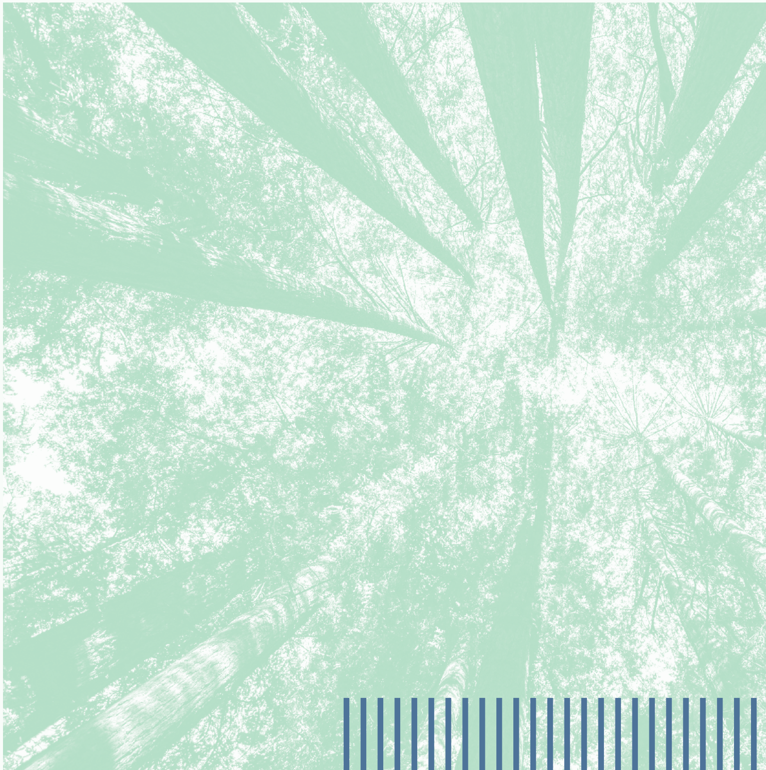
EERA
European Energy Research Alliance



White Paper

Clean Energy Transition

About EERA
The European Energy Research Alliance (EERA) is the association of European public research centres and universities active in low-carbon energy research. EERA pursues the mission of catalysing European energy research for a climate-neutral society by 2050. Bringing together more than 250 organisations from 30 countries, EERA is Europe's largest energy research community. EERA coordinates its research activities through 18 Joint Programmes and is a key player in the European Union's Strategic Energy Technology (SET) Plan.

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Endorsements

"Europe needs an accelerated energy transition where renewable energy has a key role to play. Research and innovation are essential for a successful energy transition. Many of the messages in the European Energy Research Alliance white paper Clean Energy Transition concur with IRENA's analyses. This includes for example the importance of sector coupling, the need for a systems perspective and for a systemic innovation approach. Also, the need to broaden the discussion from technology-based energy transition to an inclusive, innovation-based energy transformation that considers enabling frameworks. Europe is at the centre of the global energy transition and has an important role in the global effort to shape the energy systems of the future. More specifically, EERA, as the association of European public research centres and universities active in low-carbon energy research, plays a pivotal part in the transition. This white paper is a major contribution and a significant step in the right direction."

Dolf Gielen, Director Innovation and Technology, IRENA

"This EERA White Paper hits the nail on the head. Becoming climate neutral in 28 years is a dauting endeavour. It requires a drastic refoundation of the way we consume, eat, live, move and produce, in Europe and in the rest of the world. Such great transformation can only occur with deep and innovative socio-technical changes. Together with EERA, let us act to ensure deep exchanges between all scientific discipline, including social scientists, and policy makers, to create the disruptive innovations we need to overcome the risk of a climate disaster."

Thomas Pellerin-Carlin, Director of the Jacques Delors Energy Centre, Jacques Delors Institute.

Foreword

Not since the Paris Agreement has climate diplomacy been so relevant in the political agenda. Recently, the number of countries that have pledged to reach net zero has been growing worldwide and now covers more than 75% of current global greenhouse gas emissions. However, this major shift in the climate-related political discourse is not yet matched by actual policy measures and concrete actions.

Even assuming that all current government plans were to be implemented in full, global emissions would only stabilise in the best-case scenario. Most probably, they would fall woefully short of the Paris climate targets. This was clearly demonstrated in the UN NDC synthesis report this September, according to which we are likely to have higher emissions in 2030 than in 2019. The challenge is therefore a daunting one: the world now has less than three decades to redesign the economic and societal paradigm built over the last two centuries.

In this respect, and even though the energy sector accounts for two-thirds of total anthropogenic GHG emissions, deploying existing and future clean energy technologies faster than at any time before will not be enough in itself. Beyond decarbonising the energy sector, the economy and society need to be radically transformed. Policymakers, scientists, industries and civil society have never had such a historic responsibility. In particular, research and innovation are key enablers for progress as a society. As the most important representative of the research community, the European Energy Research Alliance (EERA) believes it is urgent to bring investments in these areas to a whole new level compatible with the climate emergency.

Echoing and building further on the net-zero scenarios recently released by the International Energy Agency (IEA) and the International Renewable Energy Agency (IRENA), EERA proposes a conceptual and methodological framework to support policymakers in designing the best transition pathways to climate neutrality.

The EERA White Paper on the Clean Energy Transition suggests a radically new approach, addressing the transition from a holistic and systemic perspective, driven by societal objectives. It constitutes a landmark contribution to breaking existing policy and governance silos by proposing a fair transition approach that is more consistent across disciplines, integrated across sectors and convergent across policy fields. From this conceptual framework, EERA has derived a set of key policy recommendations to be regarded as pre-requisites for successfully making the Clean Energy Transition possible.

Having provided evidence of the absolute climate emergency, the scientific community has supplied policymakers with the tools and roadmaps to drive the transition required. The future of our planet now depends on their ability to act immediately, collaboratively and decisively.

Nils A. Røkke
President

Leen Govaerts
Vice President

Teresa Ponce de Leão
Vice President

Table of contents

Figures and boxes

List of abbreviations and acronyms

AFOLU *agriculture, forestry and land use*
AI *artificial intelligence*
AR *Assessment Report*
ATR *auto thermal reforming*
CBAM *Carbon Border Adjustment Mechanism*
CCUS *carbon capture utilization and storage*
CET *Clean Energy Transition*
COP *Conference of Parties (UNFCCC)*
EERA *European Energy Research Alliance*
EU *European Union*
GHG *greenhouse gases*
HPC *high-performance computing*
ICT *information and communication technology*
IEA *International Energy Agency*
IPCC *Intergovernmental Panel on Climate Change*
IRENA *International Renewable Energy Agency*
LCOE *Levelized Cost of Energy*
LED *light-emitting diode*
OECD *Organization of Economic Co-operation and Development*
PV *photovoltaics*
R&I *research and innovation*
SDG *Sustainable Development Goals*
SET Plan *Strategic Energy Technology Plan*
SME *small and medium-size enterprises*
SMR *steam methane reforming*
TES *total energy supply*
TRL *technology readiness level*
UN *United Nations*
UNFCCC *United Nations Framework Convention on Climate Change*
USA *United States of America*

Executive Summary

The **European Energy Research Alliance** (EERA) was created 13 years ago as the formal research pillar of the European Strategic Energy Technology Plan (SET Plan)[1] to provide the EU with world-leading scientific expertise on low-carbon energy technologies. By coordinating the activities of more than 250 leading public research organisations at the core of the EU climate and energy ecosystem, EERA catalyses European research for a climate-neutral society by 2050, in alignment with EU long-term climate objectives.

This White Paper on the Clean Energy Transition constitutes EERA's landmark contribution to advancing understanding of the profound implications such a transition will have beyond technology for our economy and our society. It builds on existing knowledge and provides an instrumental conceptual framework to support policymakers in defining robust, actionable and efficient pathways towards a socially fair, environmentally sustainable, competitive and climate-neutral society.

The paper proposes that the "***Clean Energy Transition***" (CET), a concept central to EU energy and climate policies, extends well beyond climate neutrality to incorporate the essential dimension of social fairness and link it more broadly to the concepts of global sustainability and societal resilience. Consequently, beyond its core technological aspects, the transition entails socio-economic elements and calls for an interdisciplinary approach to policymaking.

The framework proposed in this paper adopts a holistic approach, based on addressing the sources of greenhouse gas emissions across all economic sectors. It reminds us that while energy use represents about 75% of anthropogenic greenhouse gas emissions, only a third of those originate directly from the energy sector. Achieving climate neutrality thus entails a much broader challenge than decarbonising the energy sector alone. Such an approach contrasts starkly with a more traditional, technology-centric approach to the CET. It suggests that decarbonising the energy sector should be regarded as an integral part of a broader transformation of the entire economy.

Because of the profound societal implications of the transition, this White Paper stresses the critical role of social sciences and humanities in ensuring the CET is designed for and driven by citizens. It highlights the crucial importance of building collec-

1. *https://ec.europa.eu/energy/topics/technology-and-innovation/strategic-energy-technology-plan_en* tive support and the commitment of all stakeholders to a new co-created societal model. More specifically, it calls for the development of a ***Clean Energy Transition (CET) Narrative***, defined as an overarching, coherent, robust and appealing storyline outlining transformation pathways and connecting individual imaginaries towards a desirable common future. Such a narrative is the fundamental motivational tool enabling citizens and society to envisage, endorse, concur with and eventually drive the complex transition process.

Transition Scenarios define the most effective pathways towards the desired state while integrating and optimising the complex systemic interactions across interrelated economic sectors. These scenarios are expected to differ widely between regions and countries, depending on economic activities, natural resources, industrial and energy infrastructure, and political choices. They constitute a fundamental planning tool, as they provide a well-documented, transparent and participatory co-creation setting, enabling the various stakeholder groups to assess the key drivers shaping the future and the critical obstacles to be overcome.

The Transition Scenarios are analysed in the White Paper through the prism of CET ***Themes***. These Themes cover essential cross-cutting aspects that enable and guide the CET and have a strong structuring impact on the design of the Transition Scenarios and on how the Transition Challenges are defined. The key CET Themes addressed in this paper are digitalisation; circularity; sector coupling and systems integration; policy, regulation and markets; and energy citizenship, cultures, practices and lifestyles. These give the Transition Scenarios overall societal robustness by ensuring that they are expressed as coherent, integrated policy measures and implementation actions.

Finally, the conceptual model suggests that the required research and innovation activities needed to reach the CET objectives should be framed as ***Transition Challenges***, defined as broad multidisciplinary and technology-neutral research challenges that are key to achieving the CET goals. Transition Challenges state the objectives to be attained without prescribing any specific implementation strategy or technology choice. They consequently enable the transition strategies to be expressed independently of the variable boundary conditions that will eventually determine the optimal – highly context-specific – implementation strategy or technology choice.

