IAM COMPACT

D5.1. – Making a Green Step Forward into the Post-COVID Era

WP5 – Expanding: Resilient, inclusive, sustainable development

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EC Summary Requirements

1. Changes with respect to the DoA

No changes with respect to the work described in the DoA.

2. Dissemination and uptake

This deliverable will be used as a reference document for the translation of the policy needs into scenario frameworks in the context of the IAM COMPACT project and model ensemble and can provide guidance to modelling teams and other researchers—within and beyond the consortium—on how policies can be addressed from a modelling perspective.

3. Short summary of results (<250 words)

This report first documents the development of a comprehensive database of green recovery packages globally, using data from reputational well-established sources, including the International Energy Agency (IEA), the Global Recovery Observatory, and the Energy Policy Tracker, and covering 105 countries representing more than 90% of global GDP, with green recovery funds totaling about 2.4 trillion USD and including 2109 unique policies and measures. Subsequently, using said database, this report also documents the analysis of the energy system and emissions impact of green recovery packages across energy supply and demand sectors, using three Integrated Assessment Models (IAMs): PROMETHEUS, GCAM, and TIAM. Utilising data gathered from the developed green recovery packages database, which is described in this report, four scenarios were developed to examine the impacts of green recovery funding at a global scale as well as with an additional focus on three major emitters (China, Europe, and India) under different policy contexts. The findings emphasise the positive role of green recovery packages in facilitating the transition to a low-carbon economy. However, it also underscores that, while these packages support innovation and specific national contexts, additional and robust climate policies are imperative to bridge the substantial investment gap for a net-zero transition and achieve the Paris Agreement goals effectively. Finally, this deliverable includes a national deep dive of green recovery spending in Greece.

4. Evidence of accomplishment

This report.

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Preface

IAM COMPACT supports the assessment of global climate goals, progress, and feasibility space, and the design of the next round of Nationally Determined Contributions (NDCs) and policy planning beyond 2030 for major emitters and non-high-income countries. It uses a diverse ensemble of models, tools, and insights from social and political sciences and operations research, integrating bodies of knowledge to co-create the research process and enhance transparency, robustness, and policy relevance. It explores the role of structural changes in major emitting sectors and of political, behaviour, and social aspects in mitigation, quantifies factors promoting or hindering climate neutrality, and accounts for extreme scenarios, to deliver a range of global and national pathways that are environmentally effective, viable, feasible, and desirable. In doing so, it fully accounts for COVID-19 impacts and recovery strategies and aligns climate action with broader sustainability goals, while developing technical capacity and promoting ownership in non-high-income countries.

NTUA – National Technical University of Athens	EL	EPU N·T·U·A
Aalto – Aalto Korkeakoulusaatio SR	FI	A! Aalto University
AAU – Aalborg Universitet	DK	
BC3 – Asociacion BC3 Basque Centre for Climate Change – Klima Aldaketa Ikergai	ES	bc3 BASQUE CENTRE FOR CLIMATE CHANGE Klima Aldaketa Ikergai
Bruegel – Bruegel AISBL	BE	bruegel
CARTIF – Fundacion CARTIF	ES	CARTIF
CICERO – Cicero Senter for Klimaforskning Stiftelse	NO	°CICERO
E3M – E3-Modelling AE	EL	E3Modelling Energy Economy Environment
KTH – Kungliga Tekniska Hoegskolan	SE	KTH
POLIMI – Politecnico di Milano	IT	POLITECNICO MILANO 1863
UPRC – University of Piraeus Research Center	EL	TEESlab Technoeconomics of Energy Systems
UVa – Universidad De Valladolid	ES	Universidad de Valladolid
WI – Wuppertal Institut fur Klima, Umwelt, Energie GGMBH	DE	Wuppertal Institut
IIMA – Indian Institute of Management	IN	IIM AHMEDABAD
THU – Tsinghua University	CN	
USMF – University System of Maryland	US	
AAiT – Addis Ababa University	ET	
KEI – International Civic Organisation Kyiv Economics Institute	UA	KSE Kyiv School of Economics
RUSL – Raja Rata University of Sri Lanka	LK	
TUM – Technical University of Mombasa	KE	
UNIGE – Université de Genève	CH	UNIVERSITÉ DE GENÈVE
Imperial – Imperial College of Science, Technology and Medicine	UK	Imperial College London

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Executive Summary

In response to the socioeconomic implications of the COVID-19 pandemic, governments worldwide invested substantially in economic recovery plans, a part of which is dedicated to clean energy technologies and infrastructure. Recognising the potential of these recovery funding to drive low-carbon transition, this report documents the green recovery packages, using data from reputational well-established sources, including the International Energy Agency (IEA), the Global Recovery Observatory, and the Energy Policy Tracker. The developed database covers 105 countries representing more than 90% of global GDP, with green recovery funds totaling about 2.4 trillion USD and including 2109 unique policies and measures.

The comprehensive analysis of the developed green recovery database reflects the diverse needs and priorities of countries, emphasising the inadequacy of a one-size-fits-all approach and the importance of tailored, context-specific interventions. There is a significant funding allocation towards 'Energy Affordability', showcasing the prioritisation of energy affordability, especially as a reply to the recent energy crisis. Large parts of green recovery packages are also given for investments in low-carbon transportation (23% funding share including mass transit, cycling, and walking, electric mobility), in energy-efficient buildings and industry (16% share with a mix of energy renovation strategies, energy-efficient equipment, and clean energy sources), and electricity generated from low-carbon sources such as wind, solar, and hydro power (around 10% of the total green recovery funding), underscoring a global shift towards sustainable and low-carbon solutions. The sectoral allocation of green recovery funding differs a lot among countries reflecting the divergent national priorities and circumstances.

These green recovery packages are then integrated into three well-established Integrated Assessment Models (PROMETHEUS, GCAM, TIAM) to explore their impacts on emission and energy system developments in the short and long term. The model-based analysis considers two different climate policy contexts: one where only current policies are implemented without additional climate action, and the other assuming that countries adopt climate policies so as to achieve their Nationally Determined Contributions (NDCs) and Long-Term Targets (LTTs). The imposition of green recovery funding would reduce emissions at the global and national level, through the faster uptake of renewable energy technologies, accelerated energy efficiency improvements in end-use sectors, and electrification of transport and heating uses. However, these impacts are uncertain—modest in PROMETHEUS and even more limited in GCAM and TIAM) and gradually decline post-2030 when the additional recovery investment stops. The green recovery packages close only a small part of the emissions gap towards delivering on climate pledges in 2030 and 2050 but can offer some additional benefits in terms of additional jobs created especially for the manufacturing, construction, and operation and maintenance of renewable energy technologies. Overall, the analysis shows that the green recovery packages alone are not adequate to pave the way towards the systemic transformation required to meet the Paris Agreement goals. However, their effectiveness may increase if they are combined with ambitious and sustained climate policies to meet the long-term net-zero targets pledged by national governments. Finally, a case study of Greece attempts to analyse the impacts of green recovery funding on the transition in the electricity and buildings sector. The latter analysis shows that green recovery funding can play an important role in ensuring that Greece meets its climate targets for 2030 and 2050 in a cost-effective and socially just manner.

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1 Introduction

The central focus of this deliverable, developed under Task 5.1 "Making a green step Forward into the Post-COVID Era", is to quantitatively analyse the short- and long-term emissions, energy system, technology, and macroeconomic implications of the unprecedented global response to the COVID-19 pandemic in the form of green recovery packages. In the wake of the crisis, governments worldwide have mobilised vast resources, announcing substantial investments in economic recovery plans, a large part of which is directed towards the so-called "green-recovery"—i.e., investment in low-carbon technologies and energy efficiency. Recognising the transformative potential within these investments, this report documents the project's effort to assess these recovery initiatives as opportunities to propel low-carbon transitions on a global scale.

At the heart of this deliverable is the identification, gathering, and classification of the announced recovery packages targeting low-carbon investment. This process extends beyond mere documentation as aims for transparency, by providing this information through the I^{2}AM PARIS platform. The short- and long-term emissions and energy impacts of the identified green recovery packages are then assessed using a series of national and global modelling tools. The analysis cuts across multiple dimensions, exploring the intricate interplay of emissions, energy systems, technological advancements, and macroeconomic developments.

An important feature of this study is to also capture and understand the employment implications of the models' cost-optimal allocation of green recovery budgets across sectors and technologies.

In summary, this deliverable encapsulates a comprehensive analysis on the green recovery packages, rooted in data-driven insights and advanced modelling techniques. It stands as a testament to the project's commitment to steering global recovery efforts towards a greener, more sustainable future. Through this process, we also seek to stress the potential lying within post-COVID recovery efforts to foster not just economic rejuvenation but also a paradigm shift towards a low-carbon, environmentally conscious, and sustainable future.

The report is structured as follows: Section 2 documents the process of developing the Global Recovery Package Database including the methodology followed and the meticulous data analysis. Section 3 includes the analysis of the modelling focusing on the impact of recovery packages on CO2 emissions and energy consumption. The analysis encompasses four distinct scenarios, two under current policies (CP-EI) and two under long-term targets (NDC-LTT).

Section 4 focuses on Greece's strategic energy and climate objectives, particularly its commitment to achieving net-zero greenhouse gas emissions by 2050. This section assesses the short- and long-term impacts of the National Recovery and Resilience Plan (NRRP's) recovery packages on economic, energy and emission-related aspects. The research question focuses on understanding the implications of the investments and reforms outlined in the NRRP for the Greek residential and power sectors, particularly in the context of low-carbon transition pathways derived from sectoral models.

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2 Global Recovery Package Database development

2.1 Overview and Context

The emergence of the COVID-19 pandemic marked an unprecedented global crisis (The World Bank, 2020), impacting economies across the world. As the virus spread, countries faced immediate challenges ranging from public health crisis to economic unrest. Economies experienced sudden contractions (Clemente-Suárez, 2021) as businesses shut down, travel came to a standstill, and consumer spending plummeted. These sudden disruptions led to severe economic recessions globally, with countries grappling to stabilise their financial and economic systems and protect the livelihoods of their citizens.

One of the notable impacts of COVID-19 was the widespread rise in unemployment rates (Chi-Wei Su, 2022). Businesses, especially those in sectors heavily reliant on physical presence, faced immense pressure to downsize or close operations entirely due to reduced activity and revenues. The fact that millions of individuals found themselves without jobs, at least temporarily, created not just an economic challenge but also a social one as unemployment rates soared to levels unseen in recent history. Moreover, the closure of international borders disrupted global trade, leading to supply chains disruptions, cost increases, and challenges in the transportation of goods and services across countries (Thuy Dung Vo, 2020).

Furthermore, the pandemic also highlighted vulnerabilities in global economic systems (Samba Diop, 2021). Countries with robust healthcare infrastructure and diversified economies were better equipped to weather the storm while nations heavily reliant on specific sectors (especially those heavily affected by the pandemic and subsequent lockdowns) faced heighted challenges. The crisis underscored the need for diversified, resilient economic strategies and adaptive policies capable of mitigating the shocks in the face of unforeseen global events.

During the pandemic, the energy sector, which is vital for the global economy, also witnessed significant shifts and challenges (Jan Jakub Szczygielski, 2021). Lockdowns and travel restrictions led to a notable decrease in energy demand, particularly in the transportation sector. This caused a sharp drop in oil prices and financial strains for oil-producing nations (OECD, 2020). However, the crisis emphasised the resilience of renewable energy sources, which continued to generate power steadily, highlighting the sector's stability. Supply chain disruptions impacted energy project timelines and uncertainties led to cautious investment decisions and financing challenges, which in turn have led to supply shortages that—combined with other factors (e.g., increased supply costs, fast demand recovery in 2021, geopolitical tensions—later resulted in an aggravated energy crisis with wild increases in international energy prices, in particular for gas. Despite the challenges, the pandemic underscored the need for a more sustainable, resilient, and digitalised energy future (Valentina Olabi, 2022).

The slowdown of economic activities worldwide expectedly led to a short, temporary drop in emissions, as industries shut down, people stayed home, and transportation came to a halt. As economies started recovering again, emissions began to rise as well (P. Bhanumati, Mark de Haan, James William Tebrake, 2022). This fact highlighted once more the direct link between human activities and emissions, emphasising the need for sustainable practices to mitigate climate change in the long run.

Governments worldwide deployed economic recovery packages to mitigate the economic downturn caused by COVID-19 (Johannes Emmerling et al, 2020). Economic recovery packages are often referred to as stimulus recovery plans developed to provide financial support to economies during challenging times—and the aftermath of the COVID-19 pandemic proved to be one. Their primary function is to stimulate economic activity and create jobs by injecting vital funds into various sectors of the economy. The boost on demand and the encouragement of investments make these packages act as economic catalysts, reviving stagnant markets and fostering growth (Pedro R. R. Rochedo, 2021).

One of the fundamental objectives of (green or non-green) recovery packages adopted during the Global Financial Crisis of 2008 is job creation (Jon Strand, 2016). These packages can generate employment opportunities via financing businesses, projects, and economic activities. This aspect is particularly crucial in stabilising economies as it reduces unemployment rates, provides financial security to individuals and families, and boosts social well-

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being. Moreover, the support to sectors that are most vulnerable to economic downturns like hospitality, tourism, and small businesses prevent widespread business closures. Recovery packages may also include investments in infrastructure projects. In the context of evolving environmental concerns, many recovery packages integrate green initiatives like investments in renewable energy sources, energy-efficient technologies, green mobility, and sustainable infrastructure. These green recovery packages are specifically designed to address both economic recovery and environmental sustainability. Drawing from previous examples, such as the Global Financial Crisis (GFC) in 2007-2008, it is evident that green stimulus initiatives can significantly contribute to generating economic growth, creating jobs, and exerting positive impacts on the environment (João Tovar Jalles, 2019).

It is important, though, to consider specific regional and national dynamics related to specific stimulus measures. As depicted in Table 1, the lessons learned from the recent GFC underscore the pivotal role of the energy sector in driving sustainable economic resurgence.

Table 1: The role of energy sector in Global Financial Crises (GFC) and Pandemics

In examining the profound impacts of the GFC in 2007-2008 (Laszlo Varro, Sylvia Beyer, Peter Journeay-Kaler, Kathleen Gaffney, 2020) and their subsequent parallels with contemporary challenges such as the COVID-19 pandemic, it becomes evident that the energy sector plays a pivotal role in economic recovery strategies. During the GFC, the EU faced a monumental task of stabilising its economy while simultaneously transitioning toward sustainable energy sources.

Back then, the EU implemented a series of strategic measures to rejuvenate its economy, with a keen focus on the energy sector. The bloc recognized the potential of this sector as an engine with a double character, one for economic growth and another for environmental sustainability. Significant funds were directed towards clean energy initiatives and member countries invested heavily in renewable energy projects, energy efficiency programs, and R&D in green technologies.

The establishment of the European Economic Recovery Plan (COMMISSION OF THE EUROPEAN COMMUNITIES , 2008) in 2008 was one of the notable initiatives that emphasised green investments. The EU allocated substantial funding to support renewable energy infrastructure, including wind and solar farms, and to enhance energy efficiency in buildings and industries. Moreover, the member states were encouraged by the EU to invest in sustainable transportation to reduce carbon emissions and promote a greener economy.

The EU bolstered its commitments to combat climate change with its 20-20-20 targets, which aimed to reduce greenhouse gas emissions by 20% below 1990 levels, increase the share of renewable energy to 20% in the energy mix and improve energy efficiency by 20%, by 2020 (European Environmental Agency, 2021). These targets were achieved by stimulating investments in renewable energy and incentivising the development of innovative technologies, positioning the EU as a global leader in the clean energy transition.

COVID-19 posed unprecedented challenges to global economies. In response to these challenges, the EU has once again demonstrated resilience and adaptability. With the NextGenerationEU recovery package (European Council, 2020), the EU has committed substantial funds to support the green transition and align the economic recovery efforts with climate goals. Key components of this recovery strategy include the investments in renewable energy infrastructure, R&D in clean technologies, diversification of energy sources, and the promotion of energy efficiency. For example, the EU's long term budget, coupled with NextGenerationEU which is the temporary instrument designed to boost the recovery from the largest stimulus package ever financed in Europe with a total of 2 trillion Euro (in current prices) to rebuild a post-COVID-19 Europe (European Commission, 2020).

2.1.1 Literature review: Economic Recovery Packages Databases

The development of sustainability policy databases (including COVID recovery packages) is critical for transparent governance, informed policymaking—and, in this case, fostering sustainable, equitable economic recovery. Such databases ensure accountability and transparency, empower policymakers with data-driven insights, enable comparative analysis across nations, evaluate policy effectiveness, monitor environmental impact through green initiatives, and enhance overall societal resilience.

Regarding the energy sector, the development of global recovery packages database has been a topic of interest

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for various reputable international organisations, including the International Energy Agency (IEA), the Organisation for Economic Cooperation and Development (OECD), the Oxford University Economic Recovery Project, and others.

The OECD, for example, in its pursuit to comprehensively understanding the environmental dimensions of COVID-19 recovery, developed the OECD Green Recovery Database (OECD, 2021). This initiative was a response to the lack of evaluation and analysis of green policy measures introduced after the 2008 GFC. The database encompasses a wide array of policy measures related to COVID-19 recovery efforts, aiming to capture both positive and negative environmental impacts across various dimensions. Unlike other initiatives, the OECD Green Recovery Database covers not only measures specifically targeted at environmental improvements but also more general policies that may have environmental implications. As of now, the database includes approximately 680 measures spread over 43 countries including EU member states, with a focus on national level policies but also including some important sub-national measures. The environmental impacts assessed in the database extend beyond energy and climate, covering pollution (air, plastics), water, biodiversity, waste management and climate change adaptation. While categorising these impacts presents challenges, the OECD utilised existing and emerging classification systems, such as the EU taxonomy for sustainable activities, to assess the likely environmental effects of these green recovery measures. It is important to note that the OECD's approach, as outlined in its report (OECD, 2021), serves as a high-level assessment designed for aggregate analysis rather than individual policy adjustment. This OECD initiative supplements the broader landscape of tracking exercises related to green recovery, each offering slightly different perspectives. Other initiatives, such as the Greenness of Stimulus Index by Vivid Economics (VividEconomics, 2023), the Energy Policy Tracker (Energy Policy Tracker, 2023), the Green Recovery Tracker (Green Recovery Tracker, 2023) for the EU member states, and the Oxford-led Global Recovery Observatory (Global Recovery Observatory, 2023), focus on different sectors, countries, and methodologies to gather and analyse green recovery packages.

Oxford University developed its Global Recovery Observatory (Global Recovery Observatory, 2023) by meticulously tracking and evaluating national fiscal crisis expenditures in the world's largest economies. The Observatory's primary goal has been to provide transparency to government spending practices, enabling governments and researchers to assess spending measures. The data collection spans from January 2020 up until now and is updated weekly, capturing policies at the national and global levels. The Observatory assesses policy measures with regard to their potential environmental, social, and economic impacts. The environmental impacts are assessed on a Likert scale (a rating system, typically used in questionnaires), considering both short- and long-term effects. These assessments are based on evidence from academic literature and consultation with leading experts from private, public, and research institutions. To create a comprehensive taxonomy for policy classification, the Observatory developed typologies, archetypes, and sub-archetypes. Their methodology emphasises transparency and evaluation consistency.

The OECD Low-carbon Technology Support (LCTS) database (OECD SCIENCE, TECHNOLOGY AND INDUSTRY POLICY PAPERS, 2023), is a comprehensive repository of fiscal measures announced in 2020-2021 with the goal of accelerating the development, adoption, and diffusion of low-carbon technologies. The database covers initiatives in 51 countries, including OECD members, the European Union and the G20 economies. The focus of this database is on fiscal measures adopted in response to the COVID-19 pandemic, specifically those intended to promote low-carbon technologies. The methodology involved integrating information from two prominent green recovery trackers that are described in the previous paragraphs: (a) the OECD Green Recovery Database and (b) the Global Recovery Observatory. The measures included in the LCTS database were categorised considering the sector of activity, specific technology targeted, and innovation stage of the technology. The inclusion criteria for measures in the LCTS database were specific: measures had to involve government spending, be announced in response to the COVID-19 pandemic, and aim to support the development or adoption of low-carbon technologies.

The Energy Policy Tracker (Energy Policy Tracker, 2023), is another comprehensive initiative that tracks publicly available information on commitments and policies related to different types of energy initiatives. It operates a bottom-up research approach, collecting data on individual policies at the level of governments or multilateral institutions and then aggregating them. The Energy Policy Tracker relies solely on publicly available sources of information with an emphasis on official documents and government statements. The data sources are complemented with expert commentary or media articles when appropriate. Policies are classified based on a set of criteria, primarily focusing on their environmental profile and conditionality and are distinguished into 5 main groups: Fossil Unconditional (if they support production and consumption of fossil fuels without any climate targets), Fossil Conditional (if they support production or consumption of fossil fuels with climate targets), Clean Unconditional (f they support production or consumption of energy that is both low-carbon and has negligible impacts on the environment if implemented with appropriate safeguards), Clean Conditional (if they are stated to support the transition away from fossil fuels, but unspecific about the implementation of appropriate environmental safeguards), and Other Energy (policies outside the two "fossil" and two "clean" buckets).

The IEA's comprehensive database on global recovery packages (IEA, Government Energy Spending Tracker, 2023) offers a multifaceted approach towards economic recovery and sustainability. One of its key components involves targeted green recovery packages as well as energy affordability measures. A significant portion of the database focuses on clean energy investment support, showcasing a notable shift in investment dynamics. Clean energy investments have outstripped fossil fuel investments, with 1.7 USD now spent on clean energy for every 1 USD spent on fossil fuels. Investments totaling 1.343 trillion USD since the COVID-19 outbreak in early 2020, are primarily directed towards low-carbon electricity generation projects, public transport, alternative transit modes and low-carbon vehicles. The database captures the complexities of global government support for clean energy investment while addressing immediate economic recovery needs for long-term environmental sustainability and energy resilience.

In Section 2.2, we delve into the detailed process for the development of a global recovery packages database, a comprehensive repository that stands at the intersection of economic recovery, energy policy, and global financial dynamics. This includes a focus on the methodology employed, the data sources, and the limitations faced during the database's development. Finally, we analyse this new dataset to unveil the intricate financial amounts of recovery packages allocated to various categories and technologies of the energy sector. Throughout this analysis, we uncover the diverse strategies followed by different countries in their recovery packages.

2.2 Methodology

The global recovery database presented in this section is created to provide a comprehensive and reliable repository of information and data on the economic green recovery measures implemented by governments worldwide in response to the COVID-19 pandemic. This entailed meticulous activities such as data collection, classification, and analysis to gather, categorise, and organise the green recovery packages and to examine whether the transition to a low-carbon system can be achieved by these measures.

The development of the database is based on a methodological approach to identify and synthesize data from diverse, reputable sources. These sources were systematically examined, ensuring a broad and representative dataset of almost all countries globally.

Given the complexities of data availability, which are analysed in detail in the next subsection, several techniques were employed to extract the required information. Upon gathering data, a detailed data cleaning process was undertaken. Duplicates were systematically removed, and the available data and information was structured into a coherent format. This process involved defining column names that align with the gathered information, standardising funding units, and reconciling disparate data categories from different sources. To enhance clarity and usability, the IEA's classification system was adopted. This classification not only aligns with the focus of this study but also ensures compatibility and recognition among stakeholders, given the IEA's reputable standing in the energy sector.

The final dataset developed includes policy measures related to the energy sector (recovery packages) across 105 countries. This compilation (after removal of duplicates) comprises a total of 2,109 unique identified policies/recovery packages, which collectively allocate a budget of 2.472 trillion USD from various recovery packages related to the energy sector. These support measures have been categorised into 51 specific sectors, which are further analysed in detail. This categorisation facilitates a granular analysis of the initiatives, enabling a deeper understanding of the intricate landscape of energy-related policies across the globe. Moreover, these sectors have been grouped into nine broader categories through a systematic classification scheme that follows the IEA's pattern and can thus facilitate the integration of the green recovery packages in the IAMs to assess their short- and long-term impacts on emissions, technology uptake, and energy system development.

2.2.1 Data Sources

The data collection process involved gathering information from multiple reputable sources including the International Energy Agency [1](IEA), the Energy Policy Tracker[2], and the Global Recovery Observatory[3]. The data collection process was guided by the objective of comprehensively capturing and analysing announced recovery packages worldwide. In addition to the sources mentioned earlier, other reputable platforms were also considered. These include the Green Recovery Tracker[4], the I^{2}AM PARIS PLATFORM[5] and the Organisation for Economic Cooperation (OECD)[6]. Below we provide some details about these databases and how we combined their data and information to create a unique, transparent IAM COMPACT database on green recovery packages.

The **IEA**, as a leading international organisation in energy analysis, played a pivotal role in providing valuable insights and data on government responses and recovery measures related to the energy sector. Their reports, publications and databases served as crucial references for identifying countries' recovery packages of interest. The IEA was our primary data source (IEA, Government Energy Spending Tracker, 2023); a total 67 countries were included in our developed database based on the information obtained from the IEA up-to-date repository of recovery packages.

The **Energy Policy Tracker**, a collaborative initiative by several organisations (including Stockholm Environment Institute, Columbia University, International Institute for Sustainable Development), tracked and documented energy-related recovery measures implemented globally. This platform facilitated access to information on funding allocations, policy measures, and sector-specific initiatives in various countries, for the period 2020-2021, focused on green recovery packages. To enhance the reliability and accuracy of our database, the Energy Policy Tracker served as an important resource in verifying and validating the recovery package information collected from other databases. This validation step helped to identify any discrepancies or missing information, allowing us to refine and enhance the quality of our data and findings. For example, during this process, we had the opportunity to identify and include Argentina, which could not be found in other sources, as well as supplementary information on Russia.

To complement the data gathered from the IEA's database and the validation process conducted with the Energy Policy Tracker, we used another valuable source, the **Global Recovery Observatory**, a database that tracks recovery measures with a broader focus and not specifically targeting the energy sector but including energy-related measures. This observatory provided crucial insights, data, and information on recovery packages implemented by various countries across the globe. Through a systematic and comprehensive analysis of the Global Recovery Observatory, we identified an additional 37 countries that were not included in the IEA's database, nor in the Energy Policy Tracker. The inclusion of these 37 countries ensured that the developed

[1] https://www.iea.org/
[2] https://www.energypolicytracker.org/
[3] https://recovery.smithschool.ox.ac.uk/tracking/
[4] https://www.greenrecoverytracker.org/
[5] https://www.i2am-paris.eu/rrf_policy_intro
[6] https://www.oecd.org/

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database offers broader geographic coverage and enhances the depth and breadth of our research findings, providing a more holistic view of recovery packages on a global scale.

The **Green Recovery Tracker** provided valuable insights into recovery measures with a specific focus on their environmental and climate impact on European countries. In addition to the Green Recovery Tracker, the **I²AM PARIS Platform**, a renowned global modelling platform that is also a vessel of the IAM COMPACT modelling activities, provided supplementary information on the findings obtained from the primary data sources. The **OECD**, as a prominent international organisation, also provided additional perspectives on recovery measures implemented by its member countries. By cross-referencing the information in our database with OECD data and reports, we were able to validate the funding amount and align our findings with official standards.

