fitness for renewable materials, re-use, and remanufacturing:** When it comes to renewable options, reusing materials, or remanufacturing products, specifiers and contractors are sometimes faced with questions regarding the performance and reliability of reclaimed elements. This also includes ensuring a common approach regarding toxicity. The material must meet the minimum performance (in terms of safety, durability, strength, consistency, etc.); otherwise, it becomes waste.
- **Addressing difficulties in replication, certification, and standardisation:** While 'new' energy components/products manufactured under controlled factory conditions tend to exhibit minimal variation (allowing for predictable and repeatable acceptance procedures), products incorporating renewable content (bio-based), reused or recycled materials, or remanufactured products face challenges due to the absence of standardised and replicable verification procedures for their performance.

79 Draghi, M. (2024). The future of European competitiveness: In-depth analysis and recommendations. European Parliamentary Research Service. https://espas.secure.europarl.europa.eu/orbis/system/files/generated/document/en/Draghi%20_%20The%20future%20of%20European%20competitiveness_%20In-depth%20analysis%20and%20recommendations.pdf

80 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52023DC0062

81 European Commission. (2023). Circular energy transition. European Commission. https://circulareconomy.europa.eu/platform/sites/default/files/2023-06/Circular-energy-transition.pdf

- **Developing adapted insurance schemes:** Because it is sometimes considered to be an innovative practice, insurers are not always comfortable with reused materials (due to perceived risks, considering also HOW the product is installed in a building). Dealing with this issue can increase project complexity and/or lead to higher premiums for specifiers.

There are various costs associated with the use of second-hand materials (selective dismantling, treatment, and quality testing). More efficient processes will increase competitiveness and therefore stimulate market uptake.

Expected outcomes and contribution to EU priorities

This recommendation contributes directly to EU priorities, including:

- **CEAP:** Supports the target to double the EU circular material use rate by 2030.
- **CRMA:** Helps meet the goal of sourcing 15% of strategic raw materials from recycled sources by 2030.
- **ESPR:** Promotes the use of recycled content and circular design in clean energy technologies.
- **Advanced Materials Strategy for Industrial Leadership:** Fosters research, innovation, and deployment of advanced materials—such as bio-based composites, recyclable carbon-reinforced plastics, plastics or graphite from captured carbon, and sodium-ion batteries— including more efficient processes, which are essential for circularity and reducing dependency on CRMs.
- **SSbD Framework:** Sets out guidance for designing chemicals and materials to be safe and sustainable over their full lifecycle.
- **NZIA:** Manufacturing of net zero technologies

By establishing standards and certification schemes that ensure the performance and safety of circular materials, the recommendation will:

- Facilitate market entry and stimulate demand, which in turn will help increase cost-effectiveness and competitiveness.
- Support the creation of a single market for circular materials, focusing on SET plan technologies
- Strengthen the circular economy in the renewable energy sector by fostering the use of not only recycled materials but also biobased, reused, and remanufactured materials.

Expected outcomes for the SET Plan will be:

- Feasibility assessment of using circular materials in renewable energy technologies, including standardisation and certification
- Harmonised sustainability criteria that stimulate the creation of a single market for circular materials
- Use of incentives that promote the operation and use of circular materials and components in public procurement and EU funding

This action stimulates demand for circular materials, thereby facilitating their market deployment and improving the positioning of circularity within the energy transition.

WHAT

Targeted measures that address persistent market barriers and promote the economic competitiveness of recycled and reused materials in the energy transition should be established. These could include:

- **Assess feasible use of secondary materials:** IWGs and ETIPs should integrate circularity and the use of secondary raw materials into their strategic documents. This includes identifying priority materials, more efficient processes, and (parts of) technologies where secondary and renewable materials can be realistically used, such as:
  - Silicon, silver, and glass recovered from end-of-life photovoltaic panels.
  - Lithium, cobalt, nickel, and graphite are recycled from spent batteries.
  - Rare earth magnets, aluminium, fibres, and resins recovered from wind turbine components.
  - Steel and cement reused from geothermal drilling infrastructure.
  - Platinum group metals recycled from H2 fuel cells and electrolysers.

Importantly, this involves data collection (e.g. Digital Product Passport) and quality testing of the material before it can be (re) used.