On the policy side, this paper suggests that more significant and decisive political action is needed to address the limitations of market forces, and to drive the transition at the speed dictated by the climate emergency. EERA's White Paper proposes a set of key **high-level policy recommendations** derived from the proposed conceptual framework. Taken as a whole, they must be considered an essential prerequisite to successfully drive the CET:

1. Develop a strong CET Narrative
2. Dramatically scale-up investment in R&I and technology deployment across all TRLs
3. Defragment policymaking across disciplines, activity sectors and energy carriers
4. Accelerate the innovation cycle
5. Ensure a fair transition at global, national, regional, local and individual levels
5. Reduce energy demand
6. Set up effective economy-wide carbon prices for clear market signals
7. Step up the level of ambition and challenge the dominance of current economic paradigm
8. Strategically increase international collaboration

Although the battle against climate change requires concerted action across the globe and a substantial increase in international collaboration, the proposed framework has been designed against the EU political and socio-economic backdrop. However, most of the proposed concepts are generic and thus applicable to other contexts and economies.

Policymakers in Europe and worldwide have the historic responsibility to act immediately, decisively and collaboratively. They must not only drastically increase the ambition of their climate commitments but also ensure these translate into tangible actions and actual emission reductions in the real world. This is the massive endeavour our generation is compelled to undertake if we are to secure a viable, peaceful and desirable common future.

Introduction

At the end of the 19th century, scientists – among them Nobel Prize-winning chemist Svante Arrhenius – began analysing the relationship between concentrations of carbon dioxide in the atmosphere and the Earth's surface temperature. In 1979, the Charney Report played a major role in policymakers' broad understanding of the origins and impacts of climate change, leading to the creation of the United Nations Intergovernmental Panel on Climate Change in 1988 and the publication of its First Assessment Report (IPCC AR1) in 1990[2], ahead of the 1992 Rio Summit.

2. IPCC AR1, IPCC First Assessment Report Overview and Policymaker Summaries and 1992 IPCC Supplement: *https://www.ipcc.ch/report/ar1/syr/.*

However, climate change only gradually started coming to the attention of the public at the turn of this century (see, for example, "An Inconvenient Truth", Al Gore, 2006) thanks to increasing climate activism, culminating notably in the address by Greta Thunberg in 2018 to the United Nations Climate Change Conference and the student-led movement of school strikes for climate action around the world under the name "Fridays For Future".

At the time of writing this paper, the scientific community was warning that the rise in the global average temperature would continue over the next few decades, despite action already taken. Scientific models predict that with the current policies, the world is on track for a temperature increase of up to 4°C by 2100[3].

3. IPCC AR6 WGI: *https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Full_Report.pdf*

4. United Nations Sustainable Development Goals: *https://sdgs.un.org/goals.*

Humankind urgently needs to address the dual challenge of climate change mitigation and adaptation. Combating climate change is central to the United Nations Sustainable Development Goals (SDG). SDG 7 focuses on affordable and clean energy, and SDG 13 on climate action (mitigation and adaptation), while the other 15 goals are also interconnected with this topic[4].

This White Paper intends to focus on mitigation strategies, i.e. analysing how Europe's society and economy could be transformed to drastically limit emissions, with the aim of achieving climate neutrality by 2050.

Notwithstanding the fact that the conceptual framework introduced in this paper is universally applicable, this document has been written primarily from the EU Clean Energy Transition (CET) perspective. Consequently, most of the examples and references relate implicitly to the EU context and its policy environment.

5. *https://ec.europa.eu/energy/topics/technology-and-innovation/strategic-energy-technology-plan_en*

6. *https://ec.europa.eu/clima/policies/eu-climate-action/law_en*

7. *https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en*

8. COP 21, Paris Agreement: *https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement*

9. Taking into account 2018 emission rates prior to the impact of the Covid-19 pandemic

10. IPCC, Special Report "Global warming of 1.5°C", 2018: *https://www.ipcc.ch/sr15/*

Over the course of recent decades, political decisions have promoted the rapid evolution of existing policy frameworks and the emergence of new ones. In Europe, the 2003 decision to create an EU carbon market, the launch of the Strategic Energy Technology Plan[5] (SET Plan) and the 2016 proposal for a "Clean Energy for all Europeans package" marked the emergence of a robust climate-related strategy, culminating in the European Climate Law[6].

As one of the pillars of the European Green Deal[7], the European Climate Law enshrines the EU's commitment to achieving climate neutrality by 2050 and the intermediate target of reducing net greenhouse gas (GHG) emissions by at least 55% by 2030, compared to 1990 levels.

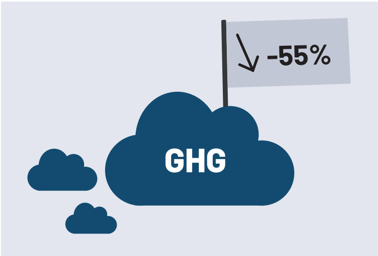
This political milestone coincides with a strengthening of international pledges to meet the Paris Agreement targets[8] on the occasion of the April 2021 US climate conference. This event also marked the return of the US, one of the top GHG emitters globally, to the Paris accord. It also renewed the international drive to combat climate change, often referred to as the global "race to net zero".

This recent new impetus can only be wholeheartedly welcomed in light of the fact there are fewer than three decades left to succeed in zeroing the world's net emissions. In this regard, there is an overwhelming consensus among analysts, highlighting the importance of a faster rate of technological innovation accompanied by an increase in the deployment rate of available technology.

However, the challenge ahead is daunting. Society needs to take decisive action now if we take into account that, at the current emissions rate[9], scientists expect the world to exhaust the entire remaining carbon budget to reach the Paris Agreement targets by 2031[10].

Reaching net zero by 2050 demands fundamental changes in every sector of our economy within the current decade. This major transformation implies the need for innovative policies that should steer an unprecedented acceleration in public and private investment in low-carbon research, assets and infrastructure. It also requires a profound change in citizens' consumption patterns and lifestyle, including but not limited to food, energy consumption, transport and living conditions. Finally, it involves redesigning markets for more efficient and circular usage of energy and natural resources.

The Covid-19 pandemic and the unprecedented economic crisis it has generated globally might act as a catalyst for more radical socio-economic transformation. The historic drop in global emis-



sions witnessed in 2020[11] due to the related global economic slowdown was exceptional and is likely to be significantly offset by the strong rebound already observed in 2021. However, this global crisis has forced major economies to unleash historic recovery packages[12 13] that significantly contribute to green investments. Besides this significant financial impetus, the societal shock created by the depth, duration and unexpected nature of the disruption has created a prime opportunity for radical change in our societies.

It is interesting to note that the Covid-related drop in 2020 global emissions is about the expected rate of annual emission abatement needed between now and 2050 to reach the Paris Agreement targets[14], which hints at the magnitude of the required transformation ahead of us.

Against this backdrop, the urgent need for accelerated conception, design and deployment of a range of new low-carbon technologies and for continuous development and deployment of already available technologies cannot be overstated. According to a recent analysis by the International Energy Agency (IEA), half of the emissions abatements to get to net zero required after 2030 will have to come from technologies that are not yet ready for market[15], while the other half will have to come from technologies that are on the market but still need to be deployed at the speed and scale required[16].

However, analysis of the facts demonstrates that the market availability of highly competitive clean technologies (notably, onshore and offshore wind, PV)[17 18], although key, is not sufficient on its own to drive the CET.

In addition, the extent of the climate emergency and the inability to properly incorporate present and future externalities into current economic and market models should be highlighted as strong deterrents for the CET to be steered only by economically driven decision-making. While inaction will vastly outweigh the estimated cost of accelerated transition to net zero, climate change constitutes an existential threat to humanity, and it can be argued that our human response should rather be fundamentally dictated by political choices.

As can be seen in Fig. 1, despite impressive cost reductions over the past decade, "new renewables" (e.g. PV and wind energy) only represented in 2018 around 4% of the global primary energy supply[19]. Such an indicator can only underscore the complex and multi-faceted nature of the challenge of transitioning to net zero. However, it must be emphasised that the transition to renewable

11. IEA, Global Energy Review, CO2 Emissions in 2020, March 2021

12. EU Recovery and Resilience Facility: *https://ec.europa.eu/info/business-economy-euro/recovery-coronavirus/recovery-and-resilience-facility_en*

13. The White House: American Rescue Plan: *https://www.whitehouse.gov/briefing-room/legislation/2021/01/20/president-biden-announces-american-rescue-plan/*

14. European Energy Innovation, Summer 2020 edition: *http://europeanenergyinnovation.eu/OnlinePublication/Summer2020/index.html#p=40*

15. IEA: Executive Director's message to global leaders: *https://www.iea.org/commentaries/my-message-to-the-leaders-at-the-climate-summit-we-need-real-change-in-the-real-world*

16. IEA: Executive Director's message to global leaders: *https://www.iea.org/commentaries/my-message-to-the-leaders-at-the-climate-summit-we-need-real-change-in-the-real-world*

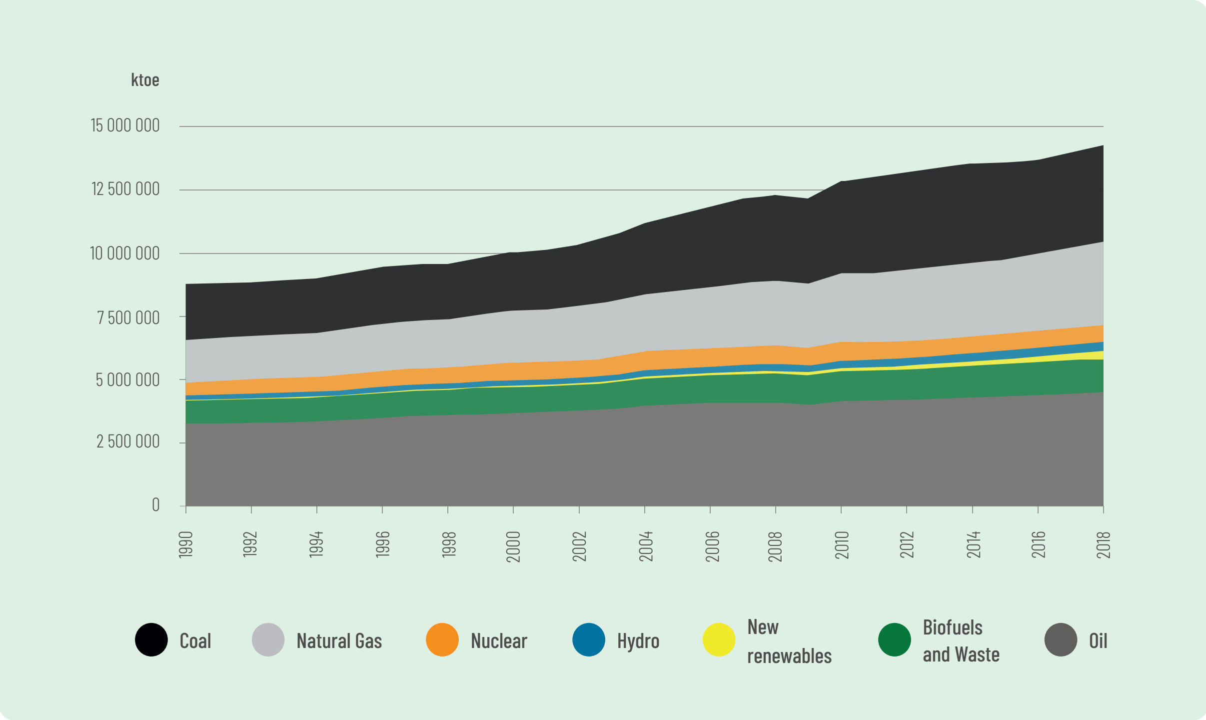
17. IEA: Levelised cost of electricity calculator: *https://www.iea.org/articles/levelised-cost-of-electricity-calculator*

18. IRENA: Global levelised cost of electricity and Auction values: *https://www.irena.org/Statistics/View-Data-by-Topic/Costs/Global-LCOE-and-Auction-values*

19. IEA data analysis, 2021

energy will reduce the need for primary energy supply to provide the same energy services (i.e. heating, cooling and power).