Throughout the data collection process, special attention was given to addressing duplicate entries and ensuring data consistency. Duplicates identified from various sources were meticulously reviewed and deleted *(to avoid double/multiple counting of packages*). The IEA database emerged as the most comprehensive and reliable source with a focus on the energy sector, encompassing a wide range of countries and recovery measures. In cases where additional countries or measures were identified in the Energy Policy Tracker and the Global Recovery Observatory, these were carefully evaluated and added to our database, complementing the information obtained from the IEA.

The data extraction process involved the utilisation of scrapping methods to gather comprehensive information from the International Energy Agency (IEA) and the Green Recovery Tracker. By leveraging scrapping techniques, we were able to systematically retrieve relevant data points such as country names, policy titles, amount of funding and other pertinent details. All the other databases were available to be downloaded online. For example, the OECD database was downloaded from https://gitvfd.github.io/OECD-Green-Recovery-Policies-April2022/data/OECD_ENV_COVID-recovery-database_final-for-web.xlsm, the I²AM PARIS one from https://www.i2am-paris.eu/rrf_policy_intro, the Energy Policy Tracker from https://www.energypolicytracker.org/search-results/ and the Global Recovery Observatory from "https://recovery.smithschool.ox.ac.uk/global-recovery-observatory-draft-methodology-document/".

Despite the comprehensive nature of the gathered databases, we encountered certain challenges during the combination and classification of data. These challenges included variations in the data format across different countries and categories and are discussed in the section below.

2.2.2 Obstacles and Limitations | Data gathering and combination process

The process of combining data for the development of the global recovery packages database faced limitations that need to be acknowledged. These limitations primarily revolved around the completeness and consistency of the information obtained from various sources.

- **Different classification systems:** One of the primary challenges in collecting and organising data from multiple sources is the existence of different classification systems used by each source. The IEA database categorises recovery measures into specific sectors, while the Green Recovery Observatory utilises archetypes and Likert assessments. The Energy Policy Tracker, on the other hand, classifies policies based on their environmental profile. These varying classification systems made it difficult to directly compare and merge data across sources. To overcome these challenges, a common classification system is established that follows the IEA's classification scheme.
- **Incomplete information**: Another limitation lied in the levels of availability and consistency of data across different sources. While the IEA database is comprehensive, it could not capture all recovery measures implemented by countries worldwide. Supplementary sources like the Green Recovery Observatory and Energy Policy Tracker also have limited coverage, focusing on specific regions and policy aspects. By cross-referencing and combining the information and data gathered from multiple sources, we addressed these gaps and enhanced the completeness of our dataset.

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- **Variability in methodologies and metrics:** Each source and database employed different methodologies and metrics to gather and assess recovery measures. For instance, the Green Recovery Observatory relies on evidence from academic literature and expert input for assigning Likert assessments, while the Energy Policy Tracker uses criteria related to environmental profiles. These methodological differences introduced bias or variations in the evaluation of recovery measures, which proved to be challenging in harmonising the data for a consistent analysis.

Despite efforts to develop a comprehensive database relative to the recovery packages, many measures and policies related to the energy sector might be missing for several reasons. First, many governments worldwide lack sufficient reporting on stimulus packages (especially low-income countries); second, while the fiscal support was given to all economic sectors, several recovery packages adopt an industry-agnostic approach; finally, benefits raised from tax breaks that were hard to be quantified are excluded.

2.2.3 Data organisation

Once the data was extracted and collected from the databases described above, a thorough process of data organisation and cleaning was undertaken to ensure the integrity and quality of the dataset. The following steps were followed to organise and clean the collected data:

First Step	Database structure

The following columns are included in the data structure:

- **Country**: Represents the country for which the recovery package was announced.

We were only able to select a subset of countries from each data source. The IEA database provided data for 63 countries, as listed in Table 2 below, based on their economic significance, regional representation, and availability of recovery package information. Three additional countries were extracted from the Energy Policy Tracker, and the remaining 41 countries were sourced from the Global Recovery Observatory. Overall, our database includes green recovery packages for 105 countries globally.

Table 2: Selected countries by each data source

Data Source	Countries
IEA	Albania, Australia, Austria, Bangladesh, Belgium, Bosnia and Herzegovina, Brazil, Bulgaria, Canada, Chile, China, Colombia, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Guatemala, Honduras, Hungary, Iceland, India, Indonesia, Ireland, Israel, Italy, Japan, Kenya, Korea, Latvia, Lithuania, Luxembourg, Malaysia, Malta, Mexico, Netherlands, New Zealand, Nicaragua, Nigeria, Norway, Oman, Peru, Philippines, Poland, Portugal, Romania, Saint Lucia, Singapore, Slovak Republic, Slovenia, South Africa, Spain, Sweden, Switzerland, Thailand, Turkey, United Kingdom, United Republic of Tanzania, United States
Energy Policy Tracker	Argentina, European Institutions[7], Russia

[7] The region 'European Institutions' refers to measures and policies announced by the European Union members. Due to the absence of detailed breakdowns specifying individual EU members in the available data sources, we have retained this region as 'European Institutions'. The reason behind this is that this region includes policies

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Global Recovery Observatory	Antigua and Barbuda, Bahamas, Barbados, Belize, Bolivia, Burkina Faso, Costa Rica, Democratic Republic of the Congo, Dominica, Dominican Republic, Ecuador, Egypt, El Salvador, Ghana, Grenada, Guyana, Haiti, Iran, Iraq, Jamaica, Kazakhstan, Kyrgyz Republic, Mauritius, Mongolia, Morocco, Pakistan, Panama, Paraguay, Russia, Rwanda, Saint Kitts and Nevis, Saint Vincent and the Grenadines, Saudi Arabia, Senegal, Suriname, Taiwan, Trinidad and Tobago, United Arab Emirates, Uruguay, Vietnam

- **Policy Name:** Provides the name of the policy associated with the recovery package.
- **Announced Year:** Indicates the year in which the recovery package was announced.
- **Sector:** Refers to a specific sector to which the policy is primarily targeted. This categorisation includes the 51 unique sectors below, as identified in the three databases:

Energy affordability, General, Low-carbon vehicles, Other efficiency, Other Innovation, Residential/commercial PV, Walkways and bike lanes, Urban transit, Charging infrastructure, Electric 2- and 3-wheelers, Biogas, Efficient passenger cars, Aircraft (efficient/electric/alt fuel), Critical minerals, Industry EE, Grids, Energy efficient retrofits, Hydrogen, Transmission, CCUS, Batteries, Low-carbon power, Energy efficiency, Just transitions, Electric passenger cars, Distribution, Thermal storage, General (No selection appropriate), Utility-scale PV, Alternative fuel passenger cars, Recycling, Mass transit, Appliances, Other technologies/measures, Onshore wind, Heat pumps, Offshore wind, Efficient new builds, Biofuels, Clean cooking, Energy access, Other renewables, Hydro, Methane abatement, Advanced biofuels, Busses (efficient/electric/alt fuel), Nuclear, High-speed rail, Electricity access, Ships (efficient/electric/alt fuel), Trucks (efficient/electric/alt fuel)

- **Policy Title:** Offers a concise title or description of the policy.
- **Funding billion USD:** Represents the funding amount allocated for the policy in billion USD. Standardisation was applied to ensure consistency across different databases, as funding amounts were originally reported in various currencies (e.g., euro/local currencies, millions, etc.).
- **Data Source:** Identifies the source from which the data for each policy was obtained, such as the IEA, Energy Policy Tracker, Global Recovery Observatory, and other supplementary sources.
- **ISO_CODE:** Provides the ISO country code for each country. The insertion of the ISO_CODE allows to facilitate data integration and comparison across different datasets.
- **Classified Sector:** Offers an additional classification of each policy into a more concise set of broad sectors, following the IEA's classification scheme: Energy affordability, Low carbon and efficient transport, General, Fuel & technology innovation, Low carbon electricity, Energy-efficient-buildings & industry, Electricity networks, People-centered transitions.

  The application of the IEA's classification scheme ("Classified Sector") to the entire database provides a structured and standardised framework for analysing policy measures related to energy across sectors and countries. Categorising policies into broader sectors (based on the detailed mapping in Table 3) allowed for a nuanced understanding of the sectoral allocation of green recovery packages. This classification simplifies the landscape of recovery packages and enables comparative analysis across the

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that were not found in other sources. We aggregate these data to the EU-27 region (covered by the models) on a measure-by-measure basis to avoid double counting.

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databases.

Table 3: Policy classification: Broader categories and specific sectors

Low carbon electricity	'CCUS', 'Hydro', 'Low-carbon power', 'Nuclear', 'Offshore wind', 'Onshore wind', 'Other renewables', 'Residential/commercial PV', 'Thermal storage', 'Utility-scale PV', 'Biogas', 'Low-carbon power'
Electricity networks	'Distribution', 'Grids', 'Transmission'
Low carbon and efficient transport	'Advanced biofuels', 'Aircraft (efficient/electric/alt fuel)', 'Alternative fuel passenger cars', 'Batteries', 'Biofuels', 'Charging infrastructure', 'Efficient passenger cars', 'Electric passenger cars', 'High-speed rail', 'Hydrogen', 'Low-carbon vehicles', 'Busses (efficient/electric/alt fuel)','Trucks (efficient/electric/alt fuel)','Urban transit', 'Mass transit', 'Ships (efficient/electric/alt fuel)', 'Electric 2- and 3-wheelers', 'Walkways and bike lanes', 'Mass', 'Aircraft', 'Trucks', 'Busses', 'Ships'],
General	'Critical minerals', 'Energy efficiency', 'Just transitions', 'Methane abatement', 'Recycling', 'Other efficiency', 'General (No selection appropriate)', 'Electricity access', 'Other Innovation'
Energy-efficient-buildings & industry	'Appliances', 'Efficient new builds', 'Energy efficient retrofits', 'Heat pumps', 'Industry EE', 'Clean cooking'
Fuel & technology innovation	'Batteries', 'Hydrogen', 'Other Innovation', 'Other technologies/measures'
People-centered transitions	'Just transitions'
Energy affordability	'Energy affordability'

The decision to structure the data in this manner was rooted in the need to comprehensively capture essential information relevant to recovery packages. The chosen categories allow an in-depth analysis of policy funding and sectoral distribution. The IEA's sector-based classification was employed as a guiding framework, providing flexibility and precision in understanding policies and thereby aligning with the objectives of this research. Additionally, as widely recognised, the IEA's approach offers a robust and well-established framework that has been extensively tested and validated, making it a reliable choice for our new global-scale database.

Second Step	**Data Validation**

To ensure accuracy and consistency, a thorough data validation process was undertaken. This involved cross-referencing information from multiple sources, such as the Green Recovery Tracker, I^{2}AM PARIS, and the OECD database. Discrepancies or inconsistencies were thoroughly investigated, and efforts were made to reconcile conflicting data through additional research.

Third Step	**Data Standardisation**

To ensure consistency and comparability, the data was standardised across categories. This involved mapping and harmonising the schemes used in the original sourced to a unified set of categories based on a thorough

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literature review (e.g., based on the sectoral classification scheme described above).

Fourth Step	Duplicate Removal

Special attention was given to identifying and removing duplicate entries within the dataset. Advanced matching techniques including string similarity algorithms were applied to detect and eliminate duplicate records. This step helped to eliminate redundancy and improve the accuracy of the final dataset.

Fifth Step	Handling Missing Data

The presence of missing values in certain fields was addressed through careful data imputation or exclusion, depending on the extent and nature of missingness.

Sixth Step	Data Documentation

Throughout the data cleaning process, detailed documentation was maintained to record the steps taken, decisions made, and any modifications applied to the original data, and thus to increase the transparency of the research.

2.3 Data Analysis and Reporting

The developed database provides a foundation for in-depth analysis and reporting on global recovery packages. The collected data from various sources was compiled and structured into a centralised database as presented earlier. A standardised data scheme was established to facilitate data organisation and analysis. This scheme includes key variables such as country name, recovery package details, and sector-specific allocations. Additionally, the database was designed to allow for future updates and integration of new data sources as they become available.

The set of 105 countries, whose announced measures were included in the developed database, account for 86% of global population and 94% of global GDP. The database includes a total of about USD 2.4 trillion of announced recovery packages worldwide. These measures have been designed for disbursement over multiple years, with some extending their implementation plans as far as 2032. Figure 1 presents the geographic coverage of the newly developed global recovery package database.

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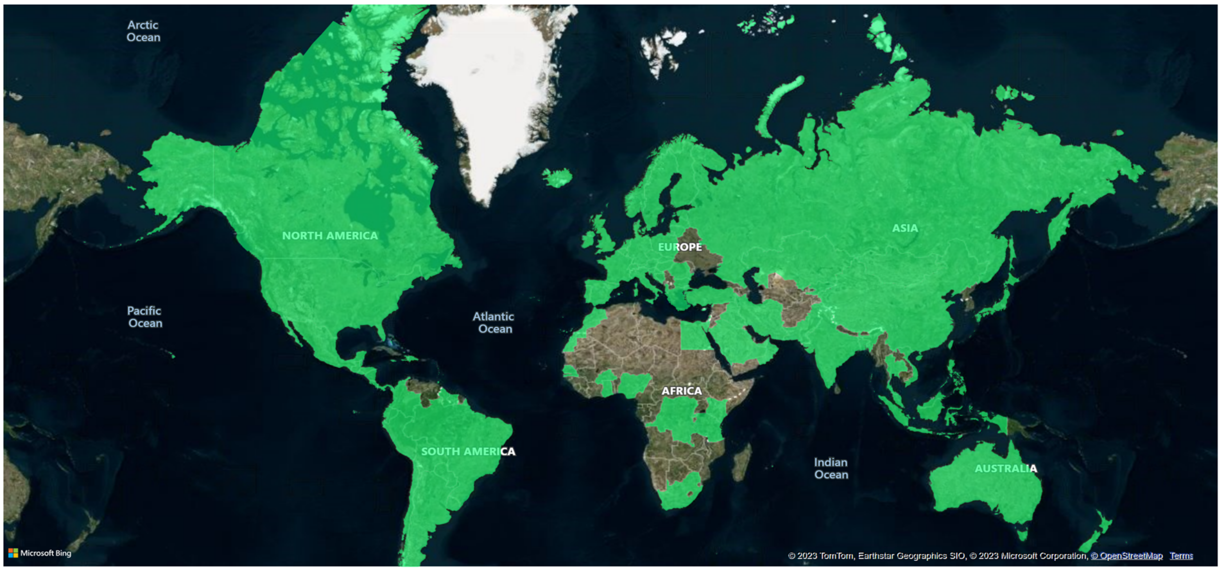

Figure 1: Geographic coverage of the developed Recovery Package Database

Below, we examine the database on a global scale to gain insights into the collective efforts and strategies employed worldwide to address the post-COVID economic recovery, while also analysing the results for major economies. Moreover, we delve into a more detailed analysis of the recovery packages within each classified category. The analysis of recovery packages by sector should allow to identify sectoral trends, funding allocations, and policy measures employed to facilitate the recovery from the impacts of the COVID-19 pandemic. All figures presented in this section are produced with data from the newly developed recovery package database.

2.3.1 Global level analysis

The budget allocations for recovery measures in different countries provide valuable insights into their respective needs, strategies, expansion plans, and goals in response to the COVID-19 pandemic. Figure 2 shows that the highest funding in green recovery packages was adopted by the United States (about 20% of the global recovery efforts), followed by Germany (about 14% of global recovery efforts), while Italy and France had a share of about 7% and 6% respectively.

The allocation of approximately 542 billion USD in the United States reflects a substantial investment in green recovery efforts. As one of the world's largest (and most populous) economies, the United States had the financial capacity and resources to allocate a significant budget for its green recovery package. Significant portions were dedicated to the classified categories, 'low carbon electricity' (38%) and 'low carbon and efficient transport' (24%), emphasizing the shift towards renewable energy (especially solar PV and wind) and sustainable transport.

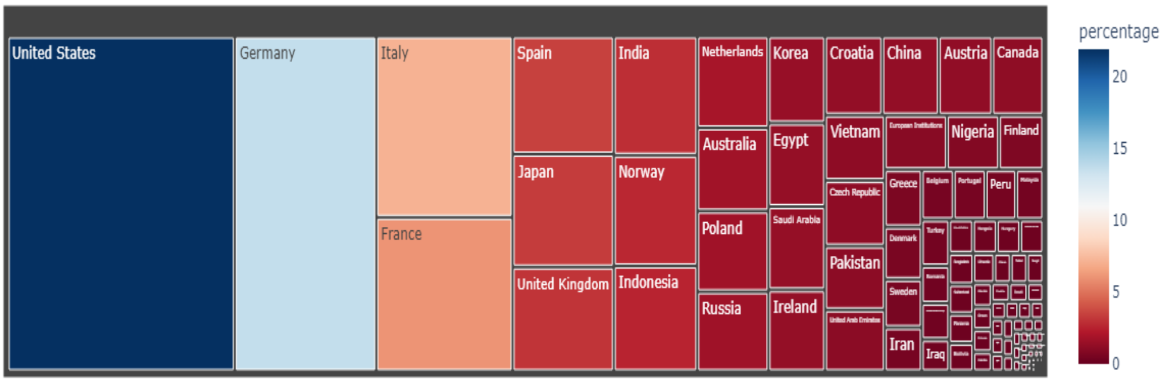

Figure 2: Budget Allocation by country

With an allocation of around 337 billion USD, Germany stands as the second-highest funding country among the 105 countries included in this database. Germany prioritised 'energy affordability' by allocating 73% of funds to ensure accessible energy for all, a measure that cannot be explicitly classified as "green" as it involves subsidising the price of various energy forms. Additionally, investments in 'low carbon and efficient transport' (11%), 'energy-efficient buildings and industries' (10%), and 'fuel and technology innovation' (5%) underscore a commitment to green mobility, sustainable infrastructure, and green technological advancements. Italy's allocation of approximately 175 billion USD reflects its recognition of the urgent needs resulting from the COVID-19 pandemic as one of the countries that the pandemic hit the most. Italy's allocation strategy reflects a balanced approach to energy funding. For example, Italy dedicated about 37% to 'energy affordability' to ensure accessible energy for its citizens (again, not classified as "green"). Investments in 'low carbon and efficient transport' (27%) demonstrate a focus on sustainable mobility solutions, while the large allocations to 'energy-efficient buildings and industry' (25%) highlight efforts to improve energy efficiency in the demand sectors. France, on the other hand, took green recovery measures of around 149 billion USD to mitigate the effects of the crisis and ensure a resilient recovery. France also prioritised energy affordability and dedicated 55% of its funding to ensure accessible energy for its population. Investments in 'energy-efficient buildings and industry' (20%) indicate a focus on green infrastructure and energy efficiency, while allocations for 'low caron and efficient transport' (13%) showcase efforts towards sustainable mobility solutions. France's commitments to advance its innovative clean energy solutions are confirmed through its 9% allocation to 'fuels and technology innovation'.

Figure 3 illustrates the Share of Recovery Package Funding by classified sector across countries. This graph underscores a discernible trend in fund allocation across nations. For example, the category 'Energy affordability' has become a key concern especially in developing nations (Albania, Bulgaria, Tanzania, etc.), where ensuring that energy remains accessible and affordable for all is a critical aspect for societal equity and economic stability. On the other hand, developed countries such as Germany have also taken measures for energy affordability (package of about €246 billion) to constrain the impacts of the rising energy prices (Arne Delfs, Kamil Kowalcze, and Vanessa Dezem, 2022).

Regarding the category of low-carbon electricity, Australia's Net zero 2050 Long Term Emission Plan focuses on ambitious policies geared towards fostering low-carbon power generation with a substantial investment of about 30 billion USD to advance renewable energy sources and reduce greenhouse gas emissions. Netherlands, on the other hand, has dedicated green recovery measures to boost the development of renewable resources through investments in support for offshore wind energy (11,62 billion USD) to foster a strong recovery from the COVID-19 pandemic (European Commission, 2022).

Iceland utilised its recovery packages to support low carbon and efficient transport (75 million USD) by offering tax incentives for eco-friendly cars (IEA, State support for electric vehicle imports, 2022). Spain's recovery packages also prioritise low carbon and efficient transport (85 billion USD) by promoting public transport, cycling, and rail infrastructure. Investments in hydrogen and electric mobility, particularly for rail transport, are also part of the budgetary orientations, because of the recommendations and conditions set by the EU and of the opportunity represented by the Recovery Plan (Nicodeme, 2022).

Analysis of the electricity networks category shows that various nations are strategically investing in their power infrastructures to boost economic growth and sustainability, while also supporting the accelerated uptake of variable renewable energy sources like solar and wind. For example, the United States introduced the 'Infrastructure Investment and Jobs Act' to allocate significant funding (12.5 billion USD) toward upgrading its power infrastructure, which underscores the nation's commitment to modernise its electricity networks. Similarly, Spain's 'Electricity grid development Plan' for 2026 involves 8.29 billion USD to enhance the country's electricity grids. Meanwhile India's 'Revamped Distribution Sector Scheme' (RDSS) demonstrates a strategic approach (13.21 billion USD) to ensure the transformation of its distribution networks and reduce grid losses.

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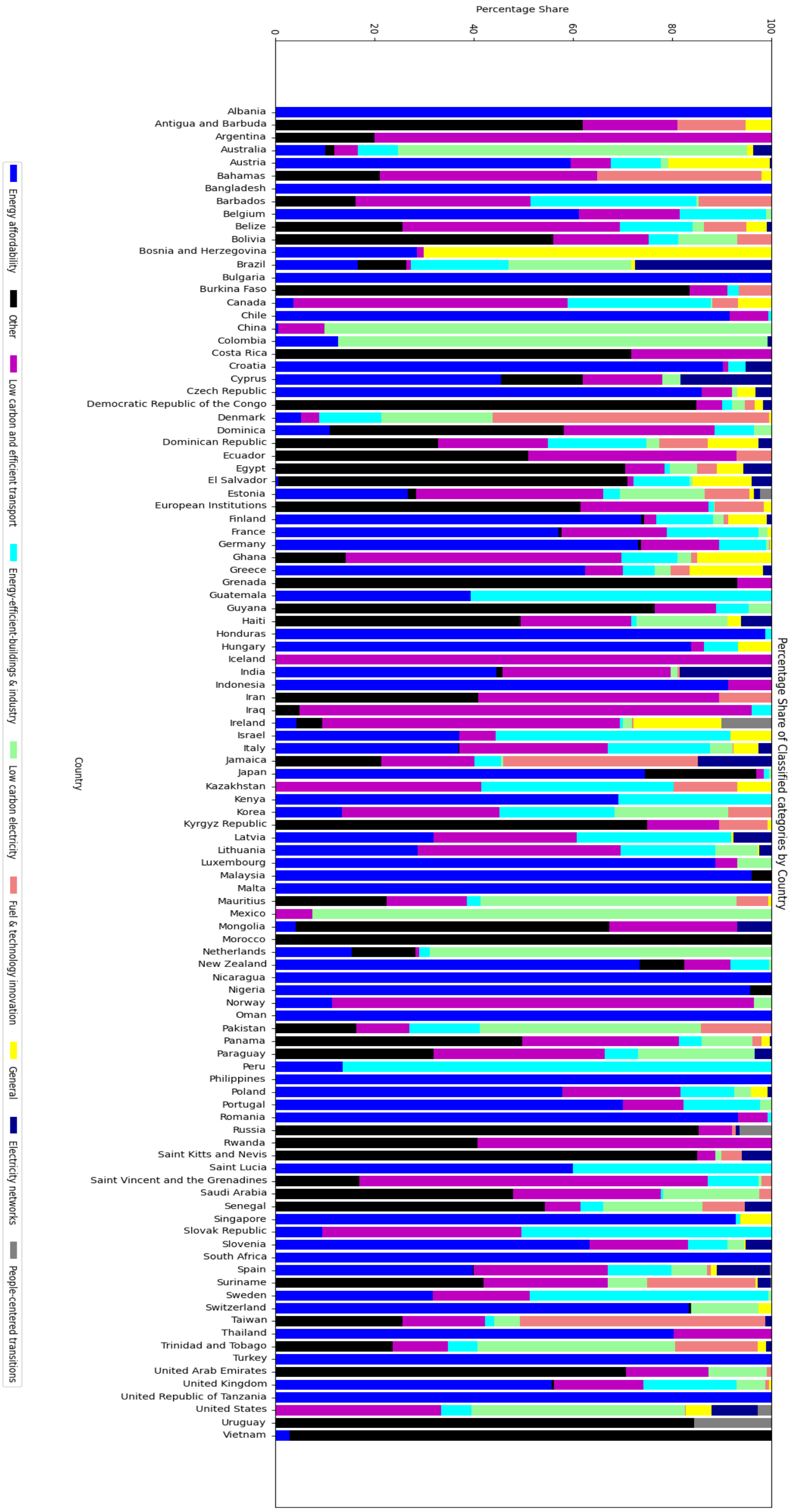

Figure 3: Share of Recovery Package Funding by classified sector: Country-wise distribution

Figure 4 presents a sectoral allocation of the green recovery packages from the developed recovery packages

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database, revealing the strategic priorities by sector and key focus areas in global recovery efforts.

Noteworthy is the dominance of the 'Energy Affordability' category, which represents 35% of the total funding. This highlights the pivotal role of energy affordability in driving socioeconomic development, a crucial aspect of global recovery measures. The category 'Low carbon and Efficient Transport' is following closely with a significant share (23% of total funding), aligning with the collective goals and initiatives to address climate change and promote environmentally friendly transportation solutions. Investments of this class are instrumental in reducing the carbon footprint of transportation systems. Furthermore, the 'Energy efficient buildings & industry' category constitutes 16% of the total funding, emphasising the importance of stationary energy demand sectors (and most importantly buildings) in achieving global climate goals. Investments in 'Low carbon electricity' (10% of total funding) include flows towards (especially solar and wind power) projects that contribute significantly to reducing reliance on fossil fuels and associated CO_2 emissions. The remaining categories account for less than 10% each, reflecting a diversified approach to sectoral funding.

This distribution of funds, as presented in Figure 4, signifies a concerted effort towards comprehensive, inclusive, and environmentally conscious recovery strategies.