- **Create a single market for recycled/reused/circular materials:** The EU must work towards harmonisation of sustainability criteria across Member States, including a robust standardisation and certification framework that guarantees performance, safety, and reliability. Relevant ETIPs and standardisation bodies (CEN/CENELEC) should work together to develop standards and certification protocols, with ETIPs providing the technical requirements and use cases to standardisation bodies. A unified framework would create clarity for investors and stimulate cross-border industrial cooperation. Alternative technologies that offer balanced trade-offs need to be promoted. This can be improved through a robust system of market incentives—including green taxonomies, bonus schemes for circular content, preferential scoring in funding calls, and innovation premiums. Such mechanisms would reduce the economic disadvantage faced by circular solutions and help them reach cost parity with conventional options.
- **Use public procurement selectively to support early demand:** Where relevant, sustainability and circularity criteria should be integrated into public procurement processes—particularly in sectors where public authorities play a direct role in technology deployment, such as public infrastructure, transport, or demonstration projects. IWGs and ETIPs should assess the applicability of procurement-based incentives within their respective technology areas and promote their use where they can effectively stimulate early market demand. The SET Plan should advocate for the European Commission to update its GPP criteria to explicitly include and incentivise the use of certified circular components in all energy infrastructure projects co-financed by the EU. Member States should be strongly encouraged to adopt similar rules for their national tenders. There are best practices available. Several Member States have successfully used GPP to stimulate demand for more sustainable products in sectors like IT and construction. For example, by mandating that a certain percentage of new office equipment must meet high environmental standards, public bodies have created a significant market for more sustainable products

WHO

The recommendation is addressed to:

- **ETIPs and IWGs**, since all of them are involved in the market uptake of circular solutions.
- **EU bodies, national policymakers, and local authorities** that are part of the ETIPs should focus on harmonising the sustainability criteria and, therefore, aim to integrate circularity criteria in public procurement rules. This is particularly relevant to update their CIIPs.
- **Public authorities and investors** could work together to create a robust system of market incentives.
- **Standardisation (CEN/CENELEC) and certification bodies** should participate in establishing a framework for the applicability of renewable and secondary materials, particularly in high-performance applications, e.g. wind turbine components, batteries, and H2 production and transportation.

HOW

- Develop best practice guides on integrating circularity into procurement processes. Introduce financial and regulatory incentives to help achieve cost parity for recycled/reused/renewable materials, including tax credits, feed-in premiums, and procurement bonuses.
- Launch targeted campaigns and pilot schemes to build early demand and demonstrate feasibility.
- Align EU funding mechanisms (e.g. Horizon Europe, Innovation Fund) with circularity goals, prioritising projects that scale high-TRL technologies using renewable, recycled, reused materials/components, functional materials designed for sustainability, particularly those complying with the SSbD framework. Introduce the mandatory use of the Digital Product Passport.

WHEN

Short term (2026-2027):

- Develop best practice guides on integrating circularity into procurement processes. Introduce financial and regulatory incentives to help achieve cost parity for recycled/reused/renewable materials, including tax credits, feed-in premiums, and procurement bonuses.
- Launch targeted campaigns and pilot schemes to build early demand and demonstrate feasibility.
- Align EU funding mechanisms (e.g. Horizon Europe, Innovation Fund) with circularity goals, prioritising projects that scale high-TRL technologies using renewable, recycled, reused materials/components, functional materials designed for sustainability, particularly those complying with the SSbD framework. Introduce the mandatory use of the Digital Product Passport.

Medium-term (2027-2030):

- Expand green taxonomies and preferential procurement scoring, e.g. GPP.
- Launch financial instruments to support SME-led circular business models. Create financial incentives (e.g. European Investment Bank – EIB) to foster the use of certified circular components.
- Support pilot projects enabling material reuse and substitution.
- Establish a third-party certification scheme that ensures compliance with standards, certifications, and adherence ot the Digital Product Passport

Long-term (post-2030):

- Achieve cost parity for circular solutions through incentives and economies of scale.
- Institutionalise circularity in energy and industrial policy frameworks, including regulatory obligations for materials designed for circularity.
- Establish a permanent EU observatory to monitor uptake and refine mechanisms.

KEY PERFORMANCE INDICATORS (KPIS)

- Number of financial and regulatory incentives to help achieve cost parity for recycled/reused materials.
- Number of financed/funded projects and pilots incorporating circular materials
- Integration of sustainability and circularity criteria into public procurement and EU funding mechanisms.