Figure 1: Total energy supply (TES) by source, world, 1990-2018 (Source: IEA, all rights reserved)



20. See, for example the Innovation Landscape for a renewable-powered future report by IRENA: *https://www.irena.org/publications/2019/Feb/Innovation-landscape-for-a-renewable-powered-future.*

21. Eurostat, Final energy consumption by product: *https://ec.europa.eu/eurostat/cache/infographs/energy_dashboard/endash.html?geo=EU27_2020&year=2019&language=EN&detail=1&nrg_bal=&unit=MTOE&chart=chart_9&modal=0*

The literature on quantitative energy scenarios for reaching climate neutrality abounds. However, many of these scenarios are technocentric and focused primarily on the energy sector, and generally overlook the importance of socio-economic dynamics and the political and legal framework.

This White Paper does not intend to challenge the rich base of existing quantitative analysis. On the contrary, it attempts to complement existing studies[20] by adopting a fundamentally different and overarching conceptual perspective of the challenges ahead. As such, the stated objective of this paper is to provide policymakers with a robust conceptual framework to help design CET policies to drive the transition effectively, consistently and measurably at a speed compatible with achieving the Paris Agreement targets.

To reach the CET goal, this paper stresses the complex intertwined nature of the CET and attempts to highlight some common misconceptions. According to official statistics[21], power generation in Europe represents less than 25% of the final energy consumption, while fossil fuels still account for more than 65% of the latter. This highlights the fact that achieving decarbonisation requires strategies across traditionally analytically disconnected sectors.

In summary, this paper highlights the systemic, cross-sectoral and multidisciplinary implications of the CET. It builds on the existing body of academic literature focusing on the key role of societal transformation for achieving climate neutrality[22]. Aiming to contribute to already existing knowledge, this paper provides a CET framework that can be instrumental in defining the best pathways to transition towards a just, environmentally sustainable, competitive and climate-neutral society.

22. See, for example: *https://www.science.org/doi/abs/10.1126/science.aao3760; https://www.sciencedirect.com/science/article/abs/pii/S2214629614000073*

1.

The CET conceptual framework

The latest EU climate commitment is to reach climate neutrality by 2050 with an intermediate target of reducing net greenhouse gas emissions by at least 55% by 2030, compared to 1990 levels. The process of transitioning to climate neutrality is generally referred to as CET.

Although usually seen primarily in relation to the EU's long-term climate-neutrality commitment, the scope of the CET includes other vital aspects.

First, it points to the proposition of an environmentally sustainable model regarding biodiversity protection and restoration, water and food security, air, soil and water quality, and sustainable use of natural resources. Second, it carries the promises of a "fair and just" transition, "leaving no one behind" and providing for an ethically and socially acceptable base of services to all European citizens. Finally, it assumes that the target societal model will enhance EU competitiveness globally, protecting EU values and citizens' welfare.

Box 1: Definition of the Clean Energy Transition

"The widespread transformation of the energy system to achieve a fair, environmentally sustainable, competitive and climate-neutral society by 2050". Such a transformation will impact the way humans eat, live, travel, produce and consume in the 21st century.

The European Energy Research Alliance (EERA) is the formal Research Pillar of the SET Plan, which was drawn up 12 years ago, and has provided the EU with world-leading scientific expertise in developing critical low-carbon technologies and strategies. Recognising the broader scope of the CET, EERA recently revised its mission statement towards the societal objective of "catalysing European energy research for a climate-neutral society by 2050" in complete alignment with the EU's long-term strategy.

23. Stockholm Resilience Centre: *https://www.stockholmresilience.org/research/planetary-boundaries/planetary-boundaries/about-the-research/the-nine-planetary-boundaries.html*

It is argued that a fast and efficient CET requires transnational integration, sector coupling, innovative and consistent market design and regulation, and technology development in all areas of joint and national interest. Moreover, the CET is holistically addressed while preserving and capitalising on the diversity and complementarity of its Member States.

The proposed conceptual framework (Box 2) incorporates techno-economic, socio-economic, legal and environmental perspectives into a holistic and interconnected approach across all economic sectors of society to achieve the goals of the CET. As such, it addresses the fundamental overarching issue: *«How to design fully integrated CET solutions compatible with the principles of environmental and social sustainability, leading to an increase in social welfare, in full respect of the planetary boundaries*[23] *and climate objectives, while preserving Europe's geopolitical leadership»*.

Box 2: EERA's CET Framework

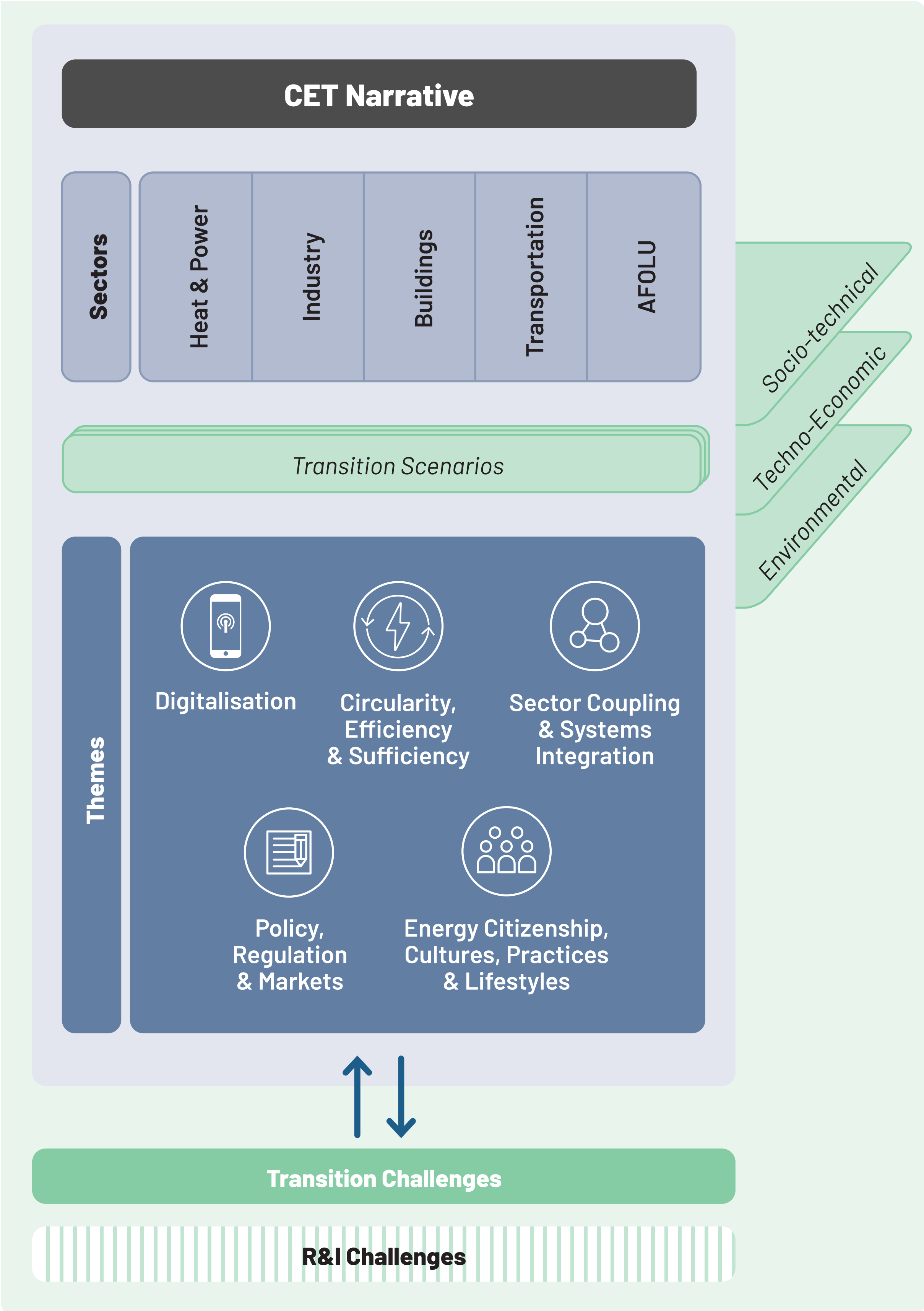
The **CET Narrative**, the top part of Fig. 2, refers to the overarching political vision of how society as a whole will transition from its current state to the future target state, i.e. a fair, sustainable, competitive and climate-neutral society. It reflects the broad societal consensus and boundary conditions under which the Transition Scenarios will be implemented. In contrast with scenarios that define the sequence of concrete actions and events, the CET Narrative describes a high-level, credible, tangible and desirable vision shared by all stakeholders, including researchers, policymakers, businesses and citizens. It connects with individual emotions and imaginaries to create a shared appropriation of a desirable future. The CET Narrative is an essential tool for fostering collective commitment to the CET.

The **Sectors**, shown in Fig. 2 below the CET Narrative, have been defined following the division of economic sectors, as identified by the IPCC (more details in Section 3 of this paper). This segmentation accounts for a total amount of GHG emissions (both anthropogenic and natural) produced by each sector.