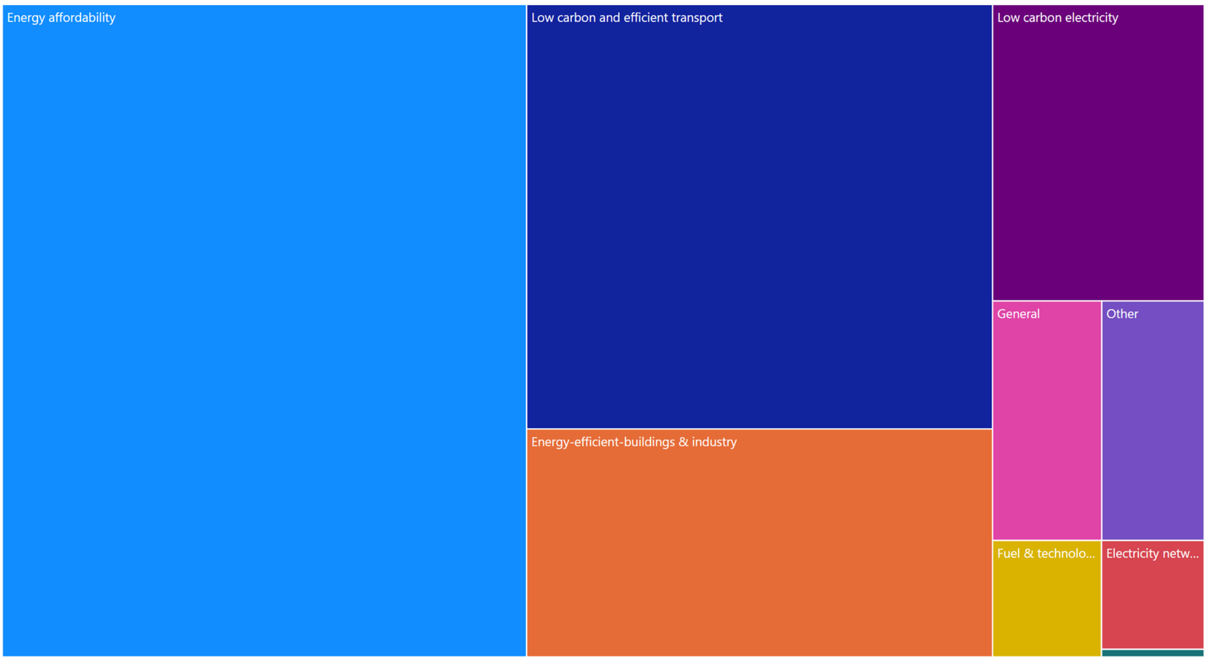

Figure 4: Classified Sector tree map on a global scale

Table 4 presents the funding in billion USD for 11 major economies. As we showed earlier in this report, it is evident that the 'USA' region registered the highest green recovery funding across all categories, with particularly significant allocations in the sectors of "Low Carbon Electricity" and "Low carbon and efficient transport". On the other hand, the European Union (EU) stands out for allocating considerable funding across various sectors, notably in Energy Affordability and Low Carbon and Efficient Transport. These results indicate regional priorities in addressing specific aspects of recovery, with an emphasis on renewable energy, energy efficiency in demand sectors (buildings and industry), and low-carbon transportation. These insights underscore the diverse strategies and priorities adopted by different regions in shaping their recovery packages to address energy-related challenges and promote sustainability while ensuring a strong and resilient recovery from COVID-19.

Table 4: Gathered Funding in Billion USD per region and classified sector

	Electricity networks	**Energy affordability**	**Energy-efficient-buildings &**	**Fuel & technology innovati**	**General**	**Low carbon and efficient**	**Low carbon electricity**	**Other**	**People-centred transitions**	**Total**

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			industry	on		transport				
Australia/New Zealand	1.6	5.3	3.5	0	0.5	2.1	29.7	0.9	0.04	43.9
Canada	0	0.9	8.2	1.5	1.9	15.8	0.06	0.02	0.07	28.6
China	0	0.1	0	0	0	2.9	28.6	0	0	31.7
EU	18.7	592	132.4	10.4	31	206.9	58.9	11.6	3.9	1066.3
India	13.2	31.3	0	0.29	0	23.9	0.9	0.8	0	70.7
Japan	0	60.4	0.7	0.04	0.1	1.3	0.3	18.2	0	81.3
Korea	0	4.6	8.1	3.1	0	1	7.9	0	0	34.9
Other	4.0	123.6	21.3	14	4.3	116.1	34	139	0.06	456.7
Russia	0.3	0	0	0.3	0	2.6	0	34.5	2.7	40.5
UK	0	41.8	14.1	0.6	0.5	13.6	4.2	0.3	0	75.3
USA	50	0.3	33.5	1	28.2	179.9	232.7	0	16.3	542.3

2.3.2 Sectoral analysis

2.3.2.1 Low carbon electricity

Figure 5 examines the category 'Low-carbon electricity' on a global scale. The results show that the highest share of funding allocation has been announced for low-carbon/renewable power (57.38%) which indicates a strong global emphasis on the deployment of renewable energy sources. This allocation reflects a recognition of the importance of transitioning towards sustainable power generation to mitigate climate change and reduce carbon emissions. It also suggests a commitment to expanding renewable energy capacity and accelerating the deployment of wind, solar, hydro, and biomass projects globally. Here, it is important to note that this share includes the technology-agnostic renewable energy category, but smaller shares of green recovery funds were also given to specific technologies: around 9% to solar PV (residential and utility-scale), 1.8% to wind offshore, and 2.8% to other renewable sources. This means that around 72% of 'low-carbon electricity" funding is provided to the development and deployment of renewable energy sources.

The share of Carbon Capture Storage and Use (CCUS) (15.08%) indicates growing recognition of the role of CCUS technology in reducing carbon emissions from fossil fuel-based power generation (and industrial plants). CCUS technologies capture CO_2 emissions from power plants or industrial processes and store them underground or utilise them for the manufacturing of products and/or fuels to prevent their release into the atmosphere (Chris Greig, Sam Uden, 2021). The allocation demonstrates a commitment to advancing CCUS deployment, which is still in its infancy and lacks industrial maturity, recognising its potential for decarbonising electricity production and energy-intensive industries, while also providing the potential for generating net negative emissions when combined with biomass-fired plants—considering Carbon Dioxide Removal (CDR) is widely acknowledged as necessary to ensure that the Paris temperature goals are met.

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The share of nuclear power on announced green recovery packages globally (10.5%) signifies continued investment and support for this technology in some countries. This allocation suggests that certain countries or regions consider nuclear power as part of their energy mix strategy to achieve their low-carbon objectives. However, as nuclear share is much lower compared to renewable energy, the focus is seemingly shifting towards a greater share of renewable energy in the global energy transition.

The allocation for residential and commercial photovoltaics (PV) with a 4.79% share suggests support for decentralised renewable energy generation. This funding allocation targets the installation of solar panels on residential and commercial buildings. It demonstrates an emphasis on empowering individuals and businesses to generate clean energy and reduce their carbon footprint. The allocation recognises the potential of small-scale PV installations in driving the energy transition and promoting energy self-sufficiency at the local level. On the other hand, the allocation for utility-scale photovoltaics highlights the significance of large-scale solar projects in the energy transition. This supports the development of utility-scale solar installations to meet renewable energy targets and replace fossil fuel-based power generation.

The relatively lower share directed to hydro (0.2%) compared to other energy sources is because, in many regions, a significant portion of viable hydroelectric resources have already been tapped. This fact led to a slower growth rate in hydroelectric capacity expansion compared to other renewable energy sources like solar and wind power.

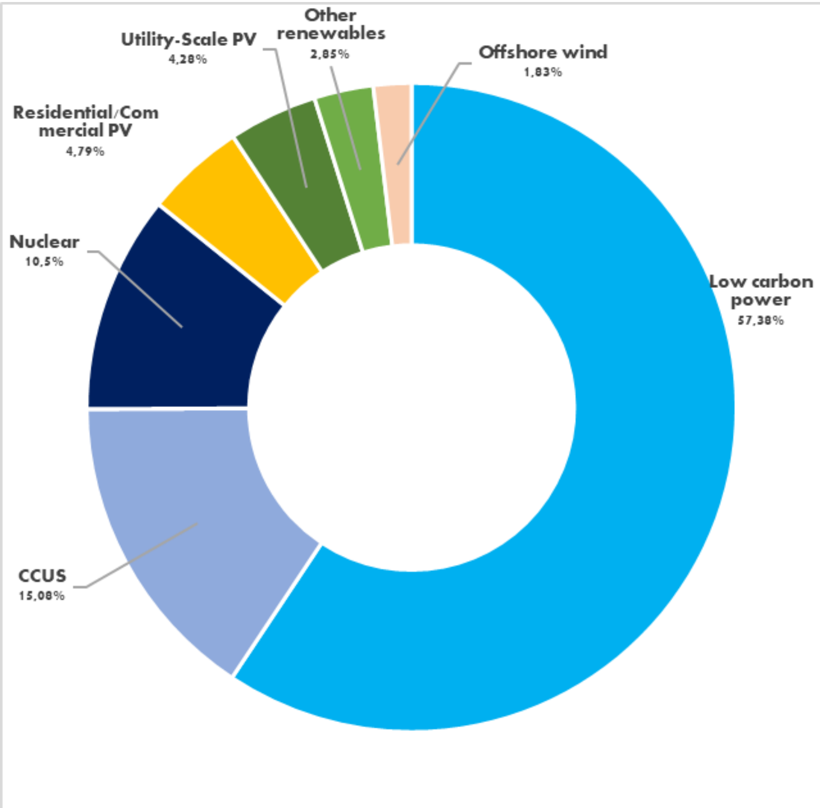

Figure 5: Funding shares in Low carbon Electricity globally

Overall, the funding allocation shares highlight the commitment to shifting towards low-carbon power. The emphasis on low-carbon renewable electricity power, along with investments in nuclear, CCUS, PV, and other renewables, showcases a multi-faceted approach to decarbonising the power sector. The result of the developed database reflects a recognition to diversify the energy mix, reduce reliance on fossil fuels, and leverage a range of technologies to achieve sustainable and clean power generation.

2.3.2.2 Low carbon and efficient transport

The results of the developed database on recovery packages focusing on the low-carbon and efficient transport category highlight several notable shifts and opportunities.

- **Emphasis on the sustainability of public transportation (52% share in the 'low carbon and efficient transport' category):** The budget allocations to high-speed rail, mass and urban transit, and buses highlight a significant focus on enhancing sustainable public transportation systems as a means to reduce emissions from the transport sector. These Investments demonstrate a commitment to expanding and improving rail and bus networks, which can reduce congestion and promote more sustainable and efficient travel options based on the development of the required infrastructure. The allocation for ships underscores efforts to develop efficient and environmentally friendly alternatives, such as hybrid propulsion systems or low-emissions fuels.
- **Shift towards Electric Vehicles (EVs) with a share of about 28% in the category of 'low carbon and efficient transport':** The significant allocations for batteries, electric two- and three-wheelers, and electric passenger cars demonstrate a clear shift towards electrification in the transportation sector. The above reflects a growing emphasis on promoting and supporting the adoption of electric vehicles to reduce carbon emissions from conventional ICE vehicles and improve air quality. Additionally, the substantial allocation for low-carbon vehicles and efficient passenger cars indicates efforts to promote vehicles with lower emissions, such as hybrid and plug-in hybrid models, alongside EVs.
- **Alternative fuels have a share of about 14% in the category 'low carbon and efficient transport':** The allocation in hydrogen suggest an increasing focus on developing hydrogen fuel cell technologies as an alternative to conventional internal combustion engines (especially in countries like the USA and Australia). Hydrogen can be used to power various modes of transport, including passenger cars, buses, and trucks, reducing carbon emissions relative to conventional ICE vehicles if hydrogen is produced with low-carbon resources (i.e., based on electrolysis using low-carbon electricity). Furthermore, the allocations for advanced and conventional biofuels reflect ongoing support for sustainable alternative fuels in the transport sector. Advanced biofuels are derived from non-food feedstocks and offer fewer carbon emissions compared to traditional fossil fuels. Biofuels, derived from organic matter, also provide a renewable alternative for certain transportation applications, including passenger cars, trucks, airplanes, and ships. These budget allocations indicate continued efforts to diversify fuel options and reduce reliance on fossil fuels while promoting the use of low-emission fuels.
- **Active transport infrastructure:** The allocation of recovery packages for walkways and bike lanes signifies support for the development of infrastructure that promotes walking and cycling as modes of transport. This suggests the importance of active transport in reducing reliance on cars, improving public health, and decreasing traffic congestion and carbon emissions from short-distance travel. The share of charging infrastructure further indicates efforts to develop a robust charging network to facilitate the widespread adoption of EVs.

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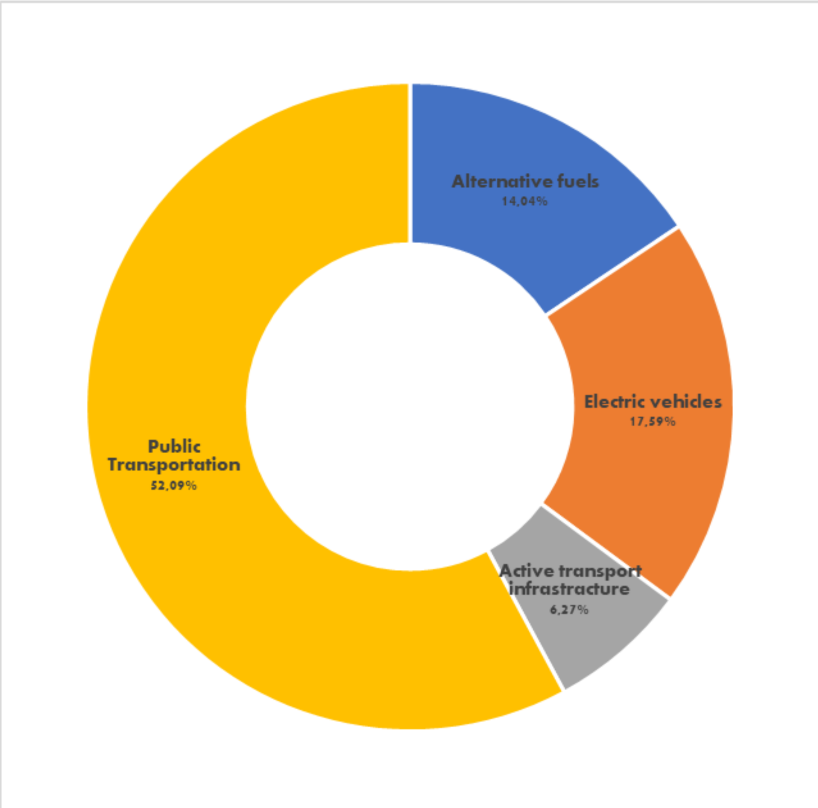

Figure 6: Shares in Funding for Low-carbon and efficient transport

In summary, the allocation of green recovery packages demonstrates a significant shift towards low-carbon and sustainable transport options. The focus on electric vehicles, hydrogen, low-carbon vehicles, advanced biofuels, and sustainable public transport indicates a commitment in decarbonising the transport sector and improving overall environmental performance. The opportunities presented by the recovery packages include advancements in EV adoption, the development of hydrogen infrastructure, and the expansion of sustainable public transportation networks and other relevant infrastructure to support public and active transport modes. These initiatives can contribute to reducing greenhouse gas emissions, improving air quality, and building more resilient and sustainable transport systems.

2.3.2.3 Energy-efficient-buildings & industry

The analysis showed moderate green recovery package allocation to energy efficiency in buildings and industries (about 16% of total funds). Figure 7 illustrates that 56.8% of the recovery packages related to the 'Energy-efficient buildings and Industry' category is allocated to energy efficient building retrofits while 23.6% to industrial energy efficiency. The high allocation share for energy-efficient retrofits highlights the significant potential for energy savings in existing buildings. The industry energy efficiency measures reflect the acknowledgment of the importance of reducing energy consumption and improving efficiency in industrial processes.

The allocation of recovery funding for efficient new builds (6.3%) suggests a global focus on incorporating energy-efficient measures and stricter codes in new construction projects (emphasising energy-efficient design, materials, and technologies during the construction phase that result in buildings that consume less energy and have a reduced carbon footprint). The uptake of heat pumps receives 5.9% of global green recovery funding, indicating their potential in providing efficient heating and cooling solutions. The recovery package allocation for clean cooking, with a share of 4.5%, reflects a commitment to promoting clean and sustainable cooking practices,

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particularly in low-income countries and regions where traditional cooking methods prevail.

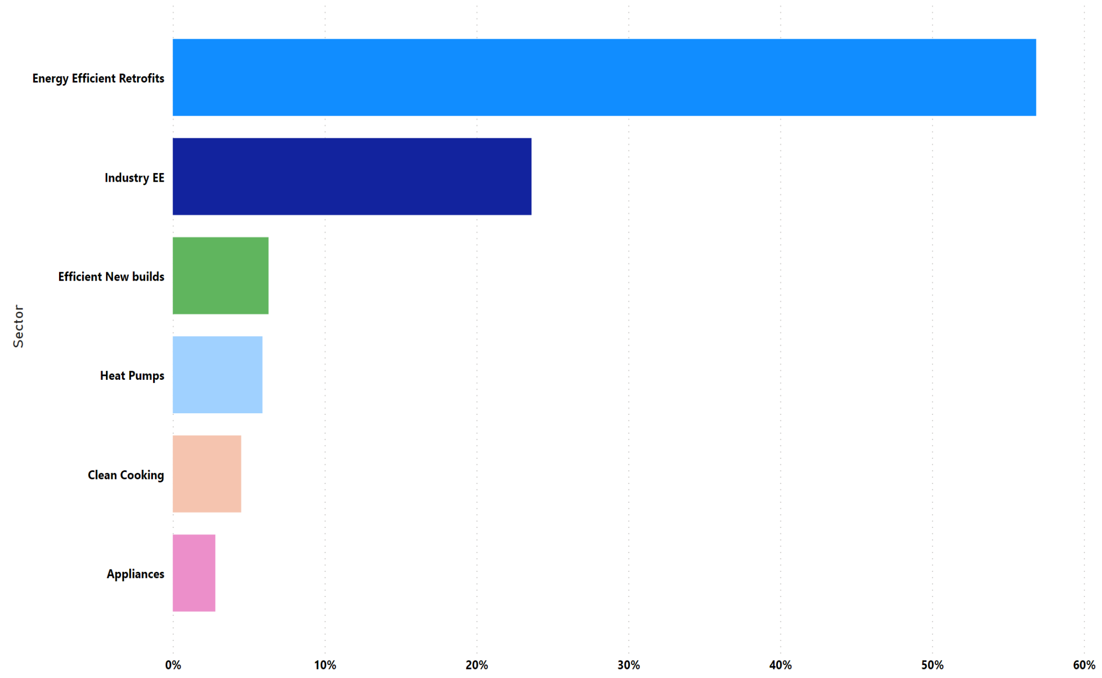

Figure 7: Shares in Funding for Energy-efficient buildings and industry

In this category, the substantial allocation for energy-efficient retrofits suggests extensive efforts to improve energy efficiency in the existing building stock, while the allocation for industry energy efficiency signifies the drive to improve energy performance in industrial sectors and processes. The allocations for efficient new builds and heat pumps highlight the importance of integrating energy-efficient, low-carbon technologies and practices in the construction of new buildings while the funding to clean cooking practices can also offer large benefits to low-income, developing countries. Together, these allocations reflect a commitment to reducing energy consumption from buildings and industries, mitigating emissions and environmental impacts, and advancing broader sustainability goals.

2.3.2.4 Fuel & technology innovation

The category of Fuel and technology innovation includes the sectors "Other Innovation" and "Other technologies/measures" (Figure 8) as identified from the recovery packages policy classification.

• Other Innovation: The allocation for "Other Innovation" signifies funding directed towards various innovative solutions, technologies, or measures that do not fall into specific subcategories within the fuel and technology sector. This includes emerging technologies, novel approaches, or experimental projects aimed at advancing fuel efficiency, reducing emissions, or promoting sustainable practices. This result reflects a commitment to exploring diverse avenues for fuel and technology innovation beyond the specific categories outlined.

• Other technologies/measures: The allocation for "Other technologies/measures" suggests the allocation of resources towards additional technological advancements or measures not explicitly classified within the provided breakdown. These could include a wide range of initiatives, such as research and development of new fuel sources, technological improvements for energy efficiency, or measures to support sustainability in the energy sector. The allocation demonstrates an openness to supporting innovative solutions and technologies that contribute to the overall goals of fuel and technology innovation.

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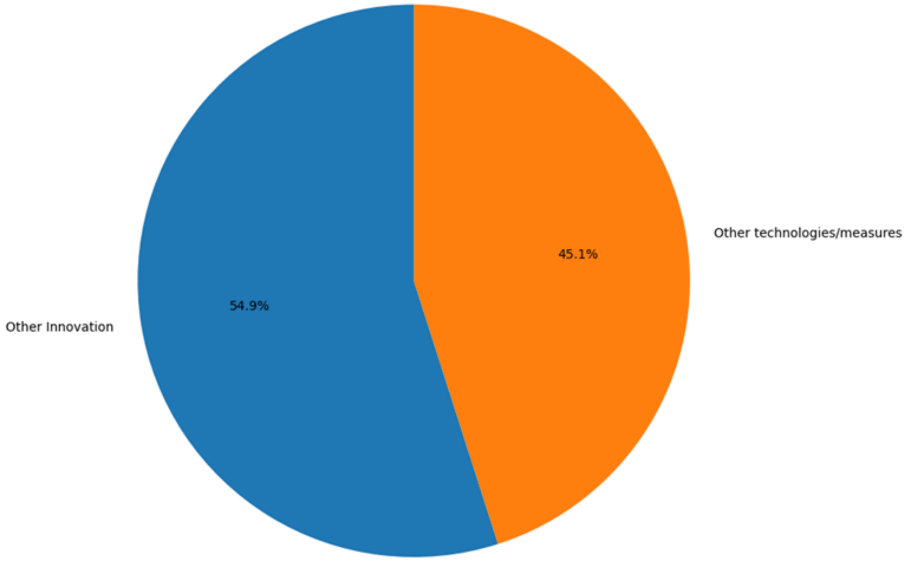

Figure 8: Funding shares in Fuel and Technology innovation

The allocations in this category reflect that there are innovative solutions and technologies that are not explicitly captured by the predefined subcategories.

To address this gap, it would be beneficial to further investigate and identify the specific innovations and technologies included in the "Other Innovation" and "Other technologies/measures" allocations. This could involve additional research, engaging with experts or stakeholders in the field, and reviewing relevant literature or reports to better understand and categorise these initiatives accurately. By filling this gap and providing more detailed information on the specific innovations and technologies represented by these categories, our global recovery database can offer a more comprehensive and nuanced representation of the fuel and technology innovation sector. Additionally, as new technologies and innovations continue to emerge, it is important to regularly update and expand the classification structure of the database to accommodate these developments, ensuring that the database remains up-to-date, relevant, and inclusive of the latest advancements in fuel and technology innovation across the globe.

2.3.2.5 Electricity networks

The allocation shares in the electricity networks category indicate the distribution of resources within different components of the power grid. The significant allocation for transmission grids (49.4%) highlights the importance of strengthening and expanding the high-voltage transmission infrastructure to also support the deployment of renewable energy sources. Transmission lines are responsible for carrying electricity over long distances from power generation plants to distribution centers or large consumers. The allocation suggests a focus on improving the efficiency, capacity, and reliability of the transmission system to ensure the smooth and uninterrupted flow of electricity with limited grid losses.

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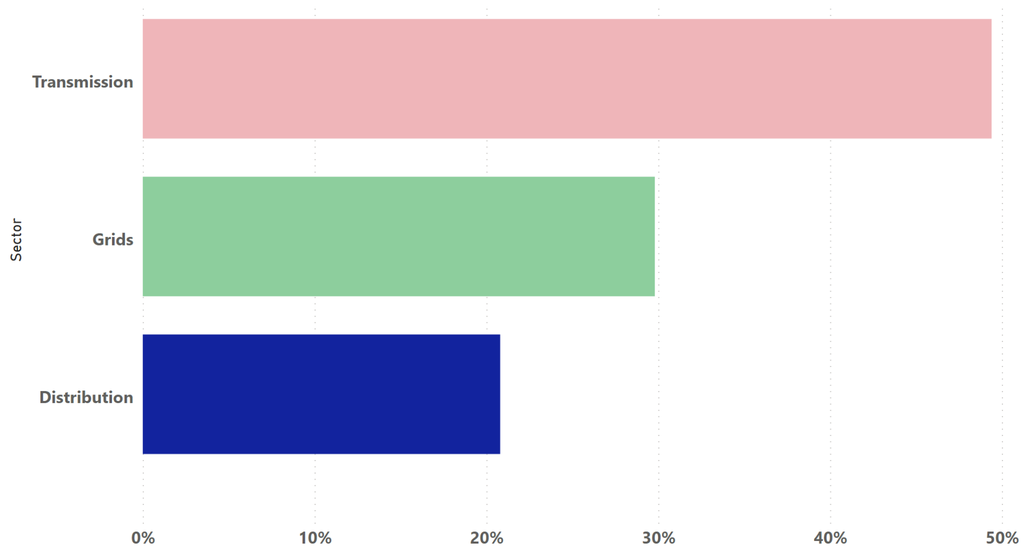

Figure 9: Funding shares in electricity networks

The allocation for grids (29.8%) represents investments in the overall electricity grid infrastructure. This allocation suggests a commitment to modernising and upgrading the entire grid infrastructure to enhance its flexibility, resilience, and ability to integrate renewable energy sources (upgrades to the grid can facilitate the efficient integration of decentralised and intermittent power generation, smart grid technologies, and advanced communication systems).

The allocation for power distribution (20.8%) indicates the focus on the local distribution networks that deliver electricity to end consumers. Distribution networks comprise medium- and low-voltage lines, substations, transformers, and other components necessary for delivering electricity to homes, businesses, and other consumers. Also, this allocation reflects the interest in investments that enhance the upgrading and modernising distribution infrastructure to improve reliability, reduce losses, and accommodate changing patterns of electricity consumption and decentralised production. Overall, the allocation shares in the electricity networks category demonstrate a comprehensive approach in improving and optimising the entire power grid infrastructure as a major enabler of the clean transition.

2.3.2.6 General Category

The sectors in the general category of our global recovery database represent broader areas or themes that encompass multiple subsectors or initiatives. The general category allows for the inclusion of sectors that may not fit neatly into specific predefined categories or sectors but are still important components of the recovery packages.

For example, the significant budget allocation for energy efficiency (44.9% of the "general category") indicates that a substantial portion of the recovery packages is focused on promoting energy-saving measures and technologies across all sectors. This allocation reflects the recognition of energy efficiency as a key strategy to reduce energy consumption, lower greenhouse gas emissions, and improve overall energy performance in various sectors.

The allocation for critical minerals (1.16%) indicates that a small chunk of the recovery packages is dedicated to support the exploration, extraction, and development of essential minerals necessary for various industries, especially for the manufacturing of products and technologies required for the low-carbon transition. It recognises the importance of securing a sustainable supply of critical minerals to drive the transition to cleaner energy technologies (e.g. solar PV, batteries) and meet the demands of emerging industries.

Methane abatement (2.91%) targets the reduction of methane emissions, particularly in sectors such as oil and gas production, agriculture, and waste management. It demonstrates the recognition of the importance of mitigating CH_4, a potent greenhouse gas, to address climate change and improve environmental sustainability.

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A portion of the recovery packages is dedicated to expanding access to electricity in remote or low-income regions that currently lack access (especially in Sub-Saharan Africa), aiming to bridge the energy access gap and improve socio-economic conditions. A portion of the recovery packages focuses on promoting waste management systems and circular economy principles under the recycling sector. This allocation reflects the commitment to enhance recycling infrastructure, reduce waste generation, and promote the reuse and recycling of materials to minimise overall environmental impacts.