ANNEXES

ANNEX 1: PARTICIPANTS OF THE TASK FORCE

The table below lists those who have participated in the Task Force and contributed to the development of recommendations.

Name (Role/Organisation)
Task Force members
• Adele Manzella (ETIP GEO) • Ana Andrade (IWG Ocean) • Anastasios Perimenis (ETIP ZEP/IWG CCUS) • Anna Wang (IWG PED) • Antonio Iliceto (ETIP SNET) • Cristina Rocha (EERA / IWG Wind) • Edel Sheridan (IWG DCT) • Gerald Senentz (ETIP SNETP) • Giulia Cittadini (ETIP GEO) • Hervé Romano (ETIP HYDRO) • Holger Ihssen (EERA) • Ignacio Cruz (CETP) • John Korsgaard (ETIP WIND) • Katrin Kieling (IWG GEO) • Ludo Diels (IWG EEB) • Ludovic Charpentier (IWG CST) • Marte Gammelsaeter (IWG DCT) • Marcel Weil (ETIP BAT) • Maria Capogreco (ETIP RHC) • Nadine May (IWG H2) • Petra Rüther (IWG EEB) • Puzant Baliozian (ETIP PV) • Ramoon Barros Lovate Temporim (IWG RFB)
Support Office (including experts)
• Dominik Rutz (Task Force Lead, Support Office) • Chuan Ma (Task Force Facilitator, Support Office) • Benedetta Di Costanzo, (Task Force Facilitator, Support Office) • Ana Teresa Lima (Lead Expert) • Hanna Pihkola (Support Expert) • Nikolaos Arvanitidis (Support Expert) • Ricardo del Valle (Support Expert) • Luis Alberto Tercero Espinoza (Support Expert)
European Commission (Observers)
• Nicola Magnani (Lead Policy Officer, JRC) • Luca Giovannelli (DG RTD) • Teodor Kuzov (JRC) • David Pennington (JRC) • Fernando Coelho (JRC)

ANNEX 2: METHODOLOGY OF THE TASK FORCE

The sections below describe the main elements of the approach for how the recommendations were developed within a Task Force:

1. Nomination of Task Force members
2. Task Force Meetings (3x)
3. Literature review
4. Consultation with wider SET Plan community (2x)
5. Written comments from Task Force members (3-4x)

1. Nomination of Task Force members

The following 'stakeholder groups' of the SET Plan were invited to nominate representatives to participate in the Task Forces:

- Implementation Working Groups (IWGs);
- European Technology and Innovation Platforms (ETIPs);
- European Energy Research Alliance (EERA);
- Clean Energy Transition (CET) Partnership;
- Driving Urban Transition (DUT) Partnership

Each SET Plan stakeholder group (i.e. a specific ETIP or IWG) was able to nominate one primary representative for each cross-cutting Task Force. A call for expressions of interest was launched in Q3 2024 to gather nominations and establish the members of each Task Force.

There were specific roles within the Task Force that facilitated the co-creation of recommendations. These are described in the table below

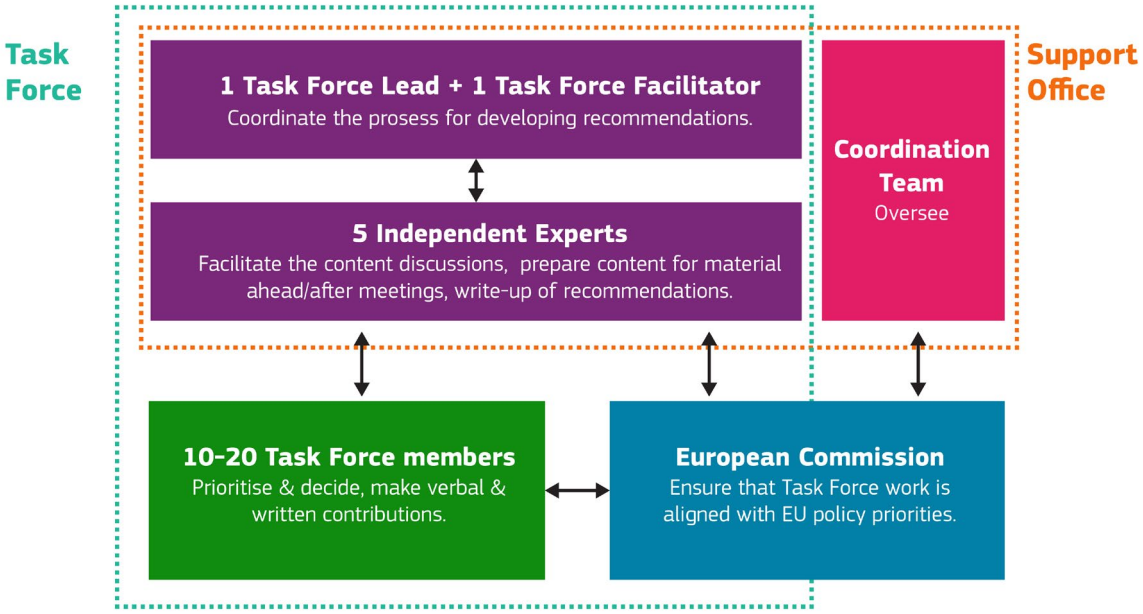
Table 3: Overview of roles for each Task Force