The **Transition Scenarios**, in the centre of Fig. 2, describe possible pathways to a fair, sustainable, competitive and climate-neutral society within the broad principles and boundaries of the CET Narrative. Transition Scenarios include qualitative and quantitative analyses of how reductions could be achieved across the various economic sectors. These scenarios enable all stakeholders to explore the future implications of specific transition pathways by analysing the impacts of political, technological and market choices for society, the economy and the environment.

Finally, **Themes**, in Fig. 2 below Transition Scenarios, are cross-cutting research areas, fundamentally structuring the design of transition pathways. The next section will focus on the different components of EERA's CET conceptual framework.

Figure 2: EERA's framework of the CET approach



2.

Analysing EERA's CET conceptual framework

2.1. The CET Narrative: visualising the future

The CET Narrative is the overarching political vision of how society will transition from its current state to the desired state of climate neutrality. It is essential to convey the sense of purpose of coordinating action across all stakeholders in a mission-led perspective, providing them with a shared understanding of a joint roadmap towards the target future state. By weaving together the disparate elements and aspects of the transition, the CET Narrative makes it possible to visualise the flow of interconnected events and how they will affect every part of society as we move towards a future desired state.

The narrative is an essential tool to ensure convergence, coherence and consistency of transformative actions across all stakeholders and sectors. It constitutes a vehicle of intermediation between the individual and the social collective, fostering convergence and social cohesion of stakeholders by creating a collective imaginary and subsequently implementing the envisioned changes.

The CET Narrative must reflect broad political options resulting from critical societal choices conveyed by the prevailing fundamental values that characterise a society. In Europe, these fundamental values traditionally refer to the "EU way of life"[24]. In this sense, the narrative outlines the main characteristics and drivers of the desired transition pathway towards the targeted future state, i.e. a fair, sustainable, competitive and climate-neutral society.

24. The EU's fundamental values: *https://ec.europa.eu/component-library/eu/about/eu-values/*

25. IPCC, AR5, Working Group III: *https://www.ipcc.ch/site/assets/uploads/2018/03/WGIIIAR5_SPM_TS_Volume-3.pdf*

2.2. The sectors: understanding where emissions originate

In contrast to most of the existing work on the CET, which is most often based on sectoral or technology-driven analysis, the proposed framework adopts a holistic, top-down approach, analysing the sources of GHG emissions across all sectors of economic activity. Such an approach is an essential prerequisite for understanding how emissions can be globally reduced to net zero and guaranteeing that all sources of emissions are accounted for.

The identification and definition of sources of GHG emissions is a subject of research on its own and has led to several classifications, depending on the research focus. The present conceptual framework is based on the IPCC Fifth Assessment Report (AR5)[25]. This classification identifies specific activity sectors responsible for GHG emissions. It also highlights the systemic nature of the transition, recognising that transformative actions within any given sector generally affect the emissions balance in other activity sectors. In particular, it suggests that the energy sector should not be analysed in isolation but as an integral part of the entire economy.

Figure 3: Global GHG emissions by economic sector, IPCC 2014
Left: direct emissions; right: emissions by sector of final use

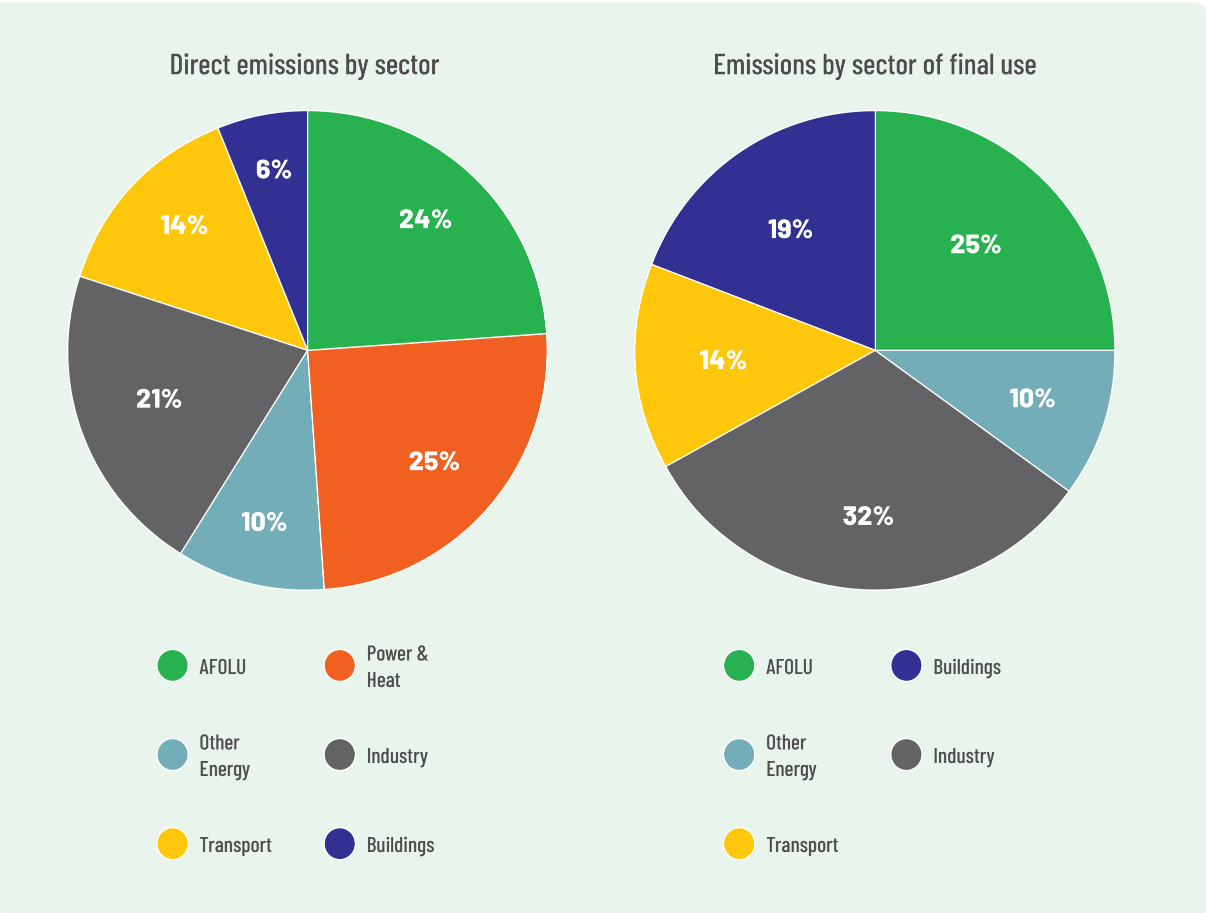


Fig. 3 provides an estimation of emissions by sector, converted into CO2 equivalents based on climate change potentials. "Other Energy" represents mainly the GHG emissions originating from fuel extraction and refining activities. AFOLU refers to Agriculture, Forestry and Land Use. The pie chart on the left of Fig. 3 shows the shares of direct emissions for the proposed sector, while the pie chart on the right shows the emissions by sector of final use. Heat and power emissions are attributed to the sectors of end energy use (also referred to as «indirect emissions»).

For instance, if we consider the 25% emissions coming from Power & Heat (left pie chart), about half is used for heating and power and is therefore attributed to the building sector, while the other half is used in and attributed to the industry sector.

In the CET conceptual framework proposed in this paper, we use the same classification by economic sector, noting that "Other Energy" is mainly attributable to the industrial activity of energy companies and should be conceptually accredited to the industry sector.

This classification is particularly relevant to illustrate the distribution of GHG emissions across the different sectors of activities. Notwithstanding the growing importance of the power sector, resulting from increased electrification of various economic sectors, it underscores the significant contribution of other sectors. Hence, the critical need to approach the CET from a holistic and cross-sectoral perspective.

2.3. Transition Scenarios: pathways to the future state

Transition Scenarios support the policymaking process by analysing the complex systemic interactions defining paths towards the desired state and enabling experts and representatives from the various stakeholder groups to collectively understand the key drivers shaping the future and critical obstacles in a participatory setting. Transition Scenarios include quantitative parameters supported by qualitative storylines that make it possible to explore ways of achieving abatements across the various economic sectors. It is important that for each Transition Scenario the major benefits, disadvantages and potential risks are clearly stated to enable policymakers to select the most desirable solutions.

Reaching climate-neutrality goals in Europe means that net emissions need to be zeroed collectively across the EU-27 Member States by 2050. It assumes, though, that Member States might have distinct individual emission reduction objectives.

In addition, given the highly diverse realities of Member States in terms of renewable energy resources' potential, existing infrastructure, industrial development, demography, democratic preferences and economic activity profile, the Transition Scenarios will differ from one EU country to another. For instance, countries such as Sweden, characterised by low population density and benefiting from extensive forestry resources, are likely to adopt different Transition Scenarios from the Netherlands or Hungary.

2.4. The Themes: structuring the analytical process

As mentioned earlier, **Themes** are essential components enabling and guiding the transition. They have a strong structuring impact on the design of the Transition Scenarios, and on how the Transition Challenges and the R&I Challenges are defined.

Themes, being cross-cutting dimensions by nature, emphasise that the Transition Challenges can best be resolved through an integrated approach linked to each of the relevant sectors. All Themes therefore need to be explored through a multidisciplinary lens across the socio-technical, techno-economic, legal and environmental research domains.

a. Digitalisation

Figure 4: Theme of Digitalisation

The digitalisation of the energy system is at the cusp of a new era. It will profoundly impact all aspects of energy across the entire cycle of generation, transformation, transport, usage and management. Information and communication technology (ICT) will affect all aspects of the energy value chain. Digitalisation will enable a significant paradigm shift, transforming energy from an undifferentiated base commodity to a highly characterised and flexible end-user service. It will be supported by innovative business models that will enable dynamic interactions across stakeholders and system components through the entire energy value chain.

For instance, the power system will be able to transform from a traditionally centralised and demand-driven power flow system into a decentralised, multi-directional system that can dynamically incorporate higher shares of variable sources based on predictive demand-supply models. This transformation will call for such improvements as short-term weather forecasting for efficient power system management.

The main drivers of accelerated digitalisation are the use of massive data repositories (big data) and artificial intelligence (AI), new cooperative digital platforms, use of blockchain system, new capabilities in analytical models, the availability of high-performance computing (HPC), platforms for advanced research, and modelling applications, as well as the widespread penetration of connected devices allowing seamless dynamic interaction of end-users with the overall system[26].

However, with the extensive and generalised integration of ICT in energy, new vulnerabilities emerge, such as cyber-security and cyber-robustness, and legal issues related to data ownership, which will become primary concerns given the potential wide-ranging effects of ICT. Scaling up the digital transformation of the energy system will lead to macroeconomic impacts beyond the energy sector, such as new markets for digital products and the creation of highly skilled jobs[27].