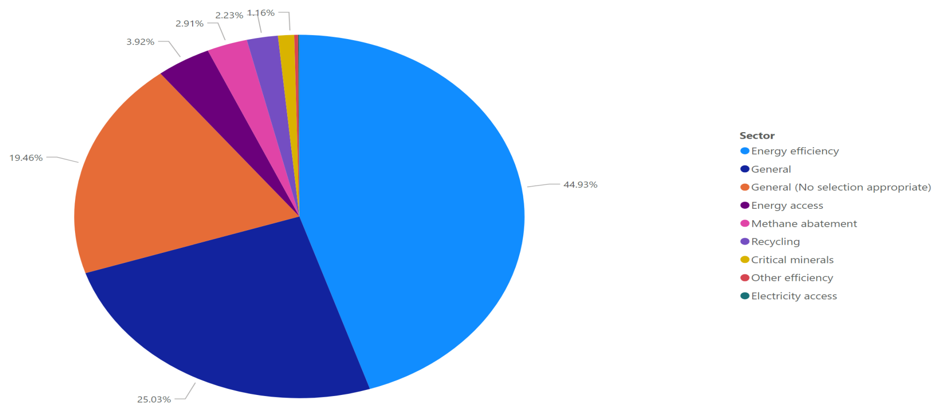

Figure 10: Funding shares in General category

In summary, the general category provides a snapshot of the funding distribution and priorities within the global recovery packages. These allocations highlight the emphasis placed mostly on energy efficiency, and then on critical minerals, electricity access, methane abatement, other efficiency measures, and recycling as part of the recovery efforts, demonstrating a commitment to address key challenges and opportunities in these sectors for global sustainability and resilience.

2.4 Limitations and Assumptions

In this deliverable, we have presented the developed global recovery package database by gathering data from multiple sources, with the IEA database serving as the primary source. The developed database encompasses recovery packages from 105countries covering more than 90% of the global GDP. The main data source was the IEA, supplemented by data from the Global Recovery Observatory and the Energy Policy Tracker. Additional validation was conducted using sources such as the Green Recovery Tracker, the pre-existing recovery policy database in I^{2}AM PARIS (based on previous efforts in the context of the H2020 PARIS REINFORCE project), and the OECD database. The database was structured and organised according to the IEA's classification framework, enabling comprehensive analysis of recovery measures across various sectors. Our approach offers flexibility in structuring and interpreting the data, and the database serves as a valuable resource for assessing the short and long-term impacts of COVID-19 green recovery packages using a series of national and global modelling tools with consistent integration of the data (see Section 3).

However, it is important to acknowledge the limitations of our study. The data quality and reliability may vary across sources, potentially introducing inconsistencies or inaccuracies into the database. Data availability and coverage may also vary, leading to gaps or uneven representation. Subjective decisions were made in the categorisation and standardisation process, while alternative categorisation schemes may have yielded different results. Finally, missing data and the potential for subjective interpretations during the data cleaning process pose additional challenges.

To address the above, we implemented a robust data validation process, cross-referencing information from multiple sources and conducting additional research where discrepancies arose. Despite these limitations, our comprehensive approach and enhanced methodological transparency contribute to the reliability and usability of the database. Future updates and integration of new data sources will further enhance the accuracy and comprehensiveness of the database.

The developed global recovery database provides insights into the national and sectoral allocation of recovery resources and the priorities in green recovery packages globally. It enables analysis of trends, funding allocations, and policy measures employed to facilitate the post-COVID economic recovery. While acknowledging the limitations, we have strived to overcome them through rigorous validation, documentation, and transparency. The database serves as the foundation for further research and analysis, contributing to the understanding of global efforts towards sustainable and low-carbon transitions. The integration of the data into a series of national and global modelling tools and the assessment of their short- and long-term emissions, technology, and energy system impacts (presented in sections below) indicates the usefulness of our approach and the developed database.

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3 Analysis | Global Modelling Results

3.1 Context

The profound impact of climate change has prompted global efforts to mitigate its consequences, with the Paris Agreement setting ambitious targets to limit temperature rise. Early climate pledges were deemed insufficient, prompting countries to increase their ambitions, although progress remained slower than required. Despite this, the 26th Conference of the Parties (COP26), held in Glasgow in November 2021, marked a significance milestone. Over 120 countries enhanced their 2030 emission reduction targets, and major emitters, accounting for over 70% of global emissions, committed net zero pledges by mid-century or later. Amidst this urgency, the aftermath of the COVID-19 pandemic with the introduction of green recovery packages as a means to achieve sustainable and resilient economies has gained paramount importance. As nations grapple with the dual challenges of economic recovery and climate action, understanding the environmental and socioeconomic implications of recovery packages has become crucial. Several studies attempted to assess these commitments and to gauge the effectiveness of green recovery plans.

For example, a study by Pollitt et al, (2021), investigated the potential impacts of green recovery plans in the context of the economic challenges posed by the COVID-19 pandemic. Drawing parallels with the complexities faced during the 2008-2009 financial crisis, the study acknowledges the inherent difficulty in modelling the combined economic and health impacts of specific policy measures. While existing models struggle to integrate both dimensions, the authors contend that insights can be derived from models with high sectoral disaggregation, particularly those grounded in post-Keynesian or complexity economics. Utilising the post-Keynesian E3ME model, the research defines the crisis as a blend of demand and supply shocks, presenting a GDP trajectory and sectoral impact pattern aligned with non-model-based estimates. The study evaluates two recovery plans – a VAT reduction plan and a green recovery plan (GRP) aimed at reducing greenhouse gas emissions. Both plans contribute to economic recovery, albeit insufficiently to counteract the negative macroeconomic effects of COVID-19. Notably, the GRP scenario, which strategically allocates public funds to emission reductions measures, outperforms the VAT cuts scenario in overall performance, leveraging private finance and addressing both economic and environmental objectives. The findings underscore the necessity of a diverse set of measures to protect jobs and reduce emissions effectively. The research concludes with a call to enhance modelling capabilities to better capture economic downturns and crises, as well as the socioeconomic and environmental impacts of recovery packages.

Another study, Gaucher et al, (2022), employed a multi-method approach to assess the impact of low-carbon investments on CO_2 emissions reduction until 2030. Firstly it utilises IAMs driven by carbon prices to simulate the relationship between low-carbon investments and carbon intensity of GDP. Four scenarios per model are considered, reflecting current policies, NDC implementation, and global carbon budgets for 2ºC and 1.5ºC targets. Linear regressions are applied to calculate emissions reductions based on low-carbon investments. Then, it integrates the World Energy Outlook (WEO) scenarios by the International Energy Agency (IEA), including STEPS2020, STEPS2021, and Sustainable Development Scenario (SDS2020). Finally, it employs an Adaptive Regional Input-Output model (ARIO) to analyse the pandemic's impact and fiscal stimuli on global emissions, considering different scenarios with varied pandemic secerity, fiscal measures, and emissions factors evolution. The study aim to estimate emissions reductions resulting from low-carbon investments and contributes to understanding the complex interactions between economic recovery, climate policies, and the development of global emissions.

A study led by Dirk-Jan van de Ven et al, (2022), highlights the intricate dynamics involved in the impact of financial support for clean energy technologies on greenhouse gas (GHG) emissions and energy-sector jobs. It acknowledges that, while they tend to create additional energy-sector jobs and reduce GHG emissions, green recovery packages are not automatically a universally cost-efficient policy instrument. Their effectiveness varies based on technology, region, and other factors such as the impact on the overall energy mix and differences in emission and employment factors. The research utilises IAMs to analyse the optimal technology portfolio for planned financial support programs, considering trade-offs between the job creation and environmental outcomes, and recognising the diverse impacts of recovery packages across different countries and models. The study's IAMs are also linked with employment factor databases to estimate the job impacts of targeted technology interventions. The study finally integrates the IAMs with portfolio analysis to simultaneously optimise emissions cuts and near- and long-term employment gains, overcoming methodological challenges in IAM analyses. The findings underscore the importance of strategically allocating green economic stimulus to specific technologies to achieve both emission reductions and increased employment, calling for political preparedness and careful consideration of environmental and socioeconomic goals when designing recovery packages in times of economic crisis. Furthermore, the study suggests that the recovery response to the COVID-19 pandemic can offer a strong green stimulus aligned with economic recovery and improved mitigation efforts in most countries.

The research led by the OECD in 2023 conducted a comprehensive analysis of the potential greenhouse gas (GHG) emissions reduction induced by post-COVID fiscal measures, utilising the GEM-E3 model. The methodology involved among others the development of a comprehensive database with the announced recovery packages worldwide that is mentioned in Section 2.1.1 in this report and simulating two scenarios, the Green Fiscal Push Scenario (incorporating low-carbon fiscal measures) and a Reference scenario (representing pre-COVID climate and energy policies). The analysis showed that the implementation of green recovery packages would lead to global GDP increase and the creation of jobs mostly in the sectors related to the development of clean energy technologies and electric vehicles.

Another research, led by Koasidis et al, (2022), aims to inform EU policymakers on the optimal allocation of the green part of the Recovery and Resilience Facility (RRF) to maximise emissions reductions and employment gains. Utilising the Global Change Analysis Model (GCAM), coupled with the AUGMECON-R multi-objective portfolio optimisation model and a Monte Carlo-based uncertainty analysis framework, the study evaluates different technology subsidisation portfolios while considering the associated uncertainties. The research addresses two principal questions: the allocation of funds towards low-carbon technologies to achieve emissions cuts and employment gains, and the dynamics and trade-offs among emissions reductions and employment opportunities. Overall, the study evaluates the EU's green recovery package, emphasising a trade-off between maximising emissions reductions and energy-sector employment gains. Identifying key technologies like onshore wind, solar PV, biofuels, nuclear power, and offshore wind, the study highlights the challenge of simultaneously optimising near-term (2025) and longer-term (2030) employment goals. The study calls for future research to explore scenarios of market evolution of clean energy technologies, employ more advanced economic models and consider additional technologies and spillover effects.

By utilising the IAM frameworks COFFE-TEA and PROMETHEUS, the study of Rochedo et al (2021) assessed the impacts of green recovery packages by assuming a baseline scenario (CurPol) with existing climate policies, incorporating short-term regional GDP growth shocks due to COVID-19. The goal was to evaluate the effects of post-COVID-19 economic recovery policies on global greenhouse emissions and the energy system transition. Based on policy screenings up until May 2021, the study assessed alternative recovery scenarios including the Recovery Packages (RecPac), the Enhanced Recovery (EnhRec), the Climate Ambition (CliAmb), and Global Governance (GloGov). Recovery funds were allocated to the sectors and low-carbon technologies following the IEA's proposals, with policy instruments like direct investments and subsidies. In particular, 33% of the total amount of green recovery packages was allocated to power generation, mostly in renewable energy technologies (wind and solar) but also to grid enhancements to support the increased uptake of variable renewable sources; 30% of the total amount was directed to low-emission transport modes, mostly in the purchase of electric cars; 30% to enhanced energy efficiency and electrification of buildings; and the remaining 7% to increased energy efficiency in industrial sectors. Overall, the study aimed to assess the ambition gap of recovery packages and their potential to close the emission gap to Paris-compatible pathways. Results indicate that green recovery packages, even when enhanced, may not be enough to close the gap between current climate policies with the aspirational Paris Agreement goals. The authors proposed the combination of green recovery packages with sustained carbon pricing—and other climate policies—to effectively reduce emissions and facilitate long-term system transformation to meet the Paris goals.

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In another study, Dafnomilis et al, (2022) found that, despite the significant volume of fiscal recovery measures announced by countries to deal with the COVID-19 crisis, most recovery plans allocate a low percentage to green recovery. Using three well-established global macro-economic and integrated assessment models, they developed scenarios exploring the medium- and long-term impact of the COVID-19 crisis including a Green Recovery scenario to analyse the impact of a low-carbon focused stimulus. The results show that a Green Recovery scenario, with 1% of global GDP in fiscal support directed to mitigation measures for 3 years, could reduce global CO_2 emissions by 10.5–15.5% below pre-COVID-19 projections by 2030, closing 8–11.5% of the emissions gap with cost-optimal 2°C pathways. The share of renewables in global electricity generation is projected to reach 45% in 2030, the uptake of electric vehicles to accelerate, and energy efficiency in the buildings and industry sector to improve. However, such a temporary investment should be reinforced with sustained climate policies after 2023 to put the world on a 2°C pathway by mid-century.

The above studies often faced limitations in capturing the intricate dynamics between economic revitalisation, climate policies, and emissions reductions. Recognising this gap, our study emerges as a comprehensive exploration.

Building on the foundation laid by previous research, our approach integrates multiple models to navigate the complexities of short- and long-term emissions, scrutinise the evolving energy system, delve into technological ramifications, and assess macroeconomic implications. This holistic analysis was underpinned by 2 distinct scenarios, as discussed in Section 3.2.

3.2 Scenario Design

To comprehensively assess the emission, energy, and economic impacts of green recovery packages, we build on the global scenarios developed under the IAM COMPACT project, in particular the CP-EI and NDC-LTT scenarios, and (on top of the climate policies) we introduce the green global recovery packages. This results in the creation of two additional scenarios to explore the impacts of green recovery packages, the CP-EI-GR and the NDC-LTT-GR (Table 5).

The scenarios reflect different levels of post-COP26 ambitions:

- Current policies (CP): level of short-term ambition that is likely to be materialised through actual policies or concrete policy targets.
- NDCs (NDC): level of short-term ambition (up to 2030) to which most countries are dedicated through law or policy, but with risks of falling short if dedication is not high enough and/or there are changes in the political landscape.
- Long-term targets (LTT): level of longer-term ambition which many countries have stated to fulfil their part in mitigating climate change, but in most cases not backed with an actual policy agenda and legislative policy measures.

The first two levels of action are aiming on 2030, which is the common year for current NDC targets as well as many current policies. To project longer-term emission futures using current policies and NDCs, the Emissions Intensity (EI) method is applied after 2030 as a function of the ambition level up to 2030:

- _EI: The rate of change in emissions intensity of GDP in each region from 2020 to 2030 is fixed (kept constant) after 2030. This method is used by Fawcett et al. (2015) and VanDyck et al. (2016) to assess the long-term implications of INDCs.

To increase the realism of how emissions reductions take place in the scenarios, current policies are represented explicitly in both the CP and NDC scenarios, both before and after 2030. After 2030, current policies are assumed to remain in place as "constant" or "minimum" bounds on effort.

The third level of action is aiming on incorporating long term pledges, predominantly net-zero emission pledges, to the modelled scenarios. These come on top of pledged NDC targets for 2030, to create another increased level of proposed climate policy ambition. These pledges will be included for each model region as a linear pathway from the 2030 NDC target (NDC_LTT).

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Model implementation of current policies and Nationally Determined Contributions (NDCs) should be conducted as carefully as possible. Policy representation depends on specific model characteristics reflecting the model differences in the level of policy implementation due to technological and sectoral granularity. An overview of collected policies and targets for G20 countries (and the entire EU) has been developed to serve as a guideline for teams to model/update their policy representation, while Post-Glasgow NDCs and Long-Term Targets (LTTs) are also collected and shared with the modelling teams. NDC targets are based on direct interpretation of countries' unconditional Paris Agreement pledges, or the less ambitious range for pledges where NDC targets are given in ranges.

On top of the basic climate policy scenarios (CP_EI and NDC_LTT), we also simulate two scenario variants where the green recovery packages (as presented in detail in Section 2 of the deliverable) are added on top of the climate policy intensity of the CP_EI and NDC_LTT scenarios. The green recovery packages collected in the database (Section 2) are then integrated in the modelling scenarios either as direct investment or subsidies to low-carbon technologies by region/country. The climate policy intensity (i.e., the level of carbon price) remains the same with the respective "basic" scenarios, so e.g. the CP_EI_GR scenario has the same carbon price as CP_EI in all regions, but the integration of green recovery packages would lead to reduced emissions.

Table 5: Scenario Descriptions

Scenarios	Description
CP_EI	Implement national-level current climate policies until 2030
CP_EI_GR	Same climate policy intensity as in CP_EI scenario but with the inclusion of green recovery packages presented in Section 2
NDC_LTT	Implement the NDC targets for 2030 and Long-term mitigation targets for 2050
NDC_LTT_GR	Same climate policy intensity as in NDC_LTT scenario but with the inclusion of green recovery packages presented in Section 2

Updating Model Harmonisation

Prior to scenario modelling, modelling teams have aligned key model assumptions with the latest projections including the following data sources:

• Socioeconomics (Population and GDP): Utilise the latest figures from Europop and UN datasets for population updates and drawn on a mix of sources for updated GDP data.

• Technoeconomics (power sector): Where feasible and relevant, integrate cost and technology projections from IEA WEO until 2050.

• Fossil Fuel Prices: Incorporate future prices from IEA World Energy Outlook and consult historical data from the World Bank where applicable.

By updating existing scenarios and introducing recovery-focused variants, this study aims to examine the emissions, energy system, technology, and economic impacts contributing to a more comprehensive understanding of the intersection between economic recovery and climate objectives.

3.3 Brief Model descriptions

The study uses four well-established IAMs (GCAM, PROMETHEUS, TIAM, and WILIAM[8]) that have been widely

[8] The WILIAM model participated in the analysis and provided the model-based scenario results, but its results diverged a lot from the coherent narrative of the three core IAMs. We identified several potential reasons for this,

used to assess the environmental, economic, and technology impacts of ambitious climate policies at national and global levels. A brief description of the three models is provided below, while detailed model descriptions can be found in the I^{2}AM PARIS platform[9].

The Global Change Assessment Model (GCAM) is a global integrated assessment model that represents both human and Earth system dynamics. It explores the behaviour and interactions between the energy system, agriculture and land use, the economy and climate. The role of GCAM is to bring multiple human and physical Earth systems together in one place to provide scientific insights that would not be available from the exploration of individual scientific research lines. The model components provide a faithful representation of the best current scientific understanding of underlying behaviour. GCAM allows users to explore what-if scenarios, quantifying the implications of possible future conditions. These outputs are not predictions of the future; they are a way of analysing the potential impacts of different assumptions about future conditions. GCAM reads in external "scenario assumptions" about key drivers (e.g., population, economic activity, technology, and policies) and then assesses the implications of these assumptions on key scientific or decision-relevant outcomes (e.g., commodity prices, energy use, land use, water use, emissions, and concentrations). It is used to explore and map the implications of uncertainty in key input assumptions and parameters into implied distributions of outputs, such as GHG emissions, energy use, energy prices, and trade patterns. Techniques include scenarios analysis, sensitivity analysis, and Monte Carlo simulations. GCAM has been used to produce scenarios for national and international assessments ranging from the very first IPCC scenarios through the present Shared Socioeconomic Pathways (SSPs) (Calvin et al., 2017).

PROMETHEUS is a global energy system model covering in detail the complex interactions between energy demand, supply and energy prices at the regional and global level. Its main objectives are: 1) Assess climate change mitigation pathways and low-emission development strategies for the medium and long-term 2) Analyse the energy system, economic and emission implications of a wide spectrum of energy and climate policy measures, differentiated by region and sector) 3) Explore the economics of fossil fuel production and quantify the impacts of climate policies on the evolution of global energy prices. The PROMETHEUS model provides detailed projections of energy demand, supply, power generation mix, energy-related carbon emissions, energy prices and investment to the future covering the global energy system. PROMETHEUS is a fully fledged energy demand and supply simulation model aiming at addressing energy system analysis, energy price projections, power generation planning and climate change mitigation policies.

PROMETHEUS quantifies CO_2 emissions and incorporates environmentally oriented emission abatement technologies (like RES, electric vehicles, CCS, energy efficiency) and policy instruments. The latter include both market-based instruments such as cap and trade systems with differential application per region and sector specific policies and measures focusing on specific carbon emitting activities. Key characteristics of the model, that are particularly pertinent for performing the analysis of the implications of alternative climate abatement scenarios, include world supply/demand resolution for determining the prices of internationally traded fuels and technology dynamics mechanisms for simulating spill-over effects for technological improvements (increased uptake of a new technology in one part of the world leads to improvements through learning by experience which eventually benefits the energy systems in other parts of the World). PROMETHEUS is designed to provide medium- and long-term energy system projections and system restructuring up to 2050, both in the demand and the supply sides. The model produces analytical quantitative results in the form of detailed energy balances in the period 2015 to 2050 annually. The model can support impact assessment of specific energy and environment policies and measures, applied at regional and global level, including price signals, such as taxation, subsidies,

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but due to time constraints, we decided to leave WILIAM results out of the D5.1. However, the WILIAM team further improves the scenario results and these will be included in a potential revision of the deliverable D5.1 or in a potential submission to a peer-reviewed journal.

[9] https://www.i2am-paris.eu/detailed_model_doc/gcam; https://www.i2am-paris.eu/detailed_model_doc/prometheus; https://www.i2am-paris.eu/detailed_model_doc/tiam

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technology and energy efficiency promoting policies, RES supporting policies, environmental policies and technology standards.

The TIMES Integrate Assessment Model, TIAM, is the multi-region, global version of TIMES, which combines an energy system representation of fifteen different regions with options to mitigate non-CO2 greenhouse gases as well as non-energy CO_2 mitigation options, such as afforestation in each of these regions. It uses emissions from these sources to calculate temperature changes using a simple climate module. As such, it can be used to explore a variety of questions on how to mitigate climate change through energy system and transformations, as well as reductions in non-energy CO_2 emissions and non-CO_2 emissions. TIMES is a modelling platform for local, national or multi-regional energy systems, which provides a technology-rich basis for estimating how energy system operations will evolve over a long-term, multiple-period time horizon (Loulou and Labriet, 2007). These energy system operations include the extraction of primary energy such as fossil fuels, the conversion of this primary energy into useful forms (such as electricity, hydrogen, solid heating fuels and liquid transport fuels), and the use of these fuels in a range of energy service applications (vehicular transport, building heating and cooling, and the powering of industrial manufacturing plants). In multi-region versions of the model, fuel trading between regions is also estimated. The TIMES framework is usually applied to the analysis of the entire energy sector but may also be applied to the detailed study of single sectors (e.g. the electricity and district heat sector). The framework can also be used to simulate the mitigation of non-CO_2 greenhouse gases, including methane (CH_4) and nitrous oxide (N_2O).

3.4 Results for Current policy scenarios

The section analyses the emission, technology, and energy system impacts of the green recovery packages in the current climate policy context by comparing the model-based results of the CP_EI with CP_EI_GR scenarios developed with the four IAMs. The comparison of the CP-EI scenario simulating the current policies with the CP-EI-GR one, enhanced by green recovery funding, provides an improved understanding of the potential transformative influence of financial support towards a cleaner and more sustainable energy paradigm.

3.4.1 Impacts on CO_2 Emissions

The introduction of the newly legislated climate policies and targets in major economies has shifted downwards the emission projections in the CP_EI scenario, with both PROMETHEUS and GCAM models showing that global CO_2 emissions may decline by 2%-3% in 2030 and 9%-15% in 2050 from 2015 levels. The integration of green recovery packages in the CP_EI_GR scenarios drives further emission reductions in both models from 2025 onwards (Figure 11) due to the faster uptake of clean energy technologies in the energy system. The impact of green recovery is found to be higher in PROMETHEUS than in GCAM with global emissions in the CP_EI_GR scenario declining by around 1.1 Gt in 2025, 1.5 Gt in 2030 and 1.9 Gt in 2050 relative to CP_EI scenario without green recovery funding, while in GCAM the emissions reduction is around 0.3-0.4 $GtCO_2$ over the 2025-2050 period. The higher emissions impact is driven by the higher flexibility of PROMETHEUS to changing assumptions and the detailed representation of recovery funding directed to specific mitigation options in all sectors. On the other hand, emissions in GCAM are already dropping much stronger in CP_EI compared to PROMETHEUS (Figure 11), which gives less "space" for recovery packages to have an impact. It should be mentioned, however, that, despite the projected emission reductions, these scenarios are far from consistent with the climate efforts required to meet the Paris Agreement goals and can only close a small part of the emissions gap with the global mitigation effort by 2030 and 2050, which can only be achieved with sustained and ambitious climate policies and investment in low-carbon technologies.

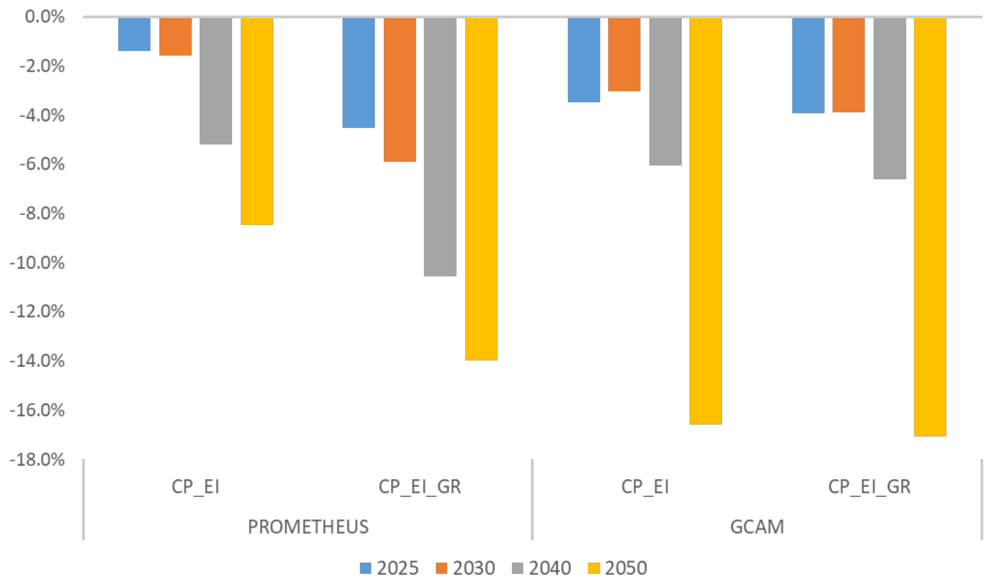

Figure 11: Changes in global CO2 emissions from 2015 to 2050 under the current policies scenarios (CP-EI and CP-EI-GR), results from PROMETHEUS and GCAM models

The impact of recovery funding on emissions is more pronounced in PROMETHEUS, with a reduction of global emissions by 5% compared to CP-EI, while GCAM demonstrates a marginal 1% decrease due to green recovery funding. The difference between CP-EI and CP-EI-GR is more pronounced in PROMETHEUS, indicating a model-specific response to the influence of recovery funding on emission levels in both supply and demand-side emissions.

3.4.1.1 CO_2 Emissions from energy supply

The model-based analysis reveals large differences across the IAMs with regard to their projections for supply-side emissions in the Current Policy setting. While PROMETHEUS and GCAM show that in the CP_EI scenario global supply-side CO_2 emissions will remain relatively constant until 2040 and slightly decline after 2040, the TIAM model shows a large reduction starting already from 2025 onwards. This is most probably due to more optimistic assumptions for the cost and upscale potential of low-carbon technologies for electricity generation (in particular, solar PV and wind power). In the GCAM and PROMETHEUS models, the large increases in total electricity requirements offset most of the emissions intensity improvements driven by the deployment of solar PV and wind power resulting in limited changes in global supply-side emissions (Figure 12).