Role	Description
Support Office (7+)	The Support Office operated the Task Forces and was made up of: • Coordination team overseeing the operation of the five Task Forces. • 1 Task Force Lead and 1 Task Force Facilitator to coordinate the meetings (incl. logistics and minutes) and outputs of the Task Forces. • 5 Independent Experts who provide knowledge and guidance in their specialised fields and write up (specific aspects of) the recommendations. They are 'independent' in the sense that they were not previously involved in the SET Plan.
Members of the Task Forces (10 – 20)	Representatives were nominated by the SET Plan stakeholder groups (ETIPs, IWGs, etc.). Specific responsibilities for Task Force members included: • Attend all meetings of the Task Force (3 online meetings took place in 2025 and 2026); • In between meetings: Gather feedback from the SET Plan stakeholder group they represent and provide written inputs; • During meetings: Make verbal contributions (e.g. rank and decide on priorities and solutions).

European Commission (1+)	• European Commission Policy Officers had an observer role in the recommendation development process.
	• 'Lead' Policy Officers: Ensured that the work of the Task Force was aligned with the policy priorities of the Commission.
	  • They reviewed and approved recommendations from the Task Force.
	  • They did not directly influence the process of the recommendations.
	• 'Other' Policy Officers: Provided oral and written inputs on an as-needed basis (e.g. for a specific policy area).

Overall, the Support Office served as a facilitator, drawing on the knowledge of the SET Plan stakeholder groups. With the help of the Independent Experts, the Support Office structured discussions and helped identify gaps and challenges for Task Force members.

Figure 5: Roles of the Task Force and Support Office



2. Task Force meetings and workshop

The following meetings were held to facilitate the development of the recommendations:

- 1st Task Force meeting (March 2025): The top priorities and related barriers/gaps were discussed and refined. Within the TF, priorities for future work were agreed upon.
- 2nd Task Force meeting (June 2025): Preliminary concepts for recommendations were discussed.
- 3rd Task Force meeting (January 2026): Finalisation of the recommendations.
- Several meetings with the Task Force Lead, Facilitator, and Independent Experts took place to discuss input, develop the recommendations and support preparation for Task Force meetings.

Initially also a Cluster Workshop took place (in November 2024), which brought together the Secretariats of the Implementation Working Groups (IWGs) and the European Technology & Innovation Platforms (ETIPs) of the SET Plan. The objective of the workshop was to identify their priorities across five cross-cutting topics to inform the future work of the respective Task Forces.

3. Literature review

Between October 2024 and April 2026, literature was reviewed by the Support Office and the Independent Experts. The literature review serves as a supporting evidence.

4. Consultation with the wider SET Plan community

Following the development of the draft recommendations, a consultation was launched to collect feedback from the IWG and ETIP Secretariats and (Co-)Chairs; European Commission members; and Steering Group members. The consultation took place between the 25th of August and the 12th of September 2025. A second consultation round took place between the 9th of February and the beginning of March. Feedback from the consultation was included in the finalisation of the recommendations on cross-cutting topics to be addressed by/within the SET Plan.

5. Written comments

On several occasions, Task Force members, European Commission and Independent Experts were able to include input comments on the Recommendations and update their expressions of Interest accordingly. These also informed the finalisation of the recommendations.