It is also essential to consider the environmental and societal impacts of digitalisation. These may account for the increased use of resources, including growing energy consumption by the ICT sector itself, and the potential widening of social inequalities associated with access to and use of digital technologies.

b. Circularity, Efficiency & Sufficiency

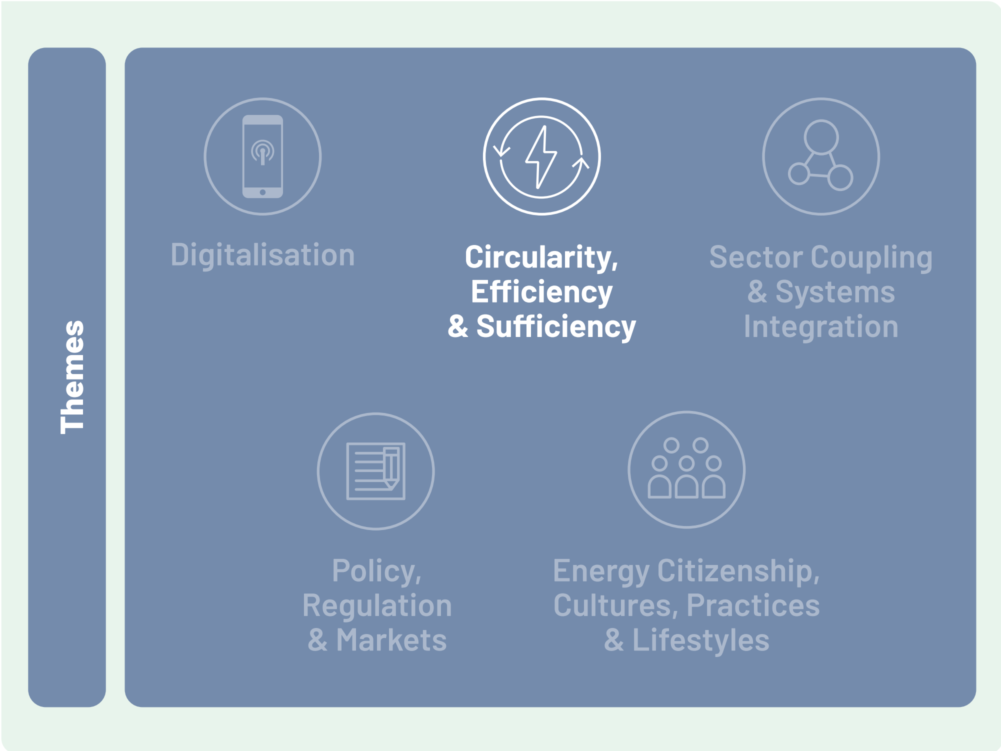
Circularity: reduce, re-use, recycle

Circularity is fundamental to the CET. It is a broad transformative concept aimed at minimising waste and reducing costs through optimal and sustainable use of resources, while limiting all forms of environmental impact. The first objective is to reduce, by minimising exploitation of ecosystems, making responsible use of mineral resources, favouring ecodesign and extending the lifetime of components and facilities. What cannot be further reduced should be re-used (e.g. materials re-use and the use of old electric vehicle batteries for the purpose of stationary electricity sto-

26. For more detailed overview of the digitalization potential to enable the CET consult, for example, with the Artificial Intelligence and Big Data report from IRENA: *https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Sep/IRENA_AI_Big_Data_2019.pdf*, the Digitalization and Energy report by IEA: *https://iea.blob.core.windows.net/assets/b1e6600c-4e40-4d9c-809d-1d1724c763d5/DigitalizationandEnergy3.pdf.*

27. *https://www.sciencedirect.com/science/article/abs/pii/S0048733319300733; https://www.sciencedirect.com/science/article/abs/pii/S0308596121001191* rage). What cannot be reduced or re-used must be recycled. The concept of circularity also calls for a paradigm shift in business models and market design.

Figure 5: Theme of Circularity and Efficiency



While including the value of natural resources and services – traditionally not accounted for[28] – circular business models redefine the meaning of value, proposing a shift from "asset ownership" towards "service provision", thus leading to a higher usage rate of material assets and reduced consumption of natural resources.

28. OECD, The economic significance of natural resources, 2011: *https://www.oecd.org/env/outreach/2011_AB_Economic%20significance%20of%20NR%20in%20EECCA_ENG.pdf*

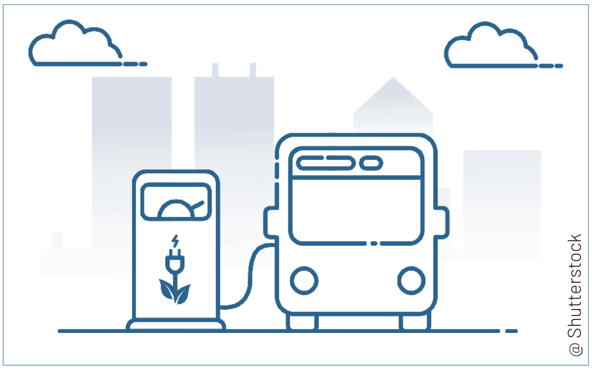
In particular, the massive scale-up of renewable generation technologies required to decarbonise the energy sector will lead to a rapid shift from the traditional security of supply characteristic of fossil fuel-based economies to the security of supply of critical minerals. Given the unequal geographical distribution and the scarcity of critical minerals, there will be an increased focus on more efficient resource usage and re-use or recycling. This focus will raise new research questions within the circularity domain, dealing with understanding the biophysical limits for renewable energy generation on different geographical scales.

Energy sufficiency and energy efficiency

Energy sufficiency and energy efficiency are two still largely underutilised sources of carbon abatement. Energy sufficiency leads to decisions favouring activities and services that are intrinsically low on energy use (e.g. in an office building, renovating the staircase to encourage employees to take the stairs). Energy efficiency leads to decisions that enable the same service to be provided using less energy (e.g. in an office building, replacing the lift with a lighter, modern model). Applying the principle of energy efficiency combined with energy sufficiency is also a strategy to minimise the rebound effect often associated with gains in energy efficiency[29].

Because of their potential application across all emission sources, sufficiency and efficiency solutions constitute an important emission abatement lever. Usually implicitly referring to the efficiency of some energy-intensive industrial processes and the energy performance of buildings, both energy sufficiency and energy efficiency should be analysed across all economic sectors and should consider low-carbon substitution options.

For example, shifting transport from air to rail or replacing cement and steel with alternative building materials such as sustainable wood must be considered complementary strategies for increasing jet fuel efficiency or decarbonising industrial steel and cement processes. Additionally, electrification of sectors like the transport sector will significantly improve energy efficiency, given that the power comes from renewable sources.



c. Sector Coupling and Systems Integration

In most countries, decarbonisation of the power sector is expected to be provided mainly by renewables such as solar and wind energy. When these sources are not available, the options for delivering renewable energy are either constrained (e.g. biomass) or need further cost reductions (e.g. long-term energy storage and other low-carbon technologies). Another way to provide low-carbon electricity is nuclear energy, an option that depends on political choices resulting from assessing a complex cost/benefit balance and democratic preferences.

It must be stressed here that the traditional concepts of base load and peak load are gradually losing relevance under the combined effect of shifting energy mixes (e.g. higher share of different variable renewables) and rapid technological developments (e.g. load-following capabilities of nuclear power plants, storage technologies, sector coupling and better predictive models).

As highlighted in Section 4.2, the bulk of GHG emissions is generated outside of the power sector. As such, the decarbonisation of society entails the implementation of transition strategies for sectors that still rely heavily on fossil fuels, such as space heating and cooling, industry and transport.

29. *https://www.sciencedirect.com/science/article/abs/pii/S0301421520307746*

Figure 6: Theme Sector Coupling and Systems Integration

30. Green hydrogen is hydrogen produced by splitting water using electrolysis powered by renewable energy sources, such as solar, wind or hydropower. This produces only hydrogen and oxygen (which can be vented to the atmosphere with no negative impact) and no CO2. Blue hydrogen is produced when natural gas is split into hydrogen and CO2, either by steam methane reforming (SMR) or auto thermal reforming (ATR). At this stage, it is called grey hydrogen. Blue hydrogen requires the CO2 to be captured and then stored using CC(U)S technologies to mitigate the environmental impacts. Pink hydrogen is also referred to as hydrogen produced by electrolysis powered by nuclear energy.

To a certain extent, decarbonisation of these sectors can be achieved through increased electrification, provided the power sector is also decarbonised. Although part of this additional power demand might be more flexible than the current electricity demand, with regard to energy consumption, a higher rate of electrification will highlight the need for extra flexibility and more widespread availability of efficient storage capabilities.

Hydrogen is called on to play a critical role in the energy transition as an energy carrier (as opposed to an energy source), allowing extra flexibility through its storage capabilities and enabling more integrated sector coupling. However, it is essential to point out that the actual carbon footprint of hydrogen usage is heavily dependent on the way it is produced (green or blue hydrogen), as well as its final use[30].

As stated earlier, the conversion of electricity to hydrogen (e.g. for the transport sector and some industrial processes) or to another molecule-based energy carrier) represents a strategy for increased flexibility, since these energy carriers can be stored and transported more easily than electricity and converted back into electricity when required.

In addition, this conversion constitutes a primary strategy for sector coupling, i.e. allowing the design of the energy system across sectors (e.g. linking the power sector with transport and industry) and across energy carriers (power, gas and heat).

However, the production of molecule-based energy carriers is still costly and associated with significant energy losses. Higher conversion efficiency and cost reduction are still needed to unleash its potential and allow widespread implementation, and will require substantial research and technological development.

These two trends – a shift in electricity generation to variable sources (such as wind or PV) with the subsequent need for additional system flexibility, and a shift towards electricity or synthetic energy carriers on the energy demand side – are leading previously independent sectors (e.g. power generation, transport and industry) to gradually become interconnected, while calling for increased integration of energy end-use and supply sectors with each other.

However, sector coupling also increases the complexity of the energy system. Small-scale local activities become more closely interrelated with national markets and infrastructures; infrastructures for different energy carriers become interdependent; and national and European markets become more closely interconnected. This also creates new challenges when it comes to market design and legal frameworks.

While energy system integration is essential for achieving the goals of the CET, the current energy system in Europe is still highly silo-based and hinders progress towards decarbonising the economy. CET-related policies and research roadmaps should therefore be designed in the context of stronger linkages between different energy carriers, infrastructure and consumption sectors.

While it is the prerogative of Member States and Associated Countries to design their own clean energy system according to their specific geophysical, political, economic and industrial context, a fully integrated, interconnected and resilient energy system must be created for Europe – not limited by geographical or regulatory frontiers.