The inclusion of green recovery packages results in a reduction of global CO_2 supply-side emissions in all models relative to CP_EI scenario driven by the accelerated deployment of low-carbon technologies globally, especially variable renewables, combined with battery storage (as part of the green recovery package). In the PROMETHEUS and GCAM models, this reduction is relatively limited in CP_EI, ranging between 100-200 $MtCO_2$ in GCAM and 200-450 Mt in PROMETHEUS over the 2020-2050 period. This is a result of two contradictory trends: on the one hand, recovery packages induce accelerated uptake of renewable energy replacing fossil-fired power generation and reducing electricity-related emissions; on the other hand, recovery packages also support the electrification of end-uses, predominantly in the transport sector (electric vehicles) and in buildings (via heat pumps). This results in higher electricity requirements and thus higher emissions, as in the current policy context fossil-based generation still plays a significant role. The net result of these trends is a limited reduction in supply-side CO_2 emissions globally as projected by PROMETHEUS and GCAM, as well as by TIAM until 2040. However, post-2040 TIAM shows very large supply-side emissions cuts, even projecting that the global electricity sector can become carbon-neutral by 2050 in the absence of strong climate policies and net-zero targets. This suggests that in the TIAM model recovery funding plays a significant role in driving supply-side emissions reductions, in contrast to the results of other models.

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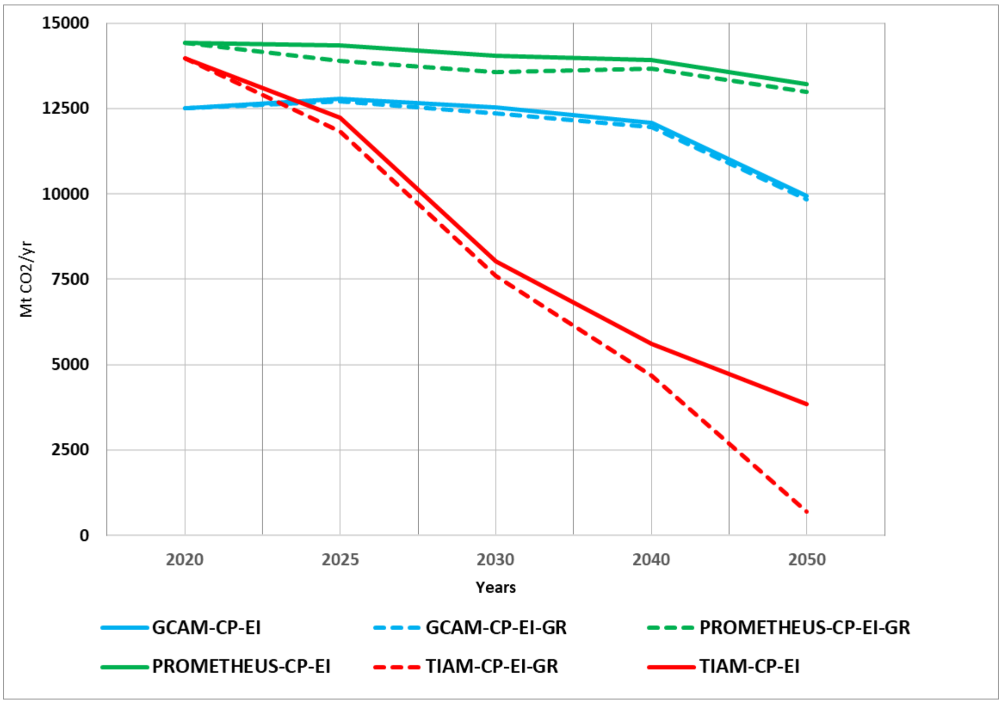

Figure 12: Energy related CO2 emissions from energy supply from PROMETHEUS, GCAM, TIAM models under the current policy scenario variants with and without the recovery funding over 2020-2050 period

A large part of the recovery funding is strategically directed towards investments, technologies and policies specifically targeting emission reductions from electricity generation, as this was deemed as a key low-cost transformational option. However, unless combined with high carbon pricing and sustained ambitious climate policies, the effectiveness of such investment can be limited, especially in the context of increased electrification of end-uses.

3.4.1.2 CO2 Emissions from energy demand sectors

The sectoral energy demand modelling results, as depicted in Figure 13, reveal distinct trends across models and scenarios. The addition of green recovery packages in the current policy scenarios drives a reduction of CO_2 emissions from energy demand sectors (transport, buildings, industries) as a result of the additional investment in energy efficiency and in low-carbon transport solutions included in the recovery packages presented in Section 2. This results in reduced energy consumption due to additional energy savings realised through the recovery investment, but also fuel shifts towards low-carbon fuels, especially electricity replacing the consumption of fossil fuels, as a large part of the recovery packages is dedicated to supporting the uptake of electric vehicles and heat pumps.

The magnitude of the projected impacts of the green recovery packages differs across models. TIAM and PROMETHEUS show a similar short-term impact, with demand-side emissions decreasing by 4%-6% in CP_EI until 2030 due to the investment and subsidisation for energy efficiency interventions and electrification. However, the behaviour of the models differs post-2030, as demand-side emissions reductions are projected to continue and even accelerate in PROMETHEUS as a result of the endogenous technology dynamics included in the model that reduce the costs and enhance the uptake of low-carbon technologies; on the other hand, both GCAM and TIAM show limited emissions reductions.

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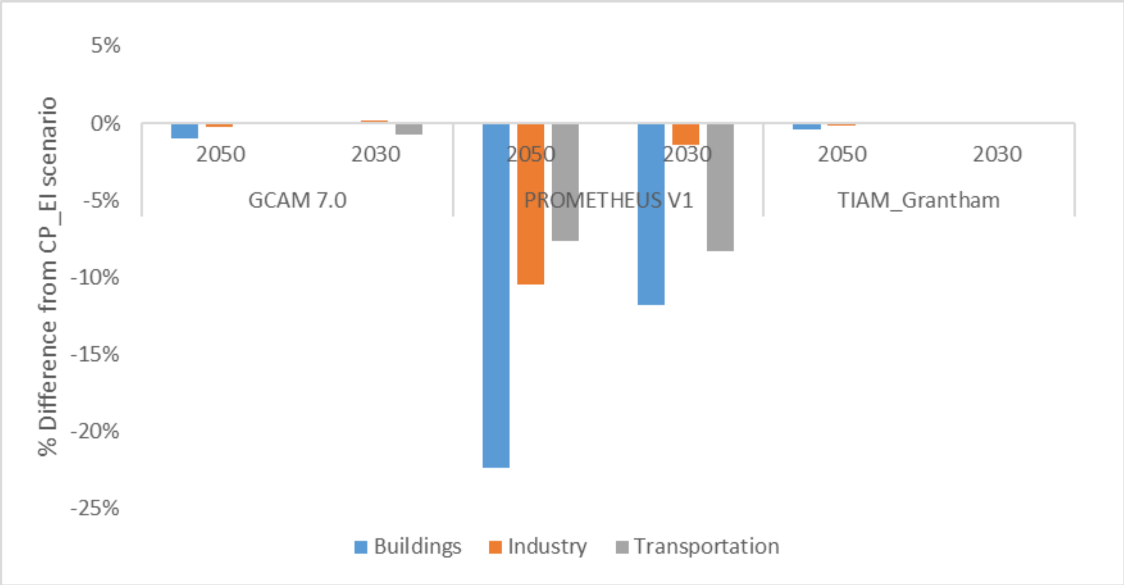

Figure 13: Impacts of green recovery packages in global CO2 emissions in main demand sectors in 2030 and 2050 based on the results of PROMETHEUS, GCAM and TIAM models

The impacts of green recovery packages also differ by sector. As a result of the higher flexibility and the representation of multiple technological options in (e.g., heat pumps, renovation strategies, EVs by transport segment), the emission impacts are higher in PROMETHEUS compared to other models, especially in the building and transport sectors. The endogenous technology dynamics in PROMETHEUS result in improved cost competitiveness and enhanced uptake of low-carbon and energy-efficient technologies even after the imposition of the recovery packages and thus emission impacts are somewhat higher than short-term impacts. In contrast, the implementation of recovery packages in GCAM results in very limited reduction of demand-side emissions in all end-use sectors; this signals the different behaviour of GCAM with regard to recovery funding impacts on the demand vs. supply sectors (with much larger impact in the latter sector).

The insertion of recovery funding would result in emissions reductions in all energy demand sectors, but the magnitude of these impacts depends on the specific model, ranging from negligible impacts in GCAM to about 4% in TIAM and 10% in PROMETHEUS. Buildings and industry appear to have the more pronounced impact in terms of emissions cuts, while emissions impacts are modest in transport despite the large allocation of recovery funding to electric cars. This shows that road transport decarbonisation is only part of the required transformation of transport and green recovery funds should target other transport segments as well (e.g., aviation, shipping, trucks, urban transport).

3.4.2 Impacts on final energy demand

In the absence of strong climate policies, GCAM, TIAM, and PROMETHEUS alike project that global final energy consumption will moderately increase by around 20%-27% in the period 2020-2050 in the CP_EI scenario triggered mostly by the growth in developing countries driven by GDP and income growth, increasing population, and rising standards of living. The green recovery funds include investments directed towards energy efficiency in buildings, industries, and transport combined with support for more energy efficient technologies and fuels (e.g., electric vehicles instead of conventional ICEs, heat pumps instead of fossil-based boilers). This would result in reduced final energy consumption globally, but the three models differ on the projected magnitude, with PROMETHEUS showing the largest impact (a 3-4% reduction in global final energy consumption from CP_EI levels). This indicates that recovery funding plays a role in moderating energy consumption, with potential efficiency gains and shifts in the energy mix towards low-carbon options. However, the reduction is more limited in GCAM (less than 1%) as this model lacks a detailed representation of energy efficiency strategies, including

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the renovation of buildings to improve their thermal insulation. TIAM shows a different trend compared to the other two IAMs, with final energy consumption increasing in the CP_EI_GR compared to the CP_EI scenario, especially in the longer term (2050). In the TIAM model, the addition of the green recovery packages would reduce electricity costs and trigger the increased uptake of Direct Air Capture to remove emissions, which however increases the final energy consumption.

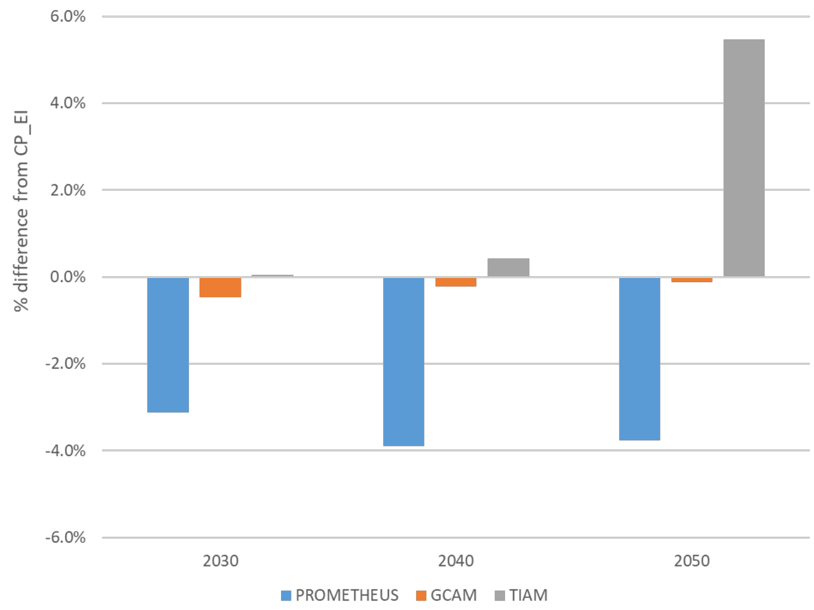

Figure 14: Changes in global energy consumption in the CP-EI-GR compared to CP_EI in 2030; modelling results from PROMETHEUS, GCAM and TIAM.

Current policies combined with a constantly increasing economic activity lead to an increase in global final energy consumption, mostly driven by rising living standards in the developing economies. The implementation of recovery packages (CP-EI-GR scenario) moderates this increase, suggesting energy efficiency gains and shifts in energy sources (towards electrification) mostly in the PROMETHEUS model with more limited impacts in GCAM and TIAM. These varied model responses underscore the complexity and model-specific considerations in assessing the impact of green recovery funding on energy consumption, including the potential for rebound effects.

3.4.2.1 Energy consumption by fuel

In the context of current policies, the models project shifts in the fuel mix used to cover energy demand requirements globally. The models agree on the basic trends in the CP_EI scenario, with an increasing contribution of electricity in final energy mix, due to the accelerated electrification of energy uses in buildings, transport, and industries. On the other hand, the share of solids and liquids in global final energy consumption is projected to decline as a result of climate policies (including carbon pricing) and their replacement by less carbon-intensive fuels and technologies, including gases and electricity. There are certain differences across models, with e.g. TIAM showing a similar increase in gases and electricity while both PROMETHEUS and GCAM project a higher uptake of electricity. The divergence in final energy trends underscores the complexity of model-specific consideration and assumptions, emphasizing the need for a thorough understanding of each model's intricacies.

As green recovery packages include investment in boosting the uptake of new, efficient, and low-carbon options (e.g., electric vehicles), the three IAMs project changes in the global final energy mix. The largest changes are shown by PROMETHEUS with increased deployment of electricity to cover energy requirements in the transport, building, and industrial sectors. In the CP_EI_GR scenario, accelerated electrification replaces the use of fossil fuels, with largest impacts for gas consumption that is projected to decline by around 10%-15% relative to CP_EI

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levels by 2050. This showcases a shift toward cleaner and more sustainable energy sources, involving a greater reliance on renewable-based electricity. The GCAM model shows relatively similar effects to PROMETHEUS, with reduced consumption of solids, gases, and liquids compared to CP_EI, albeit at a lower magnitude. On the other hand, TIAM shows that the insertion of green recovery funding would increase the consumption of gases and electricity with marginal impacts for solids and liquids. The increase in heat consumption is related to increased energy use for Direct Air Capture that is massively deployed in the CP_EI_GR scenario of TIAM.

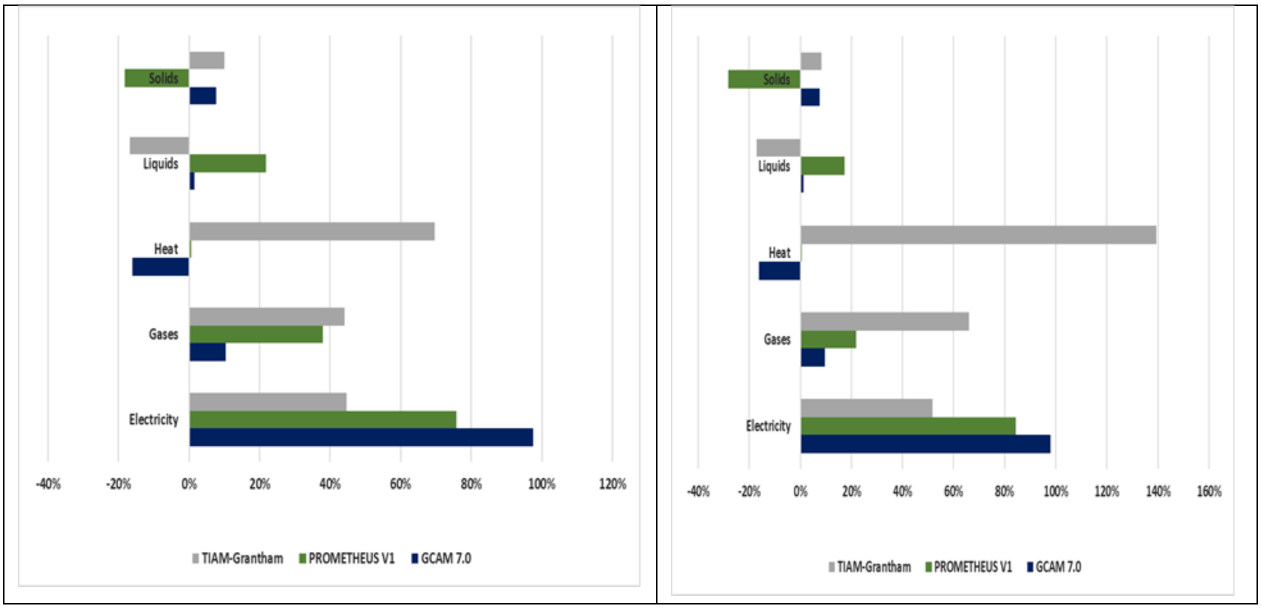

Figure 15: Changes in energy consumption by fuel in 2050 compared to 2020 in CP_EI (left) and CP_EI_GR (right) scenarios projected by PROMETHEUS, GCAM and TIAM models.

In the context of current policies, the models project shifts in the fuel mix used to cover energy demand requirements globally, with electricity and gas playing an increasingly important role, replacing the use of carbon-intensive fuels like coal and petroleum products. The imposition of green recovery packages would lead to accelerated electrification of the final energy mix and a shift to cleaner energy sources to the detriment of fossil fuels, especially in PROMETHEUS and GCAM. On the other hand, gas continues to play an important role as the "transition fuel" in TIAM results. The overall differences across models highlight the need for a multifaceted approach, suggesting that recovery funding alone might not be sufficient to accelerate climate action and address diverse energy challenges.

3.4.2.2 Energy consumption by sector

As observed above, PROMETHEUS shows the largest impacts of the green recovery packages in energy consumption across all demand sectors (buildings, transport, industries), as shown in Figure 16. In this model, the imposition of green recovery packages moderates energy demand growth in CP_EI across sectors, with larger impacts in the buildings and transport sector partly due to the uptake of energy efficient electrification technologies (electric cars, heat pumps). This is in line with GCAM projections showing that these two sectors experience the largest reduction in energy consumption, while the green recovery packages have a limited impact on the industrial sector.

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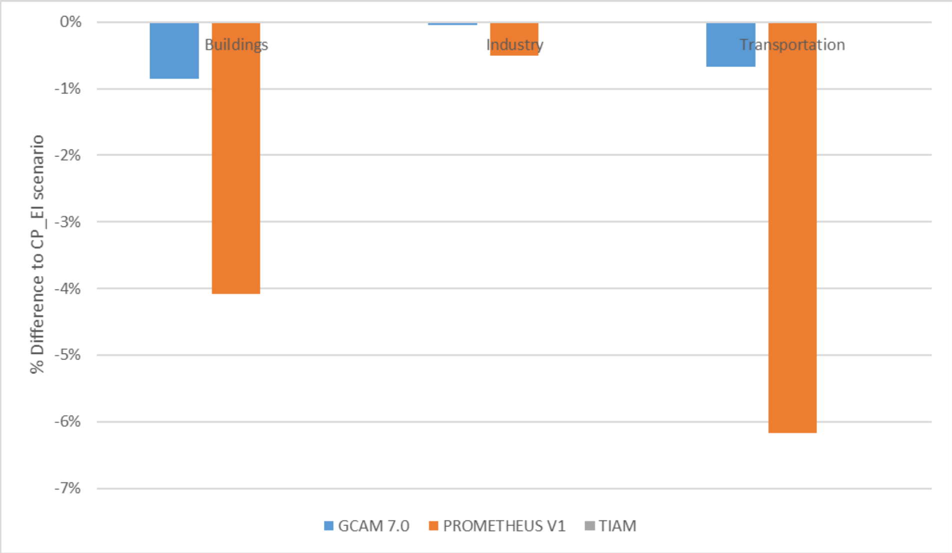

Figure 16: Changes in energy consumption by sector in 2030 in the CP-EI-GR scenario compared to CP_EI, PROMETHEUS, GCAM and TIAM results

The above results indicate that recovery funding plays a significant role in moderating energy consumption increases, particularly in PROMETHEUS, across all end-use sectors (transport, buildings, industries), but also in GCAM and TIAM, albeit at lower extent. This is due to increased energy efficiency investment and uptake of more efficient fuels and technologies, in particular EVs and heat pumps.

3.4.3 Focus on selected major emitters

3.4.3.1 CO_2 Emissions

Here, we offer a detailed analysis of the implications of green recovery packages for major emitters, including China, India, and the EU. Starting with China, the GCAM and PROMETHEUS models agree that the implementation of current climate policies would lead to a relative stabilisation of Chinese CO_2 emissions in the period to 2030, followed by a moderate decline until 2050; overall, the models show that in the CP_EI scenario CO_2 emissions in China would decline by 17-24% in 2050 compared to 2015 levels indicating sustained (but limited) progress towards decarbonisation, which is however insufficient to align with the Paris Agreement temperature goals. The insertion of the recovery packages (CP_EI_GR scenario) leads to a further reduction of China's CO_2 emissions from CP_EI levels indicating a decline of 18-27% over the 2015-2050 period. This is triggered by additional investments in renewable energy such as solar, wind, and hydropower, in energy efficiency in end-use sectors, in the uptake of electrification, and an overall shift away from fossil fuels to cleaner energy sources.

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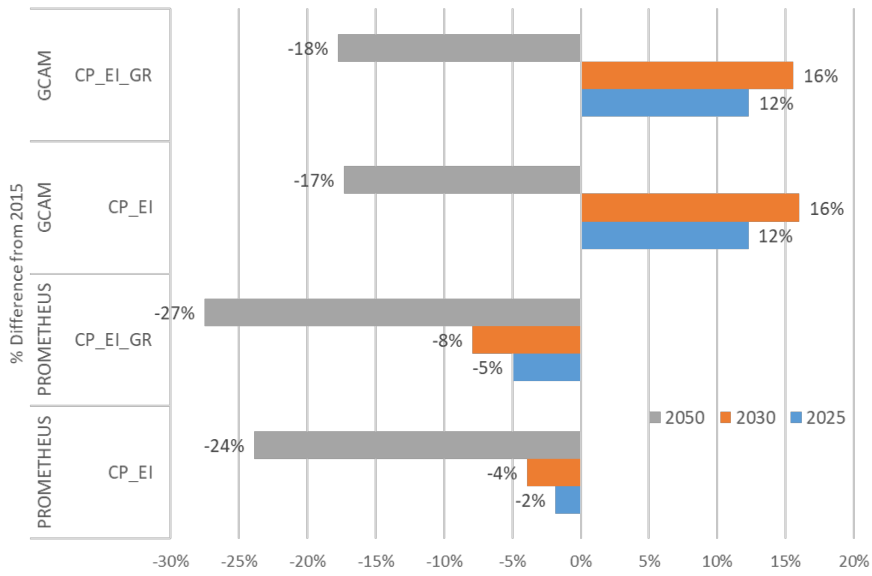

Figure 17: CO2 emissions in China under the CP-EI and CP-EI-GR scenarios over 2015-2050, PROMETHEUS and GCAM modelling results

In the CP_EI scenario, the GCAM and PROMETHEUS models show a constant increase in India's CO_2 emissions largely driven by the high GDP and population growth, increased urbanisation and rising standards of living, increasing emissions especially from the transport sector. In this scenario, CO_2 emissions in India would increase by 58-83% in 2030 and by 100-136% in 2050 relative to 2015 levels. The implementation of the green recovery packages would lead to a relatively large CO_2 emissions reduction in India from CP_EI levels, especially in PROMETHEUS, moderating the emissions increase projected under current climate policies, while the impact projected by GCAM is less pronounced. This is a result of the large recovery funding—relative to India's GDP—directed towards low-emissions transport (e.g., uptake of electric vehicles and public transport) and the upgrade of the power grid to reduce grid losses and support the accelerated development of variable renewable energy technologies, in particular solar PV and wind.

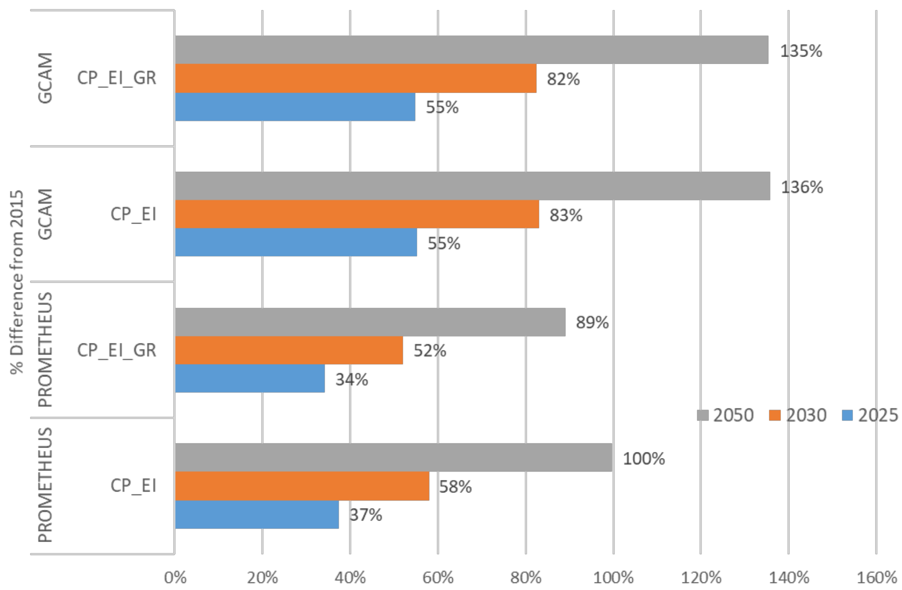

Figure 18: CO2 emissions in India under the CP-EI and CP-EI-GR scenarios from 2015-2050, PROMETHEUS and GCAM modelling results

A different situation is projected for the EU. The bloc has already adopted ambitious climate policies, aiming to

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achieve a 55% reduction in GHG emissions in 2030 relative to 1990 through various legislative policy packages and directives (e.g., related to the EU ETS, the Energy Efficiency Directive, the Renewable Energy Directive, the CO_2 standards for transport, etc.). Therefore, in CP_EI, both GCAM and PROMETHEUS project a large reduction in EU emissions in 2030 [- 40-51%] paving the way towards deep decarbonisation by 2050 with EU CO_2 emissions declining by 89-93% from 2015 levels. The addition of the green recovery packages further accelerates the emissions reduction, with EU CO_2 emissions declining by an additional 1-3% from CP_EI levels. This indicates that green recovery funds can further accelerate the EU's mitigation efforts via accelerated deployment of renewable energy, electrification of transport and heating, and energy efficiency improvements. The effect of recovery packages declines in the longer run as the ambitious efforts are the main driver for the EU's transition pathways.

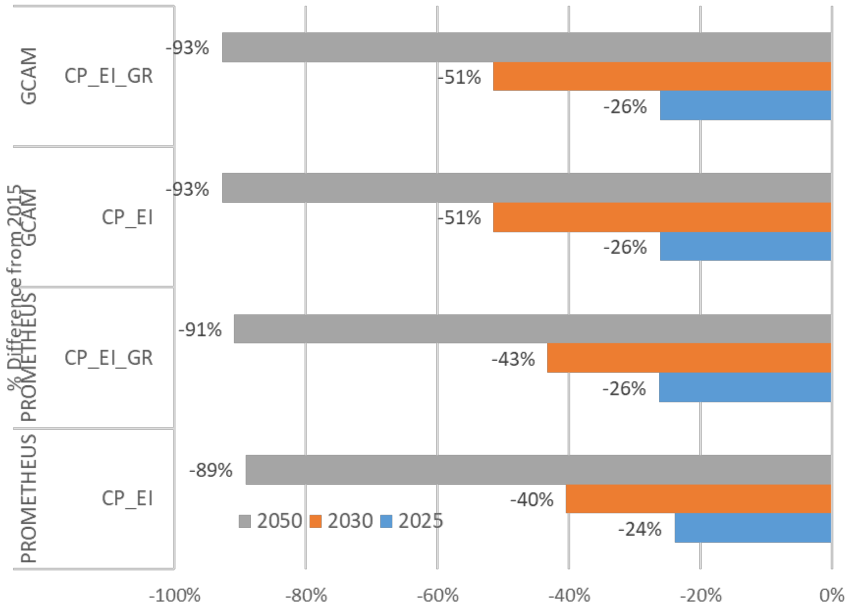

Figure 19: CO2 emissions in the EU under the CP-EI and CP-EI-GR scenarios from 2015-2050, PROMETHEUS and GCAM modelling results

The effectiveness of recovery packages varies among regions and models and depends on the underlying emissions reduction strategies and current policies included in the CP_EI scenario. The implementation of green recovery packages would result in a moderation of CO_2 emissions growth in India under current climate policies driven by additional investment in low-carbon transport and in the upgrade of electricity grids to support the uptake of solar PV and wind. In China and the EU, the insertion of green recovery packages reduces further CO_2 emissions below CP_EI levels mostly as a result of increased electrification and deployment of renewable energy.

3.4.3.2 CO_2 Emission Dynamics: Perspectives from Supply and Demand side

The PROMETHEUS model under the CP_EI scenario projects a reduction of China's CO_2 emissions over 2015-2050, from both energy demand (by 21%) and supply (by 16%), suggesting that the country is implementing measures to reduce the overall demand for energy and support the deployment of cleaner energy sources. The introduction of recovery funding in the current policies scenario variant (CP-EI-GR) deepens this reduction from demand and supply side to 22% and 17% respectively. In contrast, under current policies India's CO_2 emissions are projected to increase in both energy supply and energy demand, indicating a constantly increasing energy consumption to meet the growing needs of India's population with a strong reliance on carbon-intensive energy sources (e.g., coal used for power generation, oil products for transport); these increases are somewhat moderated by the introduction of green recovery funds signalling a shift toward cleaner energy forms, which is projected to be larger in PROMETHEUS than in GCAM and TIAM. In particular, as analysed above, GCAM shows an overall smaller emissions impact of the green recovery packages in energy demand and supply sectors alike.

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In contrast, in TIAM green recovery packages influence mostly emissions from the supply side (i.e., emissions from electricity production) as this model does not represent the multitude of demand-side mitigation options and energy efficiency investments that is available in other models such as PROMETHEUS.

The EU as a leader in global clean energy transition with already ambitious climate policies in the CP_EI scenario achieves very large emission reductions both in energy demand and in energy supply sectors by 2050 compared to 2015 levels, which are further accelerated in the CP_EI_GR scenario. This indicates that the addition of green recovery funding can accelerate emissions reductions especially in the short- and medium-term as a result of successful implementation of energy efficiency measures, electrification of transport and heating, and the uptake of clean energy technologies, including solar PV, onshore and offshore wind, but also battery storage and hydrogen.

The role of green recovery packages differs by region. While in India, they play an important role to moderate the projected emissions growth both from energy demand and energy supply sectors under current policies, their role in China is to accelerate the projected demand and supply-side emissions reduction through energy efficiency improvements, uptake of renewable energy, and electrification of heating and transport uses. As the current policies are very ambitious in the EU and drive a near-complete decarbonisation by 2050, the impact of green recovery packages is somewhat limited with strong climate policies being the main driving force.

3.4.3.3 Final Energy

PROMETHEUS projects that China will increase its energy consumption by 11% in 2050 under the CP-EI scenario compared to 2020 levels. This increase will be moderated with the introduction of recovery funding (CP-EI-GR) resulting in a 6% increase by 2050. Energy consumption is projected to more than double in India over the 2015-2050 period driven by high GDP growth and rising standards of living that fuel demand growth from transport, buildings, and industries. The recovery packages will moderate this increase as a result of the deployment of more efficient, low-carbon technologies in the transport sector, and upgrade of power grids to reduce transmission and distribution losses. The EU is expected to reduce energy consumption levels already in the CP_EI scenario driven by the ambitious policies targeting energy efficiency, including the recast of the Energy Efficiency Directive; in this context, the introduction of green recovery funding under the current policies has only limited impacts on energy consumption in the EU. As analysed in sections above, the impacts of green recovery packages are consistently higher in PROMETHEUS, compared to the GCAM and TIAM models in all countries.

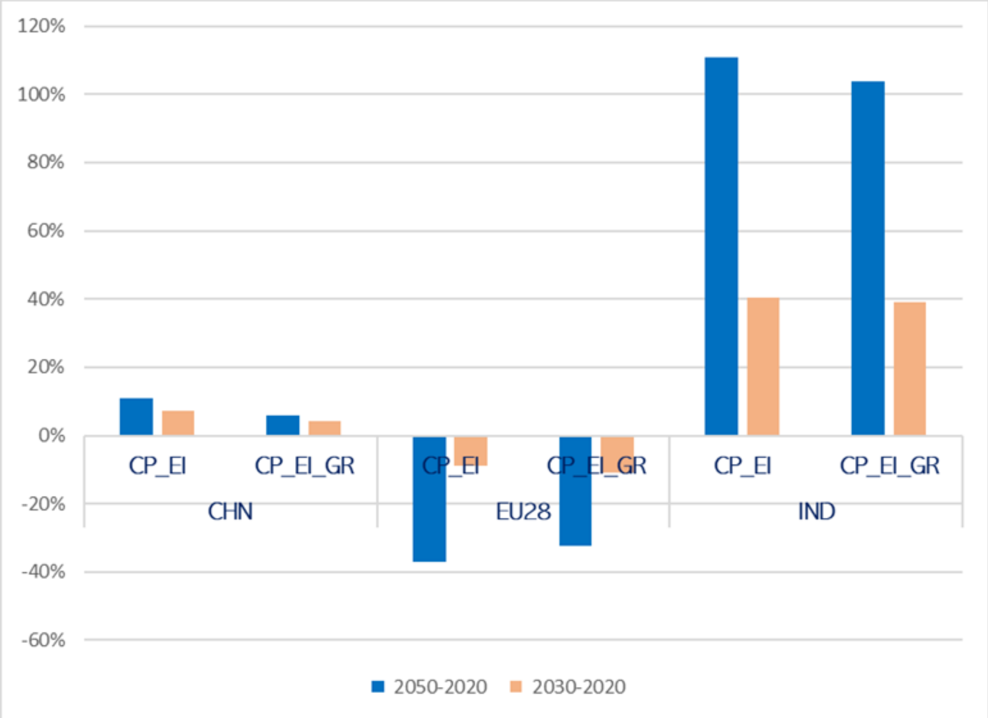

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Figure 20: Changes in energy consumption in 2050 and 2030 compared to 2020 levels under the scenarios CP-EI and CP-EI-GR, PROMETHEUS modelling results

GCAM mirrors PROMETHEUS with an 18% increase in final energy consumption for China by 2050 under the CP-EI scenario while the CP-EI-GR scenario does not affect this result. India's energy consumption as in PROMETHEUS modelling results is expected to more than double by 2050 compared to 2015 levels. Specifically, the energy consumption in India is expected to increase from a 46% by 2030 to about 100% by 2050 compared to 2020 levels. In the EU, the CP-EI scenario already triggers a decrease in energy consumption due to robust energy efficiency policies (-16% by 2050) but the subsequent introduction of green recovery funding minimally impacts EU's overall energy consumption which align with the results observed in the PROMETHEUS model.

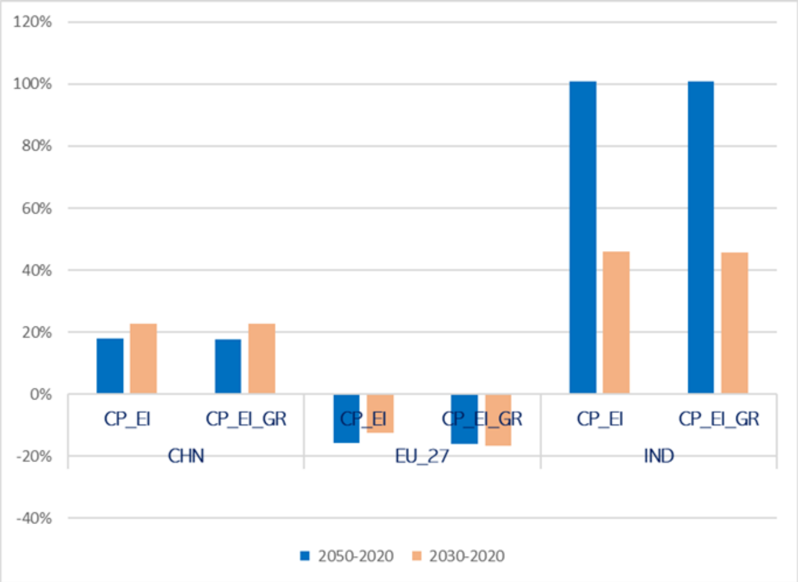

Figure 21: Changes in energy consumption in 2050 and 2030 compared to 2020 levels under the scenarios CP-EI and CP-EI-GR, GCAM modelling results

TIAM introduces a unique perspective for China, with a 13% increase by 2030 in energy consumption (compared to 2020 levels) under the CP-EI scenario followed by a decrease which reaches 7% by 2050. China, the world's largest energy consumer and biggest emitter of greenhouse gases, has a strategy that bring its total carbon emissions to a peak by 2030 and aims to be carbon neutral by 2060. For India (under the CP-EI scenario) TIAM anticipates a more tempered increase in consumption of energy which reach a 37% by 2030 and 69% by 2050 under its stated policy scenarios. The introduction of recovery packages further increases further the demand of energy by 41% by 2030 and by 76% by 2050. India's economic growth has been among the highest in the world over the last decades and each year adds a new city to its urban population. This involves vast construction of new buildings, industries, and new additional transportation networks (this also includes adding new electricity connections for 50 million citizens each year over the past decade). On the other hand, the EU is expected to reduce by 28% the energy consumption under the CP-EI scenario by 2030 while the introduction of recovery funding will not affect further this reduction. In contrast to previous modelling results, TIAM expects that by 2050 the introduction of recovery funding in the EU will increase by 24% its need for energy.

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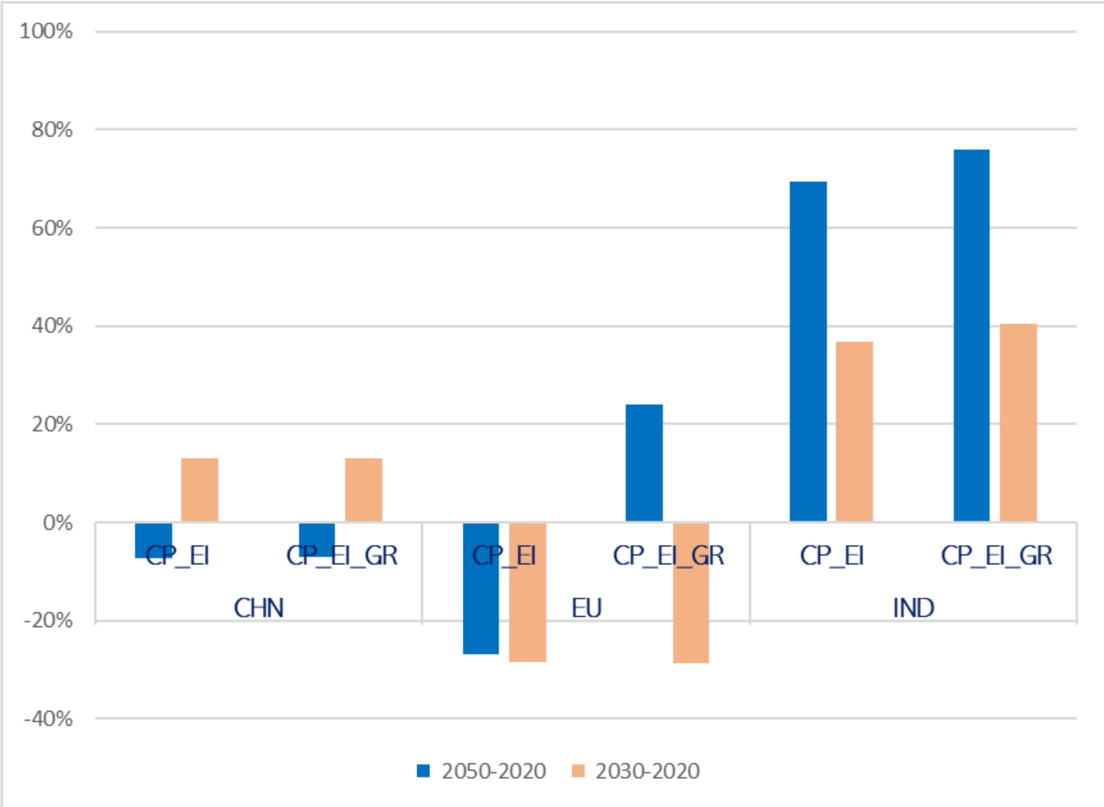

Figure 22: Changes in energy consumption in 2050 and 2030 compared to 2020 levels under the scenarios CP-EI and CP-EI-GR, TIAM modelling results

The introduction of green recovery packages is projected to moderate energy demand growth in China and India under current policies. This is a result of the introduction of more efficient, low-carbon technologies (e.g., electric vehicles) and accelerated uptake of renewable energy replacing fossil fuel-based power plants, supported by the upgrade of power grids. The green recovery packages have a more limited impact on EU energy consumption, which is mostly impacted by the ambitious energy efficiency policies included already in the CP_EI scenario. As analysed in sections above, the impacts of green recovery packages are consistently higher in PROMETHEUS compared to the GCAM and TIAM models in all countries.

3.4.3.4 Energy consumption by source

Under current policies, PROMETHEUS for the EU projects a significant shift away from coal use, which is gradually replaced by gases and electricity, while oil products see an increased consumption mostly to fuel the rapidly increasing mobility requirements. The CP-EI-GR scenario (Figure 23) would lead to reduced consumption of fossil fuels (solids, gases, liquids), combined with increased electricity use, especially in transport and buildings. Due to the high GDP growth under current policies, energy consumption is projected to drastically increase in India, but the growth would be mostly based on liquid fuels (used in transport) and electricity (used mostly in buildings). The demand growth of all fuels is moderated by the imposition of green recovery packages, except for electricity that increases its contribution to India's energy mix, due to the additional funding for low-carbon transport and electric vehicles. In contrast, the EU would reduce its consumption of fossil fuels already in the CP_EI scenario, while a further decline is projected with the introduction of green recovery packages, with the exception of electricity use that is pushed upwards, due to the additional funding for electric vehicles and electrification of heating.

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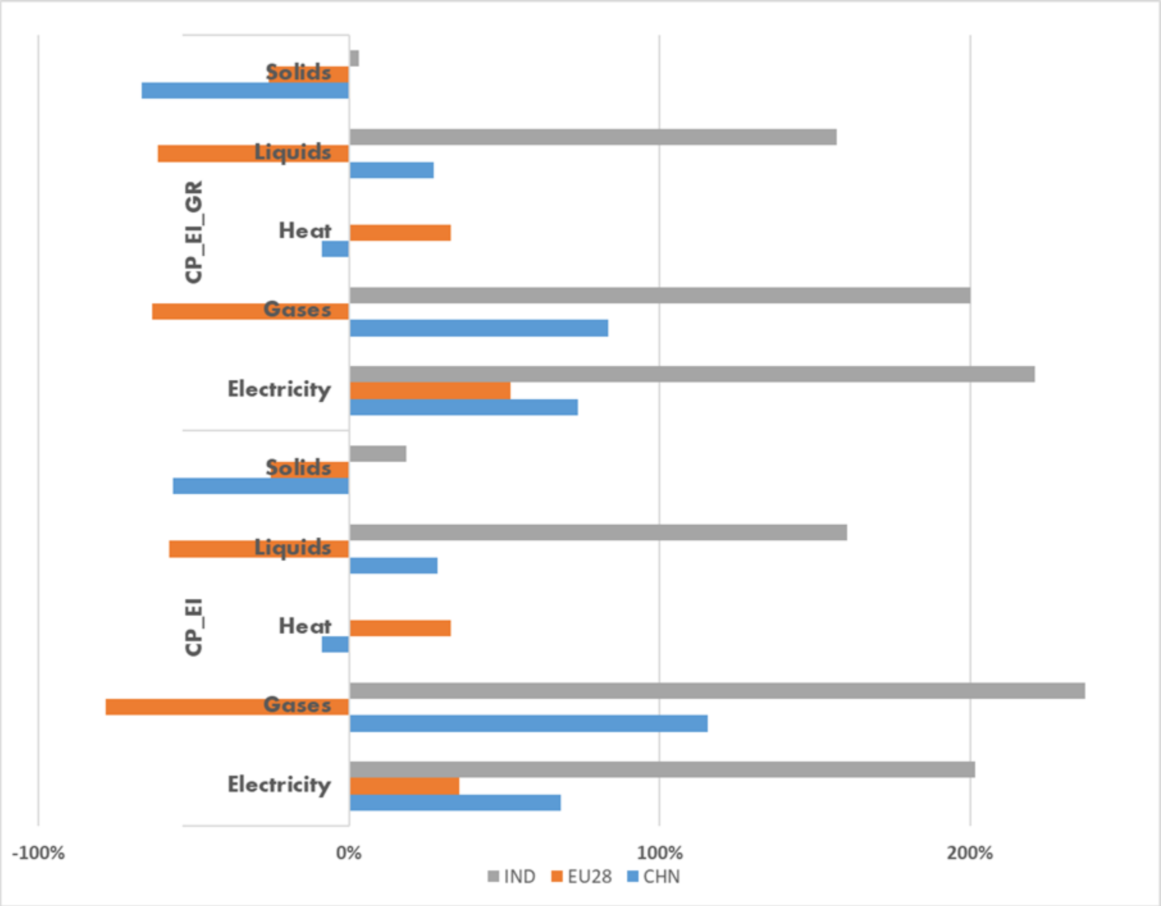

Figure 23: Changes in 2050 and 2030 compared to 2020 of fuel consumption in CP-EI-GR scenario and in CP-EI for the major emitters, results from PROMETHEUS model

GCAM shows that, under the CP-EI scenario, China will increase its electricity consumption by 48% in 2050 compared to 2020 levels due to the initiatives that promote electric vehicles and electric-powered appliances; while gases (gaseous fuels, natural gas) and liquids (oil) will increase by 60% and 26% respectively, while solids (coal) consumption will drop by 15% by 2050 indicating an effort to reduce the reliance on solid fuel and also decrease the use of traditional solid fuels for industrial and residential purposes (Figure 24). The introduction of recovery funding has only marginal impacts in the Chinese energy mix. In this model, the EU is expected to increase electricity consumption by 69% in 2050 compared to 2020 levels while the use of all fossil fuels (liquids, solids and gases) is projected to massively decline from current levels in the CP_EI scenario, while the impacts of green recovery packages is very limited on the EU's energy mix. Indian's energy need (under current policies) for electricity and gases will expand by 2050 compared to 2020 due to the increased urbanisation and industrial growth which lead to an increased demand for electricity in urban areas and industrial processes.

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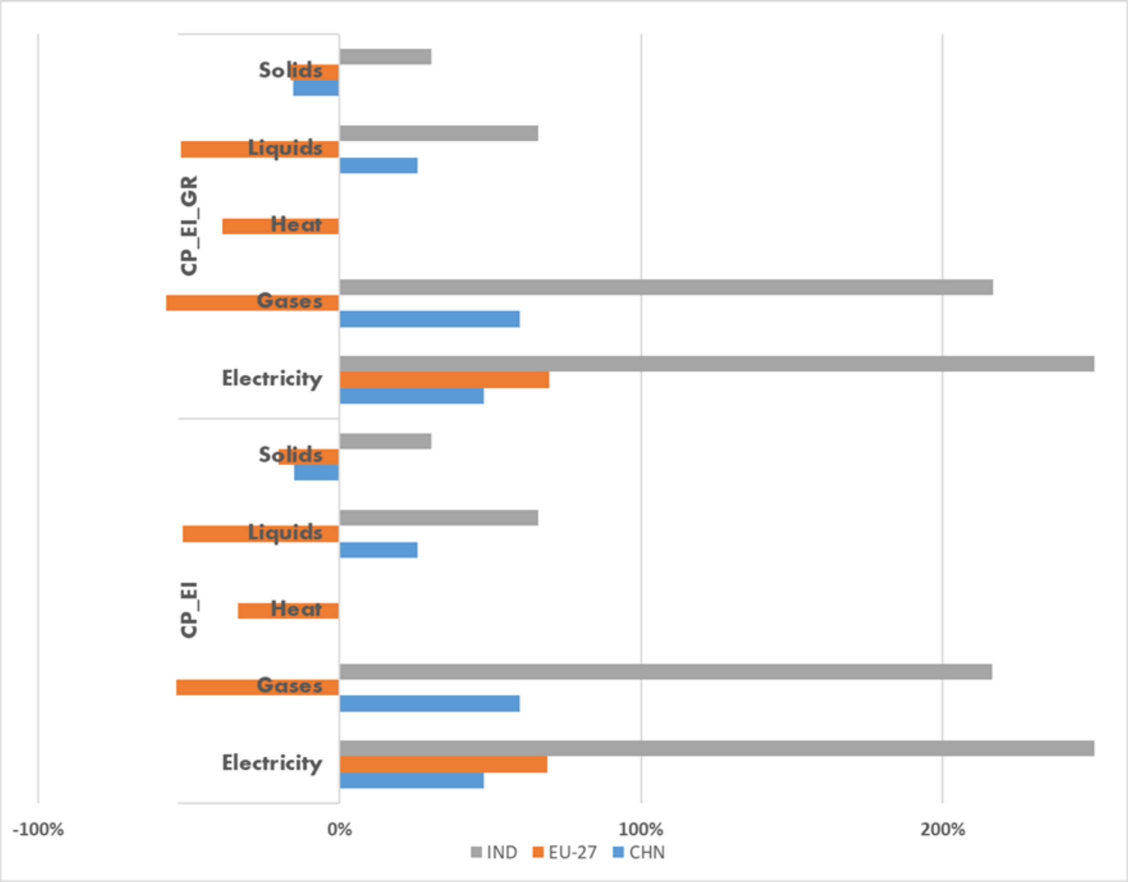

Figure 24: Changes in 2050 and 2030 compared to 2020 of fuel consumption in CP-EI-GR scenario and in CP-EI for the major emitters, results from GCAM model

The TIAM model shows that, under the CP-EI scenario, China's consumption of solids and gases will decline by 33% and 42% respectively over the 2020-2050 period due to the measures for improving industrial efficiency and promoting cleaner technologies (renewable energy and natural gas), while electricity and liquids will experience limited increases (14% and 3% respectively) driven by the growing investments in renewable energy sources (solar, wind, etc) and the overall economic growth of the country (that leads to higher mobility). The insertion of green recovery funding will affect slightly China's energy mix indicating large similarities between CP_EI_GR and the CP_EI scenario. India is projected to increase the consumption of both fossil fuels and electricity in the 2020-2050 period in the CP-EI scenario, while the insertion of green recovery funding in the CP-EI-GR scenario will have very limited impacts on the country's energy mix, when compared to the CP_EI scenario.

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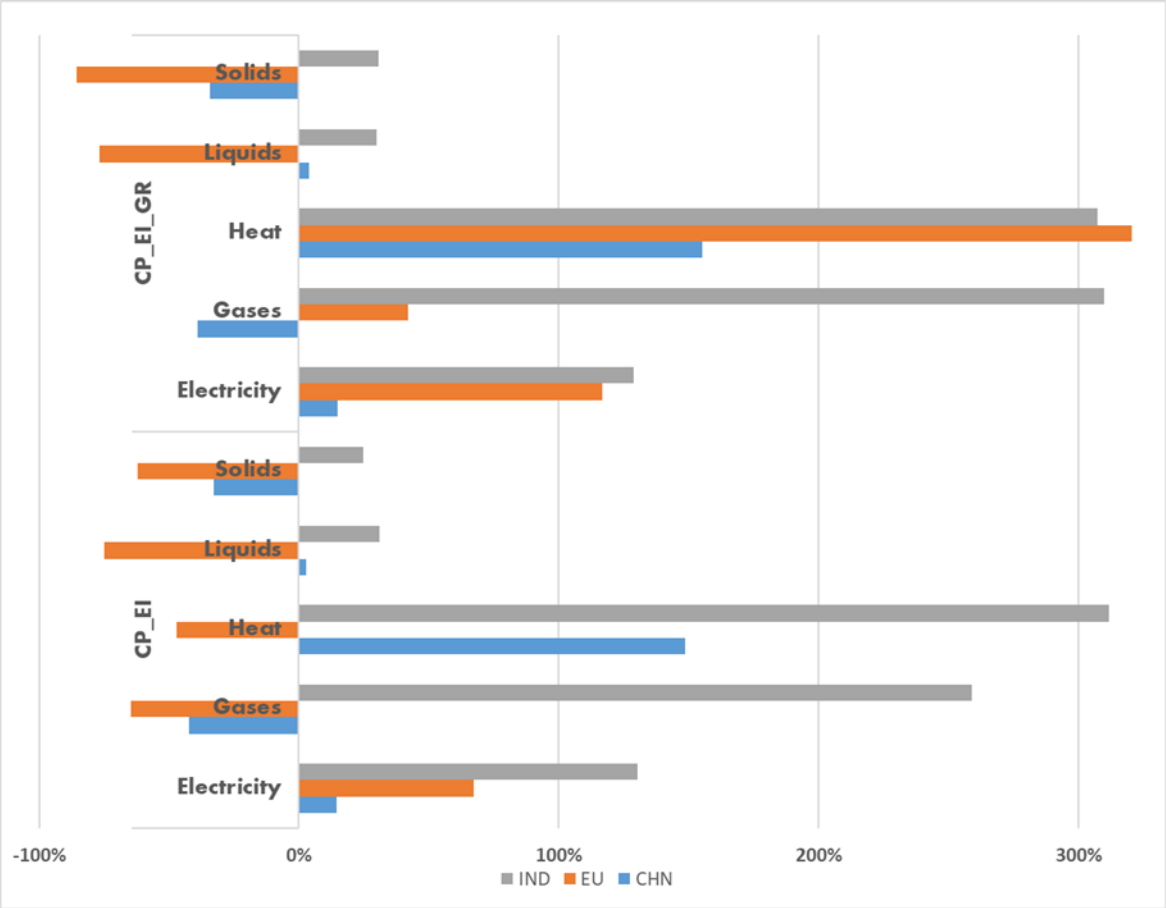

Figure 25: Changes in 2050 compared to 2020 of fuel consumption in CP-EI-GR scenario and in CP-EI for the major emitters, results from TIAM model

The variations in fuel mix among regions stem from the diverse economic structures, policy priorities, environmental considerations, fuel costs, and technological capabilities. While green recovery packages can lead to fuel shifts away from carbon-intensive and inefficient fossil fuels and towards higher uptake of electrification, they are not enough to induce transformative changes in the energy system of major emitters (China, India, the EU) required to meet the Paris Agreement climate goals. To do so, green recovery packages should be accompanied by sustained and ambitious climate policies.