Consequently, greater transnational and cross-sectoral integration is required to optimally balance energy sources resulting from the diversity of technology choices, depending on the specific conditions in each country or region. Additionally, to increase the resilience of the integrated energy system, short-term variability and long-term availability of renewable energy sources in different regions must be carefully taken into account.

d. Policy, Regulation and Markets

Figure 7: Theme of CET Policies and Market Design

A fair and just transition
While creating opportunities for economic development, the transition process carries the risk of increasing social and geographical disparities and giving rise to new types of social injustices.

It is therefore crucial that CET-related regulations and policies address issues relating to a fair and inclusive transition so as to reduce disparities and foster collective support and appropriation of new technologies across all parts of society.

In Europe, the Just Transition Mechanism[31] supports a socially fair transition towards a climate-neutral economy by providing targeted support for the most affected areas (e.g. coal-dependent regions) to alleviate the higher socio-economic impact of the transition.

Although no unified definition of energy poverty exists, the inability of citizens and families to provide for their basic energy needs has significantly increased in recent years, and is estimated to concern more than 7% of the EU population today. Supported by the Clean Energy for all Europeans package[32], transition strategies should be designed in accordance with the energy justice principle[33], prioritising support for the most vulnerable and underrepresented groups in society (e.g. low-income families, the elderly, children, migrants, people with disabilities). Support for the adoption of low-carbon technologies and the development of

31. EU Just Transition Mechanism: *https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/actions-being-taken-eu/just-transition-mechanism_en*

32. *https://ec.europa.eu/energy/topics/energy-strategy/clean-energy-all-europeans_en*

33. *https://www.sciencedirect.com/science/article/abs/pii/S2214629615300669* sustainable behaviour by all citizens must consider lifting all families and citizens out of energy poverty long term.

Multi-level governance[34] is another important aspect of the policies and regulations enabling the CET. With many different types of authorities involved in CET-related policymaking and policy implementation in the EU (from local to regional, national and EU-level stakeholders), multilevel governance is key to enable the coordination and success of the CET.

European energy integration
The ultimate goal of European market design and regulation is to achieve cost-efficient resource allocation in both the long and the short term, simultaneously aiming for a fair distribution of cost and benefits among different stakeholders and vectors of the energy system. This approach should include incentives to ensure optimal investments and operations for a secure and reliable integrated energy system.

The integration of European markets and energy infrastructures requires policy frameworks, harmonised licensing standards and market designs that foster their most efficient use. The development of energy infrastructures needs to be coordinated, with suitable investments by all market stakeholders, including prosumers. This requires a new, more integrated approach to certification, regulation and policy instruments between the Member States and Associated Countries and across sectors. Such an approach should be harmonised and validated at European level to facilitate cross-border implementation.

Crucially, EU legislation can be a very powerful tool to stimulate innovation, as it shapes markets and thus provides a clear market signal to innovators and investors[35]. In areas where clean solutions do not exist or are not yet scalable (e.g. green steel), EU directives and regulations should set clear, ambitious, binding objectives for specific sectors, products and/or services, and give innovators and companies the time to adapt and experiment, leaving them flexibility to find the best solutions to comply with ambitious climate targets. In areas where clean solutions are already on the market and can be scaled up (e.g. building renovation, batteries and electric vehicles), EU directives and regulations should accelerate the phasing-out of polluting technologies wherever clean alternatives are available (e.g. replacing the incandescent light bulb with greener alternatives like LEDs or banning the sale of new petrol and diesel cars in the EU by 2035[36]).

Macroeconomic competitiveness
As observed in all previous economic transitions, the shift to new industries and market models inevitably generates opportunities for economic growth and job creation in some economic sectors, while accelerating the collapse of others. As discussed earlier, the CET impact on the EU's economy is expected to be massive given

34. *https://journals.sagepub.com/doi/full/10.1177/1369148120937982*

35. *https://institutdelors.eu/wp-content/uploads/2021/04/PP263_Innovation4Climateneutrality_Bachelet_Pellerin-Carlin_EN.pdf*

36. https://ec.europa.eu/commission/presscorner/detail/en/ip_21_3541 the broad scope of the transformation process it entails and the unprecedented speed at which it needs to materialise. Ensuring the transition is carried out in a socially and economically sustainable way requires the potential impacts of the CET across the various economic sectors to be addressed and managed decisively and dynamically. A macroeconomic approach to identify the most optimal transition pathways will therefore be needed to understand value creation and ensure sustainable welfare redistribution.

Global industrial leadership

From a macroeconomic perspective, the CET entails a major geopolitical shift leading to a redefinition of competitive advantages and political and trade balances between existing and emerging economic blocs. Now that 75% of the global economy is located in countries with a carbon-neutrality target[37], the EU, China and the USA, in particular, are attempting to establish their own industrial dominance in clean technologies, similar to efforts by China and the USA to achieve technological dominance in digital technologies over the last two decades. It is consequently predicted that, from a geopolitical perspective, the race to net zero will fuel a race for industrial leadership in a range of existing and future critical clean technologies, while traditional fossil fuel security of supply is expected to gradually lose pre-eminence.

Among several other aspects, industrial leadership will in particular translate into a combined race for scientific dominance and intellectual property (patents) in clean technologies, as well as for access to the range of critical minerals (particularly, but not only, rare earth minerals) needed for mass production of these technologies[38].

Structural changes associated with the race to net zero offer a unique opportunity for European industry to benefit from a first-mover advantage by consolidating its current leadership in several key clean technologies and building leadership in products, services and business models of the future. This should also boost the competitiveness of the EU economy in key areas of social, environmental, climate and economic performance. The Covid-19 pandemic has also acted as a strong catalyst for an accelerated transition towards a green economy.

The post-Covid EU Recovery and Resilience Facility[39] will provide some much-needed additional funding for the "Green and Digital" transition and has furthermore already generated a highly favourable political environment for disrupting the status quo and driving radical changes across society.

The race for innovation and patents, securing access to critical resources, and accelerated industrial development will occur against the backdrop of increased global "coopetition"[40] in a wave of reshoring and defragmentation of global supply chains. In

37. *5 years after the paris agreement, the largest global economies are engaging in the race towards climate neutrality*, Jacques Delors Institute infographics, December 2020. *https://institutdelors.eu/en/publications/5-years-after-the-paris-agreement-the-largest-global-economies-are-engaging-in-the-race-towards-climate-neutrality/*

38. *https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions*

39. EU Recovery and Resilience Facility: *https://ec.europa.eu/info/business-economy-euro/recovery-coronavirus/recovery-and-resilience-facility_en*

40. *Coopetition* is a neologism describing cooperative competition. The basic principles of coopetitive structures have been described in game theory, a scientific field that received increased attention with the publication of the book "Theory of Games and Economic Behavior" in 1944 and the works of John Forbes Nash on non-cooperative games.

Europe, delivering the promises of the CET will require an in-depth redefinition of trade and industrial policies to ensure the sustainable socio-economic development of European society and avoid the relocation of critical industrial sectors to regions with lower labour or environmental standards. The Carbon Border Adjustment Mechanism (CBAM)[41] is an example of the policies needed. This is an example of bold transformational policy that highlights the increasing focus on carbon economics and the importance of addressing the related issue of carbon leakage.

Given the absence of evidence of an absolute decoupling[42] (between economic growth and environmental impacts), achieving the goals of the CET will generally require the implementation of policies aimed at moderating consumption in many traditional economic areas. Robust transition pathways will need to balance the diverging needs for maintaining global competitiveness and geopolitical independence, increasing social sustainability and citizens' welfare while fostering more sustainable consumption models. Such an approach is required to achieve the ambitious GHG emissions reduction and environmental sustainability. An additional important step towards building a sustainable society and shifting the growth-oriented production and consumption paradigm could be to reconsider the metrics of societal and economic development, such as introducing alternatives to the GDP, which is known to be a limited indicator for monitoring human well-being[43].

41. *https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12228-Carbon-Border-Adjustment-Mechanism*

42. *https://eeb.org/library/decoupling-debunked/*

43 *https://www.sciencedirect.com/science/article/abs/pii/S0959652614010932; https://www.nature.com/articles/s41893-020-0499-4*

e. Energy citizenship, cultures, practices and lifestyles

Figure 8: Theme of Energy Citizenship and Lifestyle

44. *https://www.maastricht university.nl/energise*

45. Benjamin Sovacool, 'What are we doing here? Analyzing fifteen years of energy scholarship and proposing a social science research agenda', Energy Research & Social Science, March 2014.

46. Convention Citoyenne pour le Climat, France: *https://www.conventioncitoyennepourleclimat.fr/en/*

Based on the principle that "avoided emissions are abated emissions", the contribution of citizens to driving the CET cannot be overstated. Their understanding, engagement and appropriation of the CET challenge are key to achieving the profound societal transformation required to reach net zero.

For example, the H2020 ENERGISE project defines individual energy consumption as: *"A function of who we are, where we come from, and the socio-cultural and material contexts in which we live"*. It also underscores that societal norms and routines with regard to work, education, family life, consumption and recreation greatly determine our patterns of energy use as well as our ability and willingness to change those patterns. It concludes that a comprehensive understanding of these energy cultures is essential for public policy measures to reduce energy consumption at the individual or household levels to be effective[44]. The understanding of specific cultures and the drivers behind cultural changes is therefore a key condition for successfully driving the CET.

Understanding energy citizenship in the CET process will support innovation to develop new policies, regulations, standards, business models, goods, services, financial schemes and even a conception process of R&I models.

While it is still common for the techno-centric CET paradigm to reduce the social aspect to the public acceptance of new technologies, the R&I cycle must incorporate the insights of the social sciences and humanities (including law)[45] research domain to foster social innovation and understand socially significant and culturally meaningful practices so as to inform the earliest stages of the design process of a policy, product or service.

Policies, regulations and markets will need to be designed to foster the acceleration of CET-friendly consumer choices towards low-carbon products, services and consumer behaviours. Such behaviours should be understood in terms of consumption moderation, as well as recourse to low-carbon substitutes. Consideration should also be given to the emerging role of citizens as producers of energy, either individually (e.g. prosumers) or collectively (e.g. local energy communities), as well as their roles in shaping available infrastructure, such as the repurposing of urban infrastructure from car use to bike/pedestrian use.

The example of the Citizens' Convention on Climate in France[46] provides a blueprint on how the shift in citizens' preferences and values interacts with the policymaking process: citizens can develop innovative green policies that, in turn, drive behavioural change in other citizens, resulting in the design of highly innovative CET policies[47]. There have already been similar experiences in Ireland and Germany. This is an example of how diverse citizen views and values can be included in the development of strategies and pathways to net zero – so the role of citizens goes well beyond the narrow role of consumer or user of technology.