3.5 Results for NDC-LTT scenarios

In this section, we present the findings of our analysis on the projected emissions impacts of the green recovery packages in an ambitious climate policy context, with countries achieving their NDC targets for 2030 and their long-term low-emission strategies (including their net zero pledges, if in place) by 2050 or later. The analysis is based on the comparison of the NDC_LTT scenario with the NDC_LTT_GR scenario including the green recovery packages (as presented in Section 2) on top of the NDC and LTT trajectories of countries, as simulated with the global IAMs GCAM, TIAM, and PROMETHEUS. NDCs play a pivotal role in guiding countries towards achieving their climate objectives, while the LTTs provide a strategic vision for long-term low-emission sustainable development in a climate resilient context. By examining the outcomes of these scenarios through multiple models, we aim to explore the interplay between NDCs, recovery funding, and long-term sustainability, offering insights into the effectiveness of policy interventions and recovery packages on a global scale with a focus on selected major emitters.

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3.5.1 CO2 Emissions

In the NDC_LTT scenarios, global CO_2 emissions are projected to decline by 2050 driven by the imposition of NDCs and LTTs in major economies. GCAM and PROMETHEUS show a relatively similar behaviour with global CO_2 emissions declining by 14-17% in 2030, 43-44% in 2040, and further by 68-75% in 2050 compared to the 2015 levels. The addition of green recovery packages induces a further reduction of 1.5% in GCAM in 2025 and 2030, which is moderated in the longer run; the impact of green recovery packages is projected to be higher in PROMETHEUS with a further 3% reduction of global CO_2 emissions compared to the NDC_LTT scenario without the recovery funding. This is in line with the behaviour of the models in the current policy context, as analysed in the section above. It should be noted, however, that neither of these scenarios is compatible with the Paris Agreement goal to limit global warming to 1.5ºC by 2100 as the projected emissions reductions fall short of the corresponding target of reducing global emissions by 43% by 2030 and achieving net-zero emissions by mid-century (as indicated in the IPCC's AR6 report).

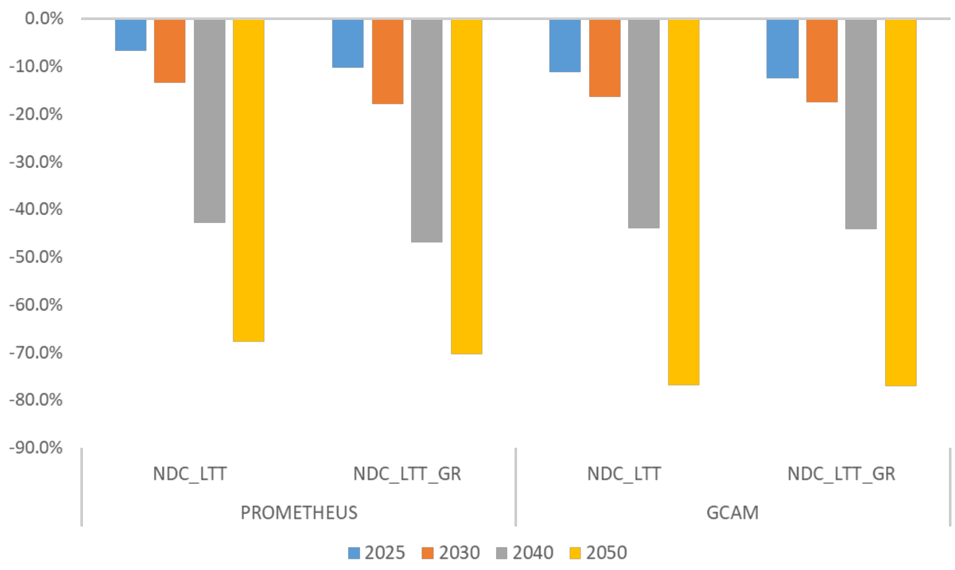

Figure 26: Changes in global CO2 emissions from 2015 to 2050 under the NDC_LTT scenarios, results from PROMETHEUS and GCAM models

The PROMETHEUS and GCAM models project rapid emissions reductions in the NDC-LTT scenarios with global CO_2 emissions declining by about 70-75% in 2050 compared to 2015. The addition of green recovery funds further accelerates the emissions reduction effort through rapid expansion of renewable energy, electrification of transport and heating uses and energy efficiency improvements. The impact of green recovery funding is consistently higher in PROMETHEUS compared to GCAM.

3.5.1.1 CO_2 Emission Dynamics: Perspectives from Supply and Demand side

The imposition of NDCs and long-term targets results in large emissions reductions both in the energy supply and energy demand sectors. PROMETHEUS, GCAM, and TIAM alike consistently show that the emissions reduction (relative to 2015 levels) is significantly higher in energy supply side than in energy demand. In fact, PROMETHEUS and TIAM project that global supply-side emissions will decline by 92-94% in 2050 induced by the large-scale uptake of low-carbon technologies, in particular variable renewables (solar PV and onshore and offshore wind) but also CCS technologies, biomass, nuclear, and hydro power, which massively replace fossil fired power plants. GCAM projections are even more ambitious, with supply-side emissions turning net negative by 2050 due to the emergence of CDR options, in particular BECCS. In contrast, PROMETHEUS and TIAM are more optimistic than GCAM with regard to demand-side emission reductions; these models show that global demand-side CO_2 emissions can reduce by around 50% in 2050 relative to 2020 levels induced by the accelerated electrification of transport and heating uses (based on renewable-based power), energy efficiency improvements in all demand

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sectors and the emergence of low-carbon fuels, including advanced biofuels and hydrogen. On the other hand, GCAM projects a 25% reduction in global demand-side emissions over the 2020-2050 period, as this model does not represent all demand-side mitigation options in all sectors and uses more conservative assumptions about the potential for energy efficiency improvements.

The introduction of green recovery packages would further accelerate the transformation both in energy demand and in energy supply sectors, leading to even high emissions reductions compared to the NDC_LTT scenario. The impacts of green recovery packages on supply-side emissions are larger in the TIAM model showing an enhanced uptake of BECCS and Direct Air Capture (DAC) generating net negative emissions, while these impacts are relatively small in PROMETHEUS and GCAM. PROMETHEUS and TIAM show that green recovery packages would result in larger demand-side emissions reductions compared to NDC_LTT scenarios, triggered mostly by the increased electrification of transport and heating uses, as a result of additional investments included in the recovery packages.

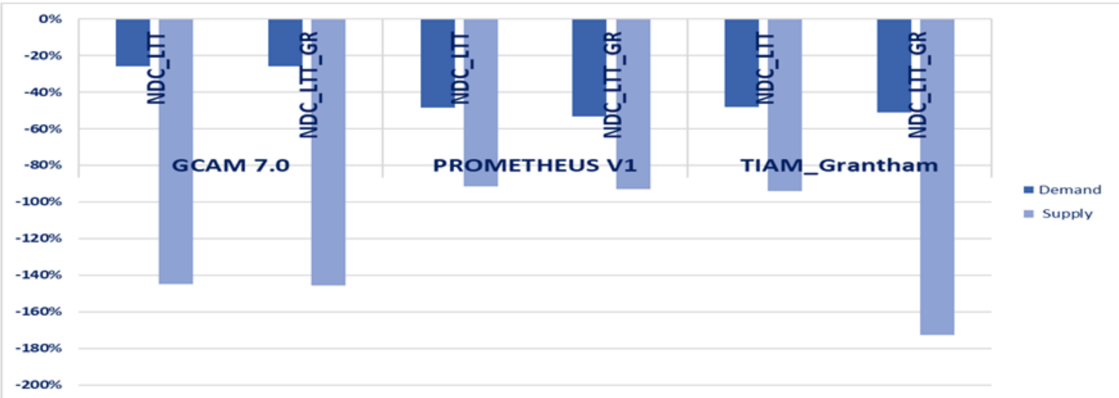

Figure 27: Changes in CO2 emissions in 2050 compared to 2020 from demand and supply sides in the NDC_LTT and NDC_LTT scenarios, results from the PROMETHEUS, GCAM and TIAM models.

The imposition of NDCs and LTTs results in large emissions reductions both in energy demand and in supply sectors, with reductions being more pronounced in the supply side triggered by rapid deployment of low-carbon and renewable energy technologies in the models. PROMETHEUS and TIAM are more optimistic with regard to demand-side emission cuts than GCAM; the latter shows a larger contribution by energy supply, which is projected to achieve net-negative emissions by 2050. The introduction of green recovery packages would further accelerate the transformation both in energy demand and in energy supply, leading to high emissions reductions compared to the NDC_LTT scenario.

3.5.1.2 Impacts on sectoral CO_2 emissions

In the NDC-LTT scenario, PROMETHEUS suggests that industry, residential and commercial, and transportation sectors would reduce their CO_2 emissions by 2050 due to the imposition of ambitious climate policies and long-term targets. Specifically, the CO_2 emissions in the industry, residential, and transportation sectors are projected to decline by 31%, 50% and 63% in 2050 relative to 2020, respectively. The addition of green recovery funding in the NDC-LTT-GR scenario achieves even higher emission reductions over the 2020-2050 period of 35%, 57%, and 67% from industry, buildings, and transportation, respectively, indicating the potential of green recovery funds to accelerate further the transformation of end-use sectors with higher deployment of electricity and clean fuels. This illustrates that, according to PROMETHEUS, the transport sector has the highest potential to reduce emissions mostly driven by the massive uptake of EVs, but also other clean fuels (advanced biofuels, hydrogen, e-fuels) in transport segments that are difficult to be electrified, such as aviation, shipping and freight trucks.

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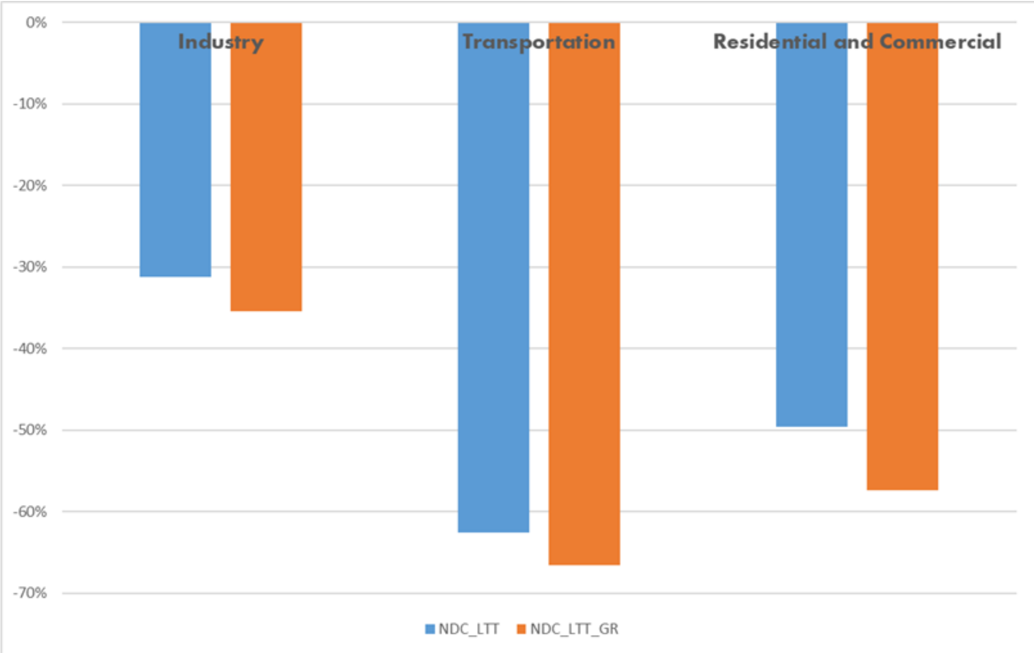

Figure 28: Changes in 2050 compared to 2020 levels by economic sector, under the NDC-LTT and NDC-LTT-GR, PROMETHEUS results

The GCAM model suggests that the NDC-LTT scenario will achieve emission reductions from industry, residential and commercial, and transportation sectors by 55%, 30%, and 16% respectively in 2050 compared to 2020 levels. Interestingly, GCAM that industry has the largest emission reduction potential, driven by the accelerated electrification of industrial processes and the emergence of green hydrogen in the steelmaking and chemicals sectors as well as the deployment of biofuels and CCS in industrial processes. The insertion of green recovery funding will have only limited effects in demand-side mitigation with emission levels in all end-use sectors projected to be similar to the levels of the NDC-LTT scenario.

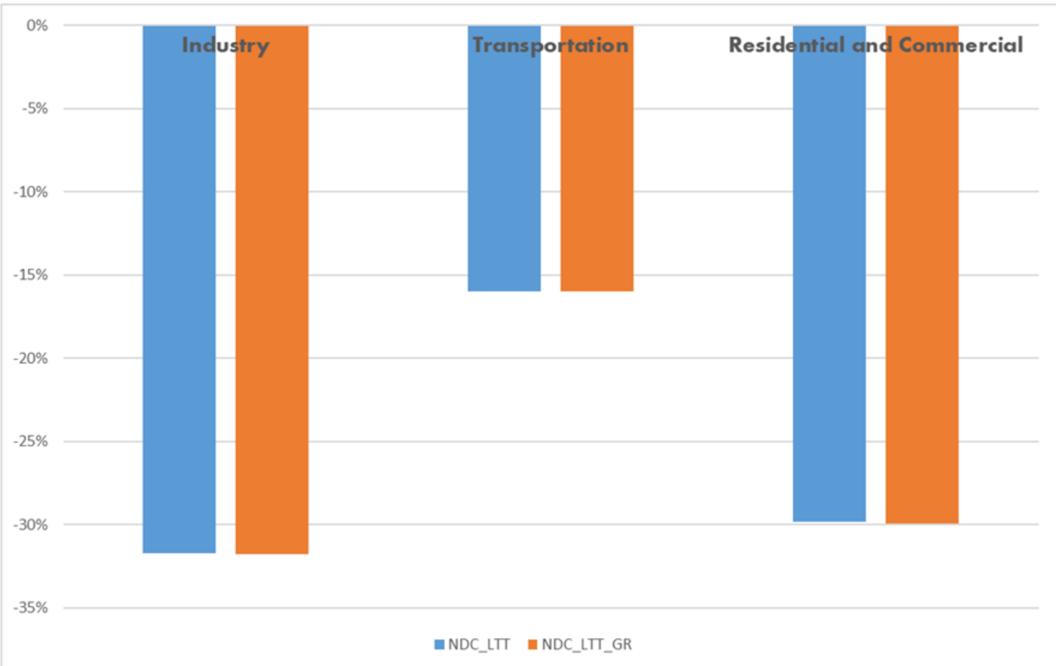

Figure 29: Changes in 2050 compared to 2020 levels by economic sector, under the NDC-LTT and NDC-LTT-GR, GCAM results

The TIAM model projects that global CO_2 emissions from the industry, residential and commercial, and transportation sectors would reduce by 60%, 27%, and 58% respectively in 2050 compared to 2020. Thus, TIAM agrees with PROMETHEUS on the high potential for emission reductions from the transport sector as a result of

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the massive deployment of EVs and the emergence of low-emission fuels (e.g., advanced biofuels, hydrogen). The introduction of recovery funding (NDC-LTT-GR) is expected to have limited impacts on demand-side emissions from all sectors relative to the NDC_LTT scenario projections.

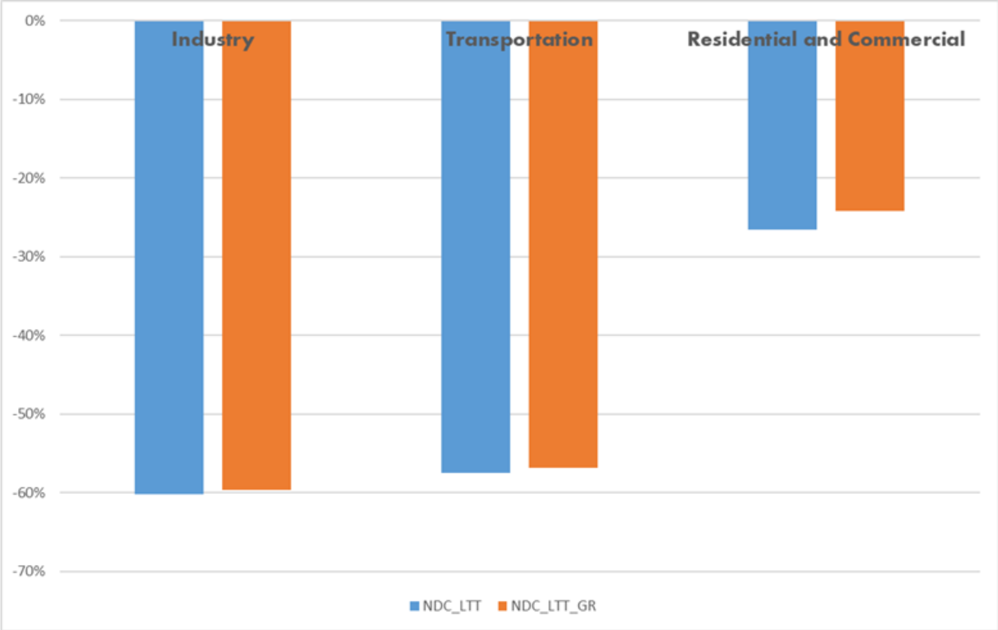

Figure 30: Changes in 2050 compared to 2020 levels by economic sector, under the NDC-LTT and NDC-LTT-GR, TIAM results

The NDC-LTT scenario would lead to large demand-side emissions reductions in the 2020-2050 period in all end-use sectors. The models disagree on which sector has the highest emissions reduction potential, with PROMETHEUS and TIAM showing largest reductions in the transport sector while GCAM and TIAM showing highest mitigation potential in the industry sector. The addition of green recovery funds would lead to somewhat stronger demand-side emissions mitigation in the PROMETHEUS model, while the impacts projected in other models are more limited.

3.5.2 Impacts on final energy consumption

The imposition of ambitious climate policies in the NDC_LTT scenarios would moderate the energy demand growth projected by the three IAMs in the CP_EI scenario. This is triggered by the increased investment in energy efficiency, the higher energy prices leading to reduced energy consumption, and the uptake of more efficient technologies and energy forms as a result of the long-term climate targets assumed in the NDC_LTT scenario. The introduction of green recovery packages in the NDC_LTT trajectory will influence the development of final energy demand leading to reduced energy consumption in transport, buildings, and industries (Figure 25). The largest impacts of green recovery packages is projected in PROMETHEUS as this model achieves a sustained energy demand reduction of about 2.5-3.5% in NDC_LTT_GR compared to NDC_LTT. In contrast, the green recovery impacts are projected to be more limited in GCAM, while TIAM shows even an increase in global final energy consumption relative to the NDC_LTT scenario. This is caused by the higher uptake of Direct Air Capture in TIAM (also visible in Figure 27) induced by the declining electricity costs, which however leads to higher energy consumption globally. This observed pattern, where green recovery impacts vary among models, underscores the complexity and model specific considerations in assessing the effectiveness of green recovery initiatives.

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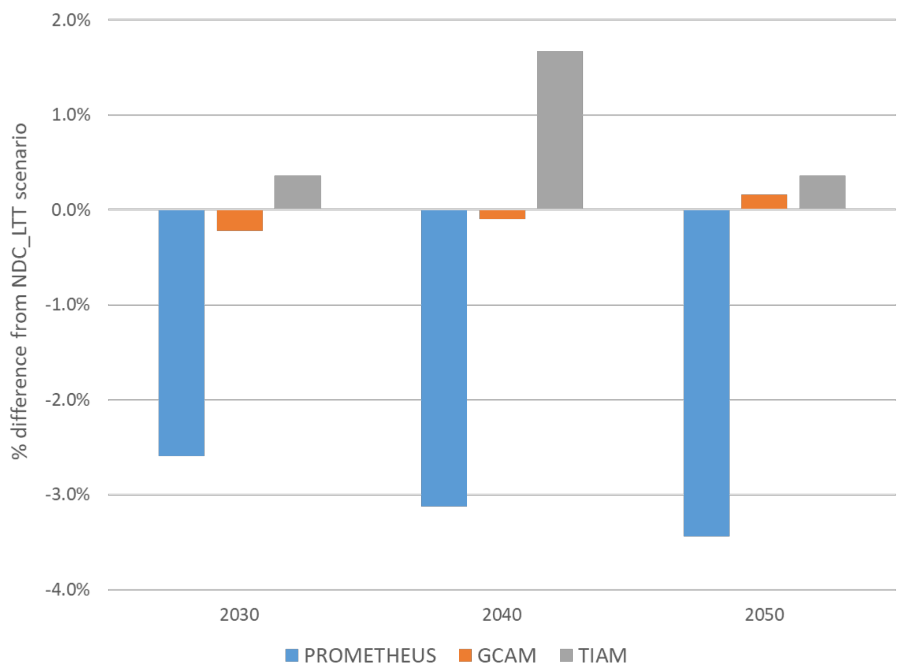

Figure 31: Changes in global energy consumption in the CP-EI-GR compared to CP_EI scenario in 2030, 2040, 2050 modelling results from PROMETHEUS, GCAM and TIAM models

The NDC-LTT scenarios lead to a decrease in final energy consumption across IAMs, emphasising the importance of energy efficiency and transitioning to more efficient energy sources. The imposition of green recovery packages would lead to further energy savings, especially in PROMETHEUS, which has more granular and detailed representation of demand-side mitigation options.

3.5.2.1 Energy consumption by source

In the NDC_LTT scenario, the PROMETHEUS model projects significant changes in the global energy mix, with bold reductions in the consumption of coal and liquids (petroleum products), which are replaced by the increased uptake of electricity and, to a lower extent, gases. The introduction of the green recovery funding has only modest impacts in the global energy mix, inducing a further reduction of petroleum products that are increasingly substituted by electricity in the transport sector (Figure 32) in the context of the NDC_LTT_GR scenario.

The imposition of ambitious long-term targets (NDC_LTT scenario) would lead to reduced consumption of all fossil fuels and heat in GCAM, which are replaced by increased electrification of end-use sectors. As expected, the insertion of green recovery packages would have very limited impacts on the projected energy mix in the GCAM model.

The TIAM model results for the NDC_LTT scenarios again differ compared to other models, projecting limited shifts in the global energy mix: electricity, gases and heat consumption are projected to increase from 2020 levels, combined with reductions in the consumption of carbon-intensive fossil fuels (coal and oil). The insertion of green recovery funding (NDC_LTT_GR scenario) accelerates the projected fuel mix changes, with gases and heat consumption declining from NDC_LTT scenario levels as a result of the transition towards cleaner energy forms.

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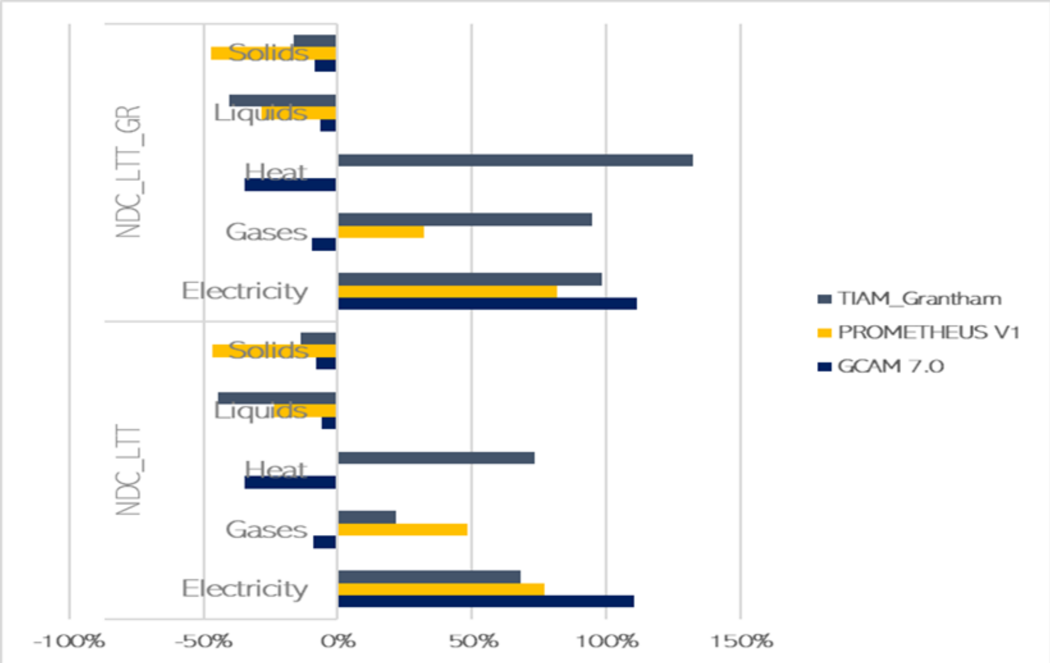

Figure 32: Changes in energy consumption by source under the NDC-LTT and NDC-LTT-GR scenarios (2050 compared to 2020 levels), results from PROMETHEUS, GCAM and TIAM

In the NDC_LTT scenarios, all models project changes in the global final energy mix, triggered by the reduced use of coal and oil products, which are replaced by the increased use of electricity and, to a lower extent, gases. The influence of green recovery packages varies among models, with GCAM showing very limited impacts in contrast to PROMETHEUS. While there are some common trends across models, the extent and nature of fuel consumption changes, as well as the impact of recovery funding, exhibit distinct characteristics across scenarios and models.

3.5.2.2 Energy consumption by sector

Delivering on ambitious climate targets in the NDC_LTT scenarios would moderate the energy demand growth projected by the three IAMs in the CP_EI scenario. This is triggered by the increased investment in energy efficiency, the higher energy prices leading to reduced energy consumption and the uptake of more efficient technologies and energy forms as a result of the long-term climate targets assumed in the NDC_LTT scenario. The introduction of green recovery packages in the NDC_LTT scenario would influence the development of final energy demand leading to reduced energy consumption in transport, buildings, and industries (Figure 25). In line with the analysis in Section 3.4, PROMETHEUS shows the largest energy consumption reductions as a result of the green recovery packages; in terms of sectors, the highest impacts are projected for the transport and buildings sectors with global final energy consumption in the NDC_LTT scenario declining by about 5% and 3% respectively compared to the NDC_LTT scenario in 2030. GCAM projections are in line with PROMETHEUS for all demand sectors, but the magnitude of impacts is much lower, as discussed already in Section 3.4. In contrast, TIAM shows diverging trends of energy demand across sectors with a 3% reduction of energy consumption in transport (in line with PROMETHEUS), but also a 2.5% increase in industrial energy consumption.