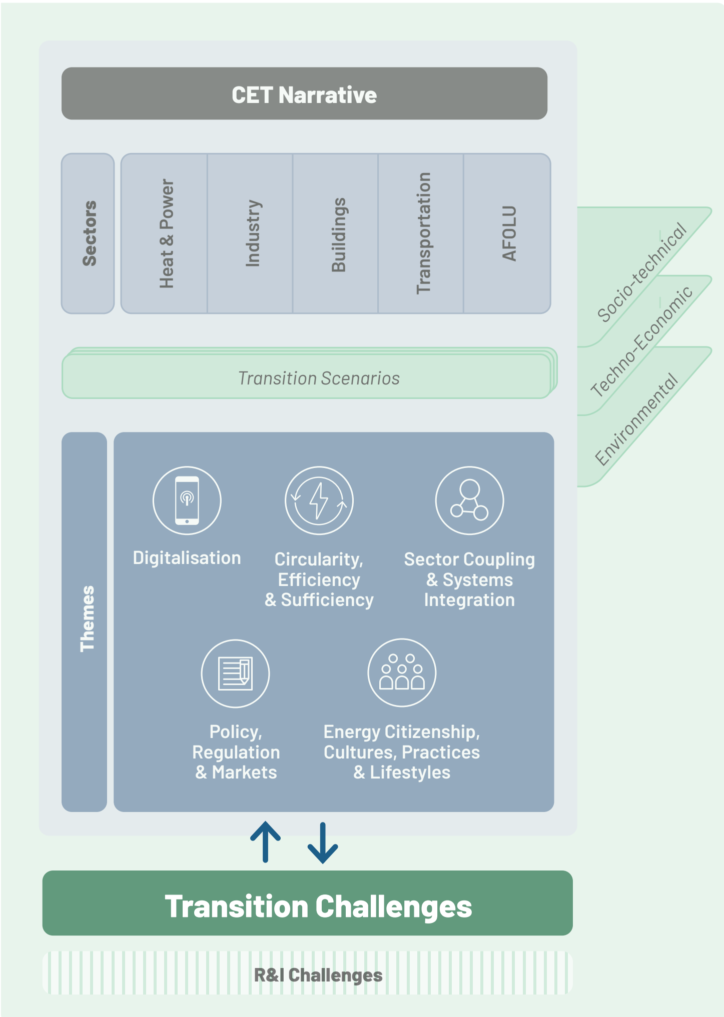
Given the highly meshed and interdisciplinary nature of social innovation, policies should also promote experimentation sandboxes[48] that provide effective platforms for radical innovation by allowing real-life experiments across the traditional boundary conditions and constraints implicitly imposed by existing structures and models. Finally, energy citizenship should become a dimension of innovation in itself. This also entails confronting the need to deal with currently inactive, disempowered energy citizens, and understand the very different expectations people have of citizenship, both across and within Member States.

47. *https://www.bfmtv.com/economie/entreprises/transports/avion-les-deputes-donnent-leur-accord-a-la-suppression-des-vols-interieurs-courts_AD-202103150158.html*

48. "Sandboxes" are generally defined as concrete frameworks that, by providing a structured context for experimentation, enable – where appropriate in a real-world environment – the testing of innovative technologies, products, services or approaches for a limited time and in a limited part of a sector or area under regulatory supervision, ensuring that appropriate safeguards are in place.

2.5. The Transition Challenges: defining broad research objectives

Figure 9: The Transition Challenges in the broader context of the CET framework



Transition Challenges can be defined as broad multidisciplinary research challenges identified as core to achieving the CET goals. They are expressed in relation to a major intermediate objective required to achieve a Transition Scenario while covering a range of research areas in a non-prescriptive way. In essence, they are by default cross-sectoral and multidisciplinary, and require systemic analysis. The concept of Transition Challenge states the objective to be achieved without prescribing a resolution strategy or a technology choice.

Consequently, addressing the Transition Challenges may entail a range of different possible strategies, the selection of which essentially depends on relevant Transition Scenarios. As such, their definition should not be limited by technology readiness levels (TRLs) and must include political and social conditions when defining Transition Scenarios.

The choice of a technological pathway will give way to defining a set of dedicated and concrete R&I Challenges, covering environmental, legal, socio-economic and techno-economic research domains.

Developing smart and climate-neutral cities constitutes a relevant Transition Challenge example, as it involves various sectors such as heat & power, smart and efficient buildings, and low-carbon transport. It also relies on deep digitalisation, sector coupling and circularity, while requiring changes in policy and regulation, market design, production and consumption patterns.

Other possible examples of Transition Challenges are “decarbonising power generation”, “electrifying carbon-intensive industrial processes”, “providing robust, resilient and flexible energy networks” and “decarbonising heavy-duty road transport».

2.6. Research and Innovation challenges: driving research efforts

The choice of specific R&I Challenges will typically depend on several contextual factors that may change over time and differ because of geophysical conditions, availability of natural resources, existing infrastructures, and differing social, political, economic and technological contexts.

The definition of R&I Challenges constitutes the basis for policy-makers to direct research efforts through appropriate policies and dedicated funding instruments. Consequently, the definition of R&I Challenges must always include legal and economic aspects. Lack of an adequate framework is hampering the CET and may also lead to sub-optimal solutions.

3.

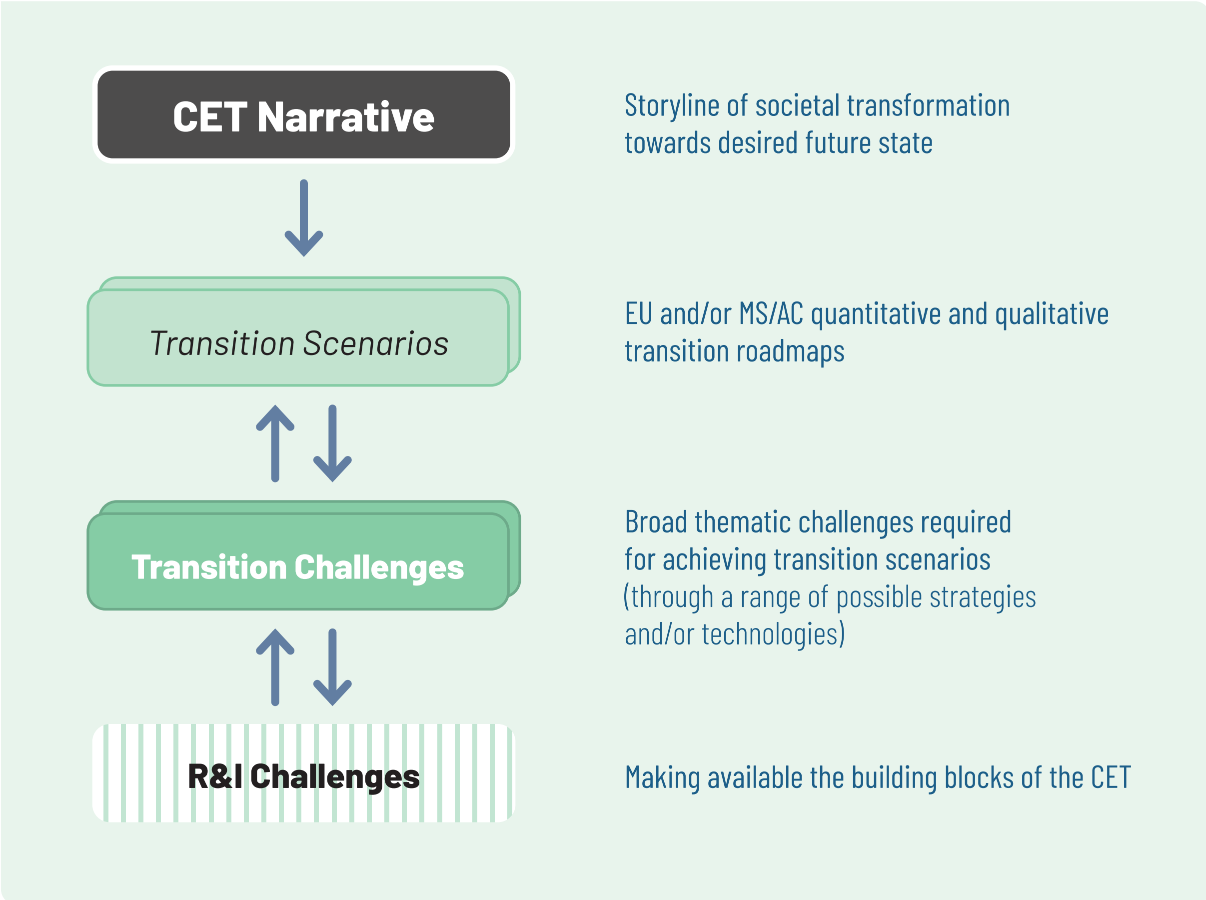
Deriving R&I Challenges from the CET Narrative

Derived from the overarching vision of the CET Narrative, Transition Scenarios describe comprehensive qualitative and quantitative concrete pathways to reach the CET goals, analysed through the prism of the cross-cutting themes identified.

The definition of Transition Scenarios is, in essence, an iterative and participatory process resulting from the interaction between a wide range of experts and stakeholders across sectors. The aim is to define a systemic, cross-sectoral, multidisciplinary roadmap to achieving qualitative and quantitative CET goals. For example, in Europe, each EU country is to design its individual Transition Scenario(s) within the boundary conditions of the CET Narrative and the quantitative objectives agreed upon at EU level. As such, the EU Transition Scenario(s) will result from the smart integration of individual Transition Scenarios from each country in the Union.

Transition Scenarios will define a range of Transition Challenges, most of which can be common to several countries. In contrast, some others might reflect specific contextual differences in any given country, such as geographical location and topology, climate, natural resources, energy and industrial infrastructure, etc. The concept of Transition Challenge allows the definition of research challenges, expressed in terms of broad objectives defined based on their expected impact. It therefore expands the scope of possible CET pathways in comparison with those that result from single-sector-driven and technology-driven approaches, allowing for systemic and thus more innovative and powerful ways to tackle the challenge.

Figure 10: Deriving R&I Challenges from the CET Narrative



Depending on the chosen strategy, Transition Challenges can then be broken down into concrete and specific R&I Challenges.

EERA's CET conceptual framework constitutes a robust analytical tool to translate the broad societal objectives of the CET into a comprehensive set of concrete R&I Challenges needed to implement the selected Transition Scenarios. We expect this framework to be instrumental for better recognising and integrating the systems-level and cross-cutting dimensions of the strategies required to achieve a fair, environmentally sustainable, competitive and climate-neutral society by 2050.

4.

High-level policy recommendations

Climate change is an existential threat to our civilisation, and without a doubt, the most complex global challenge ever faced by humanity.

Even though several analyses indicate that achieving the transition to net zero is expected to bring increased prosperity and well-being to citizens across the world, the need to keep global warming below 2°C, and as close as possible to 1.5°C, stands as an overarching goal, surpassing pure economic arguments.

Against this backdrop, EERA proposes the following recommendations to policymakers for CET to become a reality and deliver a desirable, fair and sustainable future.

A. Develop a strong Clean Energy Transition Narrative

1. **Develop a legible, robust and appealing storyline outlining CET pathways towards a highly desirable common net-zero future:** the CET Narrative must create a credible and tangible vision of resilient transition pathways, enabling citizens and society at large to envision and endorse the transition process. At the same time, it must connect individual imaginaries towards a desirable common future. Developing a CET Narrative is fundamental to fostering global commitment and galvanising all stakeholders' support for the transition process as a whole.

B. Dramatically scale up investment in research, innovation and technology deployment across all TRLs[49]

2. **Immediately boost R&I investment to step up the identification and conception of new technologies**

49. EU TRL scale: *https://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/annexes/h2020-wp1415-annex-g-trl_en.pdf.* Compare with the TRL scale proposed by the IEA: *https://www.iea.org/reports/energy-technology-perspectives-2020*

50. Communication from the European Commission: "A new ERA for Research and Innovation", *https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2020:628:FIN*

and the development of those that are not yet on the market: most of the emission abatements needed after 2030 will come from technologies that are not yet on the market. In particular, resources allocated today to low-TRL research might not yield tangible results for decades. Additionally, education must be an integral part of the R&I boost; this applies to all topics needed to meet the CET challenges.

3. **Ensure continuous innovation and development of pre-competitive technologies:** governments must invest in high-TRL R&I technologies to help bring them to a competitive level.

4. **Create market conditions for accelerating uptake, deployment and scale-up of pre-competitive and competitive low-carbon technologies**: policies should provide clear market signals to accelerate divestment of carbon-intensive assets and significantly boost the deployment of both competitive and pre-competitive low-carbon technologies.

C. Defragment policymaking across disciplines, activity sectors and energy carriers

5. **Break the silo-based policy approach of the European energy system:** CET-related policies and research roadmaps should be designed in the context of stronger interlinkages between different energy carriers, infrastructures and consumption sectors. This will be crucial to achieve greater overall policy coherence and maximise impact.

6. **Drive social innovation through innovative cross-disciplinary policies:** policies should be designed to span the traditional disciplinary silos in order to properly address the holistic and interdisciplinary nature of the CET. Given the importance of understanding the complexity of societal transformation, policy design should address the interdisciplinary and cross-cutting nature of the transition and foster social innovation by fully integrating the social sciences and humanities approach *at the beginning* of the design process. As such, funding instruments pertaining to the development of a technology, product or service should start with an analysis of the context of the end-user, including the socially significant and culturally meaningful practices pertaining to that technology, product or service.

7. **Accelerate the creation of a fully integrated, interconnected, and resilient European energy system:** greater transnational and cross-sectoral integration is required to optimally balance energy sources resulting from the diversity of technology choices, depending on the specific conditions in each country or region.

D. Accelerate the innovation cycle

8. **Support the creation of innovation sandboxes:** the depth and highly intertwined nature of the societal transformation required by the CET calls for the design of highly innovative and disruptive solutions. Policies should foster the creation of innovation sandboxes where radical low-carbon living approaches can be demonstrated.

9. **Leverage best practices for greater efficiency of existing innovation ecosystems:** higher investments in R&I should be combined with more efficient innovation ecosystems, accelerating the conversion of intellectual capital into marketable products and services and their market uptake. In line with the EC Communication, "A new ERA for Research and Innovation"[50], a change of collaboration culture needs to occur in Europe, for stronger cooperation between research and industry. Initiatives like the "European Centres of Excellence" could be seen as blueprints for highly efficient innovation ecosystems.

10. **Ensure robust industrial leadership:** robust and sustainable leadership requires the management of an innovation funnel across the entire TRL range instead of in the higher ones only. Policies should also support start-up creation, the rapid roll-out of intrapreneurship and the uptake of frugal innovation.

11. **Foster stronger public-private cooperation:** innovative policies should steer an unprecedented acceleration in public and private investment into low-carbon research, assets and infrastructure. Public-private collaboration needs to happen at all levels of governance, ranging from identifying new skills for future jobs and steering the market to aligning with decarbonisation strategies by implementing various tools such as grants, loans or green public procurement.

E. Ensure a fair transition at global, national, regional, local and individual levels

12. **Design policies that address fast techno-economic and socio-economic shifts resulting from the accelerated transition to a net-zero economy:** transition strategies should anticipate the consequences of the required societal transformation and address the significant socio-economic impact predicted, prioritising the most vulnerable groups. Such an approach will help ensure fair and acceptable pathways at all levels, from countries, regions and sectors down to individuals, moving from palliative to preventive measures.

13. **Adopt proactive upskilling and reskilling schemes at all levels to ensure a socially fair transition for all citizens:** the transition to a net-zero society will accelerate the shift from carbon-intensive to low-carbon economic activities. This will create major disruption and the displacement of labour activities, not only geographically but also towards generally new skills. Dedicated mechanisms should be put in place to address this revolution in the labour world to support workers and other stakeholders currently involved in the activities that are to be phased out.

51. Energy-related emissions dropped by 6% in 2020 during the Covid-19 pandemic, but are rebounding in 2021; IEA, Global Energy Review, CO2 emissions in 2020 – Understanding the impacts of Covid-19 on global CO2 emissions, March 2021

F. Reduce energy demand

14. **Leverage energy sufficiency and energy efficiency and develop a circular economy:** carbon not emitted is carbon abated. Energy efficiency, energy sufficiency and circularity should be applied across all economic sectors to accelerate decoupling between economic activities on the one hand, and GHG emissions and the use of natural resources on the other. A circular economy offers vast opportunities to create economic value while reducing the footprint of other existing economic activities. Low-carbon substitutions should be identified, promoted or enforced wherever possible.

15. **Foster ambitious but controlled digitalisation of the economy:** digitalisation is a major transformative force that will enable a wide range of innovations across all economic sectors and activities. In particular, digitalisation allows the design of highly innovative new business models, such as «pay per service», substituting asset ownership for service provision, thereby significantly increasing asset usage and decoupling economic value from material infrastructure. While such a transformation should be encouraged at all levels of economic activity, policies should also explicitly address the indirect footprint of digitalisation and selectively prevent its implementation when counter-productive to the objectives of the CET. The widespread introduction of digital technologies in all economic activities constitutes a growing challenge for overall system resilience and security, which should be fully understood and properly addressed. Finally, policies should also address the socio-economic and legal impacts resulting from digital exclusion.

16. **Energy citizenship should become a dimension of innovation in itself, and be developed in a CET context:** CET-related education should be promoted at all levels to enable citizens to understand the climate impacts of their practices, behaviour and consumer choices, and shift towards adopting responsible low-carbon conduct. In turn, energy citizenship will increase citizens' demands for governments to adopt more stringent low-carbon policies and regulations, further accelerating the shift towards low-carbon consumption patterns, products and services.

G. Set up effective economy-wide carbon prices for clear market signals

17. Align fiscal and market instruments with the transition goals: set effective carbon prices across all economic activities, promote the harmonisation of energy taxes, and accelerate the phasing-out of fossil fuel subsidies and fossil fuel use. Deliver a dynamic yet predictable policy and legal framework, providing an attractive and deterministic environment to accelerate the flow of private investment and drive the transition to a low-carbon economy. Set up a range of efficient public-private instruments that lower the cost of capital for higher-risk investments, while expanding the availability of risk-sharing instruments to SMEs and smaller initiatives and ventures. An economy-wide Carbon Border Adjustment Mechanism (CBAM) should be implemented to preserve the EU's global competitiveness by enforcing a level playing field, with competing regions benefiting from lower sustainability standards.

H. Step up the level of ambition and challenge the dominance of current economic paradigm

18. Design policies that maximise action ambition: while not scientifically measurable, it is increasingly acknowledged that the cost of delaying action vastly outweighs the level of funding estimated to be required for driving the CET. In addition, cost-minimisation logic should inform policymaking but not restrict the level of policy ambition in climate action that should remain a fundamentally political decision. Recognising the challenge of evaluating, in monetary terms, climate change impacts and impacts on ecosystems beyond climate change (e.g. biodiversity loss or soil degradation), the inclusion of non-monetary approaches in the policymaking toolkit would be essential to ensure that the CET is achieved in a timely and sustainable way.

I. Strategically increase international collaboration

20. Foster international cooperation and partnerships while pursuing open strategic autonomy: zeroing emissions by 2050 in a context of continued increasing global emissions[51] demands a strong acceleration and intensification of international collaboration. Policies should foster collaboration while recognising that the race to net zero will trigger fierce international competition for industrial and technological leadership. It will be essential for Europe to capitalise on its first-mover advantage and its renewable energy resource potential to ensure industrial leadership in key low-carbon technologies, both now and in the future.

In this respect, the CBAM constitutes an example of the policies needed. Yet, since the EU accounts for just under 9% of global emissions, international cooperation and partnerships are essential to address climate change globally. An active climate multilateralism in line with the UN SDGs is crucial to fostering global understanding and action towards climate neutrality.

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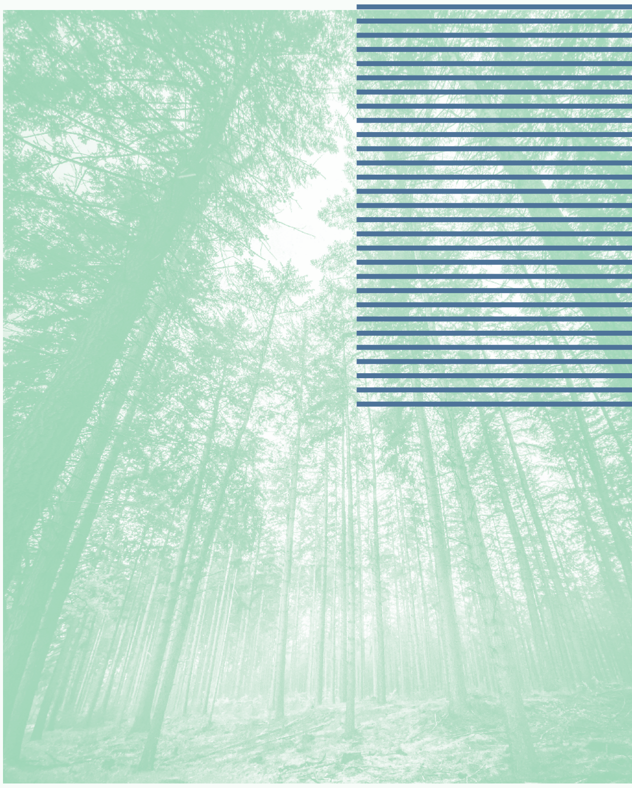

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