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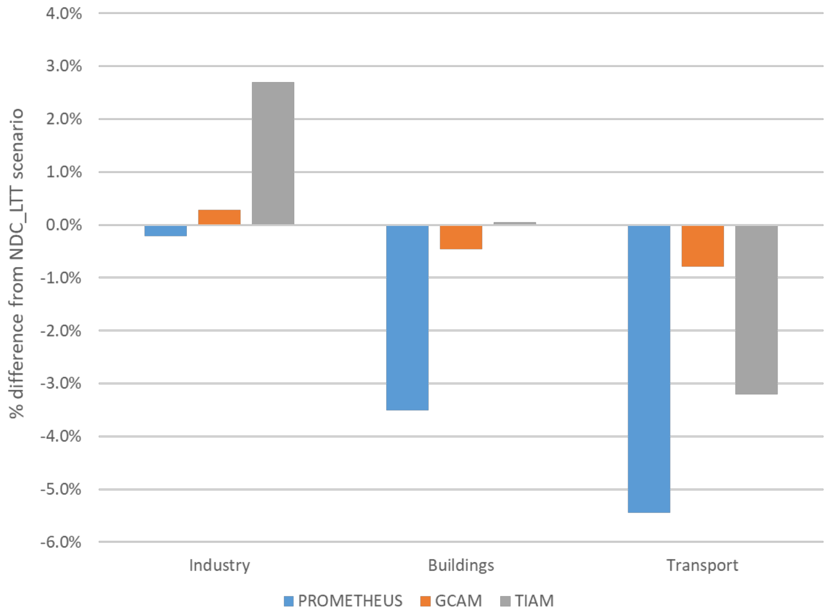

Figure 33: Changes in energy consumption by sector in 2030 in the NDC_LTT-GR scenario compared to NDC_LTT, PROMETHEUS, GCAM and TIAM results

In the NDC_LTT scenario, the imposition of green recovery packages would lead to further energy savings, especially in PROMETHEUS that has the more granular and detailed representation of demand-side mitigation options. PROMETHEUS and TIAM project that the highest potential for energy savings lies in the transport sector as a result of the large investment in energy efficient and low-carbon electric vehicles, while all three models show limited potential for energy savings in industry compared to the NDC_LTT scenario.

3.5.3 Focus on selected major emitters

3.5.3.1 CO_2 Emissions

The section includes a detailed analysis of the impacts of green recovery packages for major emitters, including China, India, and the EU, in the NDC_LTT policy context. Starting with China, both GCAM and PROMETHEUS models show that the implementation of NDCs and LTTs would lead to small changes in China's CO_2 emissions in the period to 2030, followed by a large decline until 2050; overall the models show that in the NDC_LTT scenario CO_2 emissions in China would decline by 64-66% in 2050 compared to 2015 levels indicating a sustained progress towards decarbonisation of the Chinese economy, in line with China's long term target to achieve net zero emissions by 2060. The insertion of green recovery packages (NDC_LTT_GR) leads to a further reduction of CO_2 emissions in the country from NDC_LTT levels, with a projected decline of 64-69% over the 2015-2050 period. This is triggered by the additional investment in renewable energy, in energy efficiency in end-use sectors, in the uptake of electrification, and the shift away from fossil fuels to cleaner energy sources. In line with the analysis above, the green recovery impacts are much higher in PROMETHEUS compared to GCAM, as the former includes various options to improve energy efficiency in end-use sectors and exhibits a larger sensitivity/flexibility to exogenous low-carbon investment with impacts sustained in the long-term enabled by the endogenous technology learning dynamics of PROMETHEUS triggered by the initial green recovery investment.

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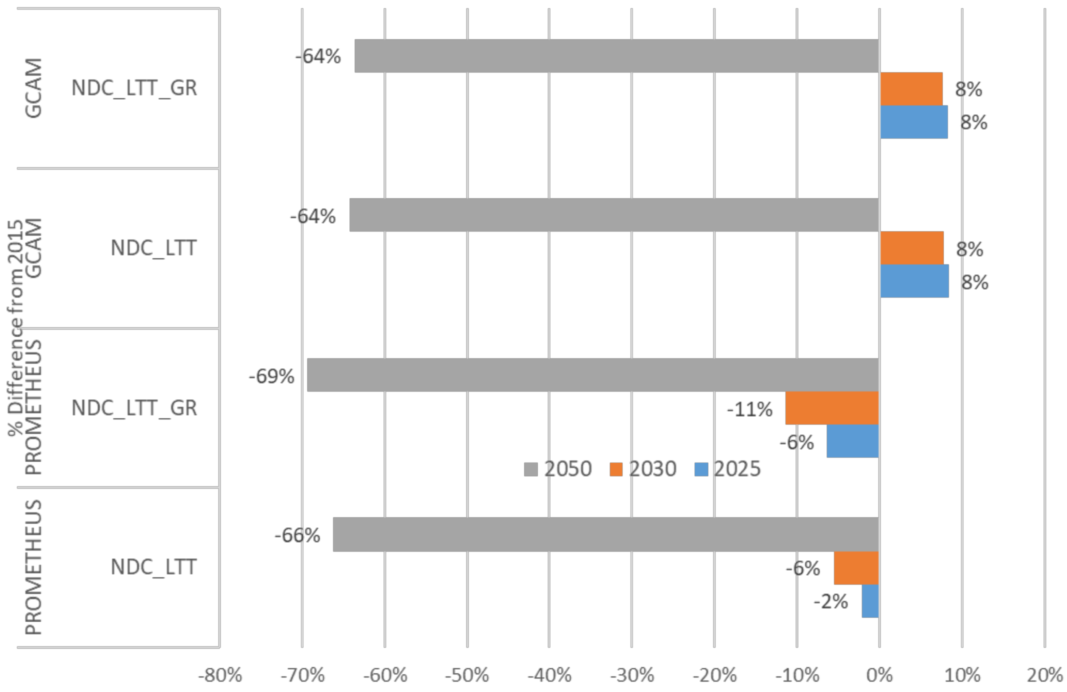

Figure 34: CO2 emissions in China under the NDC_LTT and NDC_LTT_GR scenarios over 2015-2050, PROMETHEUS and GCAM modelling results

In the NDC_LTT scenario, the GCAM and PROMETHEUS models project that India's CO_2 emissions would greatly increase by 2030 driven by the high GDP and population growth, and rising standards of living, leading to increased emissions especially from transport, combined with the limited ambition of the country's submitted NDC. However, the imposition of India's LTT targeting net-zero emissions by 2070 would result in a reversal of increasing emission trends, with CO_2 emissions stabilising by 2035 before starting a rapid decline, leading to a reduction of India's emissions by 20-22% in 2050 from 2015 levels. The implementation of the green recovery packages would further reduce emissions from India below NDC_LTT levels, especially in PROMETHEUS with only limited impacts in GCAM. This is a result of the large recovery funding, relative to India's GDP, directed towards low-emissions transport (e.g., uptake of EVs) and the upgrade of power grid to reduce grid losses and support the accelerated development of variable renewable energy.

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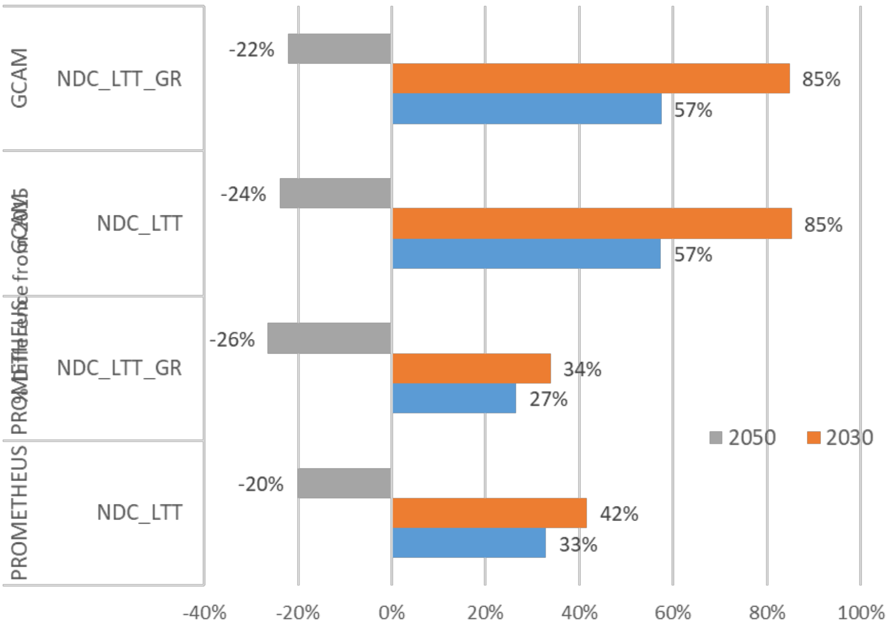

Figure 35: CO2 emissions in India under the NDC_LTT and NDC_LTT_GR scenarios over 2015-2050, PROMETHEUS and GCAM modelling results

Moving onto the EU, the region has already adopted ambitious climate policies, aiming to achieve a 55% reduction in GHG emissions in 2030 relative to 1990. This means that, in the NDC_LTT scenario, both GCAM and PROMETHEUS project a large reduction of EU emissions in 2030 by 41-49% paving the way towards deep decarbonisation by 2050 with EU CO_2 emissions reaching net zero levels. The addition of the green recovery packages further accelerates the emissions reduction especially by 2030, with EU CO_2 emissions declining by an additional 3-9% relative to NDC_LTT levels. This indicates that green recovery funds can support the EU in achieving its climate goals for 2030 through accelerated deployment of renewable energy, electrification of transport and heating, and energy efficiency improvements. The effect of recovery packages declines in the longer run as the ambitious targets are the main driver for the EU's transition pathways.

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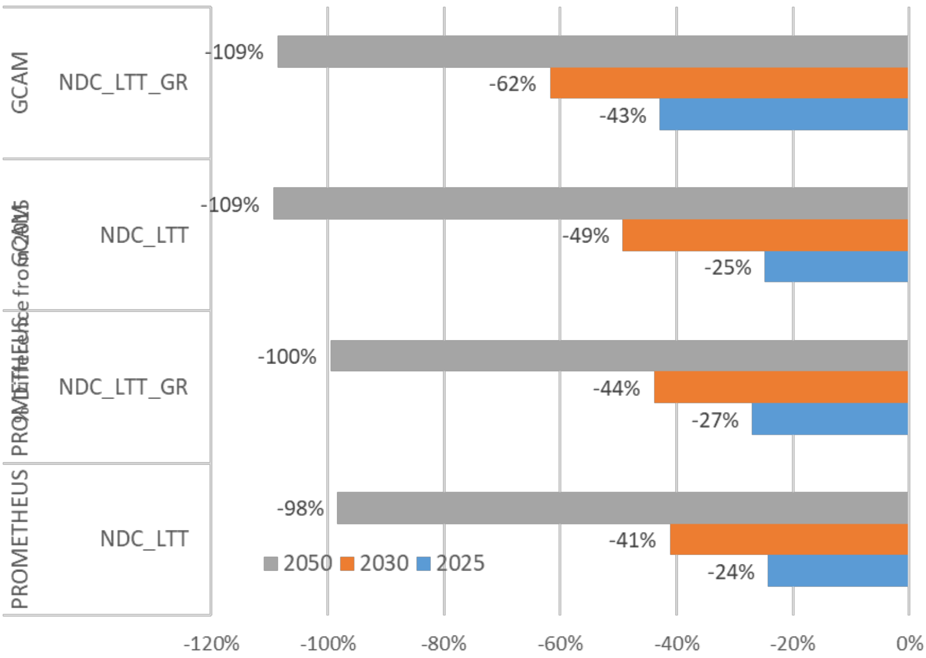

Figure 36: CO2 emissions in the EU under the NDC_LTT and NDC_LTT_GR scenarios over 2015-2050, PROMETHEUS and GCAM modelling results

The effectiveness of recovery packages varies among regions and depends on the underlying emissions reduction strategies. Long-term targets consistently lead to substantial emissions reductions in the EU, China and India with or without recovery packages. The imposition of Long-term targets towards net-zero accelerates emissions reductions in all economies with very large implications especially for rapidly developing countries, like China and India. The addition of green recovery packages on top of NDCs and LTTs can further accelerate climate action by 2030 but has limited impacts in the longer term where the net zero targets are the main driving force of scenario results.

3.5.3.2 CO_2 Emission Dynamics: Perspectives from Supply and Demand side

In the NDC_LTT scenario, PROMETHEUS shows that China's CO_2 emissions from energy supply would reduce by 71% in the period 2020-2050, triggered by the massive deployment of renewable energy capacities that replace coal- and gas-fired power generation. The introduction of green recovery funding pushes an even higher emission reduction of 74% by 2050. The imposition of the net-zero target would also lead to large reduction of demand-side emissions in China, falling by 50% in 2050 from 2020 levels; the reduction is even larger (reaching 55% in the NDC_LTT_GR scenario incorporating the green recovery packages. The situation is different in India, where demand-side CO_2 emissions are projected to increase by over 25% in the NDC_LTT scenario in the period 2020-2050. This indicates that economic growth, rising population, urbanisation, and rising living standards would yield increasing requirements from the construction, manufacturing, transport, and services sectors in India, while ambitious climate targets can only moderate, but not counterbalance, this growth. The supply side though, achieves a large reduction in CO_2 emissions by around 65% in 2050 compared to 2020 levels. The EU is expected to massively reduce both its supply and demand-side emissions by 2050. Specifically, the NDC-LTT scenario achieves an 86% reduction in demand-side CO_2 emissions over the 2020-2050 period, which increases further to 89% with the addition of green recovery packages in the NDC_LTT_GR scenario. In both scenarios, PROMETHEUS shows that the EU's energy supply is close to net zero emissions already in 2040 and achieves net negative emissions by 2050 through the emergence of BECCS to compensate for some residual emissions in hard-to-abate demand sectors, like aviation, shipping and heavy industries.

The GCAM model projects that China can reduce demand-side CO_2 emissions by 36% in 2050 compared to 2020

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under the NDC-LTT scenario, while the projected reduction is much higher in the supply side, about 96% in 2050. In line with PROMETHEUS, India's demand-side emissions in the NDC_LTT scenario are projected to increase by about 11% over 2020-2050, highly contrasting the large reduction of 79% projected for supply-side emissions in the period 2020-2050. For the EU, GCAM shows a more reserved reduction of demand-side emissions compared to PROMETHEUS (only 61% from 2020 levels), indicating the limited model flexibility to simulate demand-side transformations in transport, buildings, and industry. This means that, to achieve the net-zero EU target for 2050, GCAM needs to deploy large amounts of CDR technologies (e.g., BECCS, reforestation, and DAC) to achieve net-negative emissions from the supply side and compensate for the remaining demand-side emissions. As in previous results, the impacts of green recovery packages are very limited in GCAM.

The TIAM model projects that China would achieve a reduction in CO_2 emissions in NDC_LTT driven both by demand-side transformations (61% reduction in demand-side emissions in 2050 relative to 2020 levels) and supply-side restructuring; supply-side emissions are projected to decline by 88% in the NDC_LTT scenario over the 2020-2050 period, with only limited additional impacts from the addition of green recovery packages. In contrast to GCAM and PROMETHEUS that show increasing demand-side emissions in India in all scenarios, TIAM projects a reduction of demand-side emissions by 48% in the NDC_LTT scenarios over the 2020-2050 period. The supply side, though, is more influenced by the imposition of India's LTT with supply-side emissions reaching net-zero levels by 2050. The EU reduces its demand-side emissions by 87% under the NDC-LTT scenario in the period from 2020 to 2050, with limited additional impacts from green recovery packages. In line with the other models, the EU's energy supply sector is projected to reach net zero in the 2040s and become net negative by 2050 in order for the EU to meet its net zero target for 2050.

The implementation of long-term climate targets leads to significant emissions reductions both from the energy demand and the supply side. In particular, the models agree that supply-side emissions can get close to net zero by 2050 in China and India and even net negative in the EU to counterbalance some remaining hard-to-abate emissions and support the EU's net-zero emissions goal for 2050. The low-carbon transition is reinforced by strong demand-side transformations in all countries with strong reductions of demand-side emissions from the current policy scenarios. The importance of aligning recovery funding with ambitious long-term climate targets becomes evident in enhancing emission mitigation measures, contributing to a greener and more resilient future.

3.5.3.3 Final Energy

PROMETHEUS indicates a 3% reduction in China's final energy consumption under the NDC-LTT scenario in the 2020-2050 period as a result of the imposition of strong climate policies to meet its LTT target of net-zero emissions by 2060. The implementation of green recovery packages leads to further energy savings, with China's energy consumption declining by 7% in the NDC_LTT_GR scenarios by 2050 driven by the recovery investment in electric vehicles and energy efficiency. In contrast, India is projected to experience a substantial 73% increase in energy consumption by 2050 under the NDC-LTT scenario due to its rapid economic and population growth and rising standards of living. However, the introduction of recovery funding in the NDC-LTT-GR scenario moderates this increase. Final energy consumption in the EU is projected to decrease by 37% over 2020-2050 under the NDC-LTT scenario, while the addition of green recovery packages leads to further energy savings (39% over 2020-2050) coupled with a shift towards more efficient and cleaner energy sources.

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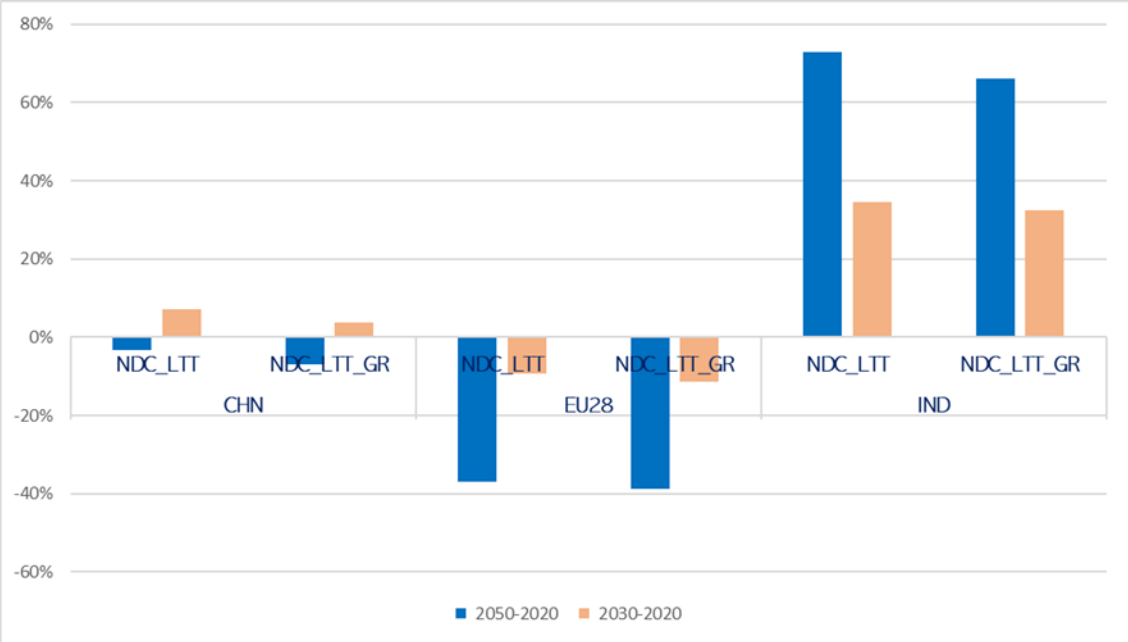

Figure 37: Differences in energy consumption in 2050 and 2030 compared to 2020 under the NDC-LTT-GR scenario and the NDC-LTT by observed region, results from PROMETHEUS

In the NDC_LTT scenario, GCAM projects a 13% increase in China's energy consumption in the period 2020-2050. India shows the highest increase among the countries analysed, with final energy consumptions increasing by 81% in the NDC-LTT scenario, and recovery funding (NDC-LTT-GR) having minimal impacts. The EU is projected to decrease its energy consumption by 16% under the NDC-LTT scenario, driven by the ambitious targets.

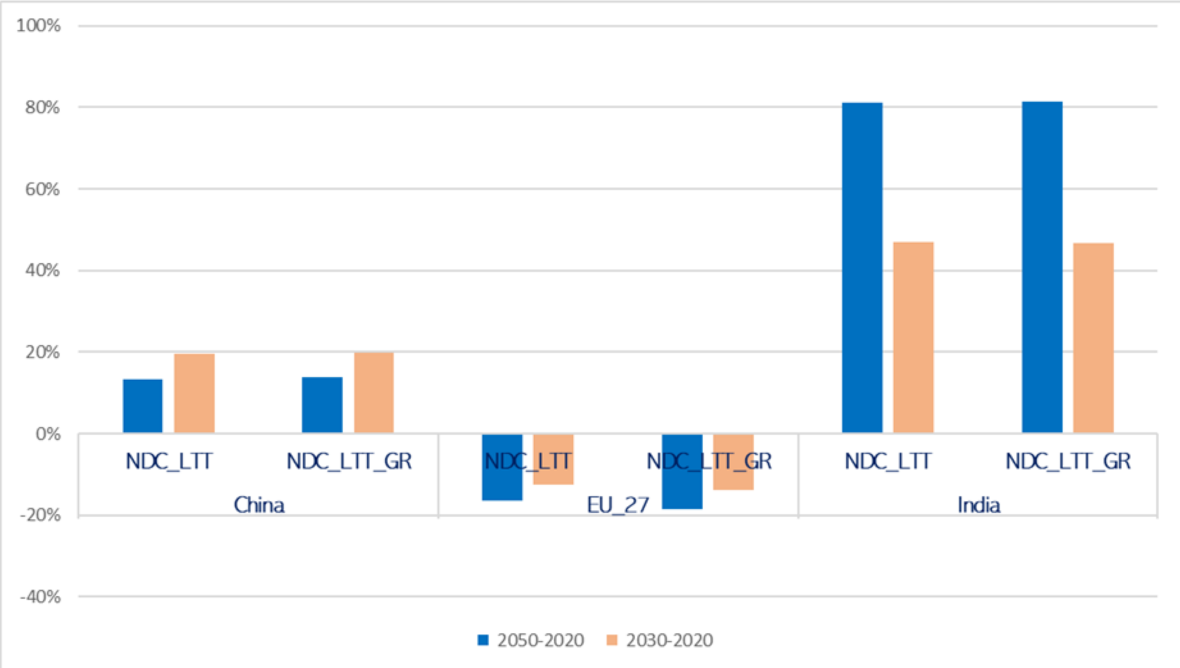

Figure 38: Differences in energy consumption in 2050 and 2030 compared to 2020 under the NDC-LTT-GR scenario and the NDC-LTT by observed region, results from GCAM

TIAM projects a 14% reduction in China's energy consumption in the NDC-LTT scenario showing that the imposition of its long-term climate targets can provide benefits in terms of energy use and CO_2 emissions mitigation. According to PROMETHEUS and GCAM, India's energy consumption in TIAM is projected to increase in the NDC_LTT scenario driven by the high economic and population growth. The introduction of green recovery funding (NDC-LTT-GR) has limited effects in energy consumption developments in both China and India compared

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to NDC-LTT. In the EU, energy use is projected to decline by 27% by 2050 in the NDC-LTT scenario with no significant influence from the introduction of recovery funding (NDC-LTT-GR).

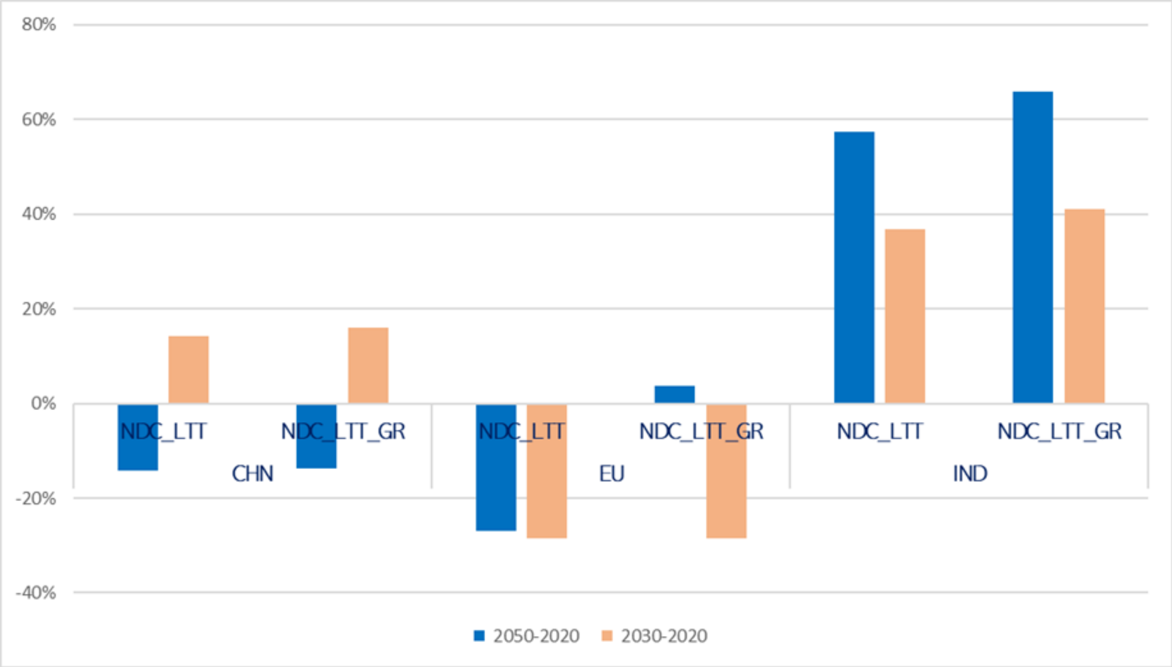

Figure 39: Differences in energy consumption in 2050 and 2030 compared to 2020 under the NDC-LTT-GR scenario and the NDC-LTT by observed region, results from TIAM

The NDC-LTT scenarios generally indicate shifts towards sustainable energy practices, with notable reductions in energy consumption in China and Europe. India's energy consumption sees substantial increases across scenarios, highlighting the challenge of balancing economic growth with sustainability. Recovery funding (NDC-LTT-GR) moderates India's energy consumption increase, emphasizing its role in shaping energy transitions.

3.5.3.4 Energy consumption by source

The GCAM model under the NDC-LTT (Figure 40) scenario indicates that in China, the consumption of electricity, gases and liquids will increase by 55%, 50% and 21% over 2020-2050 period respectively while the consumption of heat and solids will decline by 28% and 25% respectively. The insertion of recovery funding (NDC-LTT-GR scenario) has limited impacts on these results. India, according to GCAM results of the NDC-LTT scenario, will face an increased consumption of electricity, gases, liquids, and solids; the influence again from the recovery investments is projected to be minimal. GCAM also foresees that electricity consumption will be increased in the EU by 78% under the NDC-LTT scenario while gases, heat, liquids, and solids will be decreased by 65%, 43%, 54% and 32% respectively in 2050 compared to 2020 levels. The European Union will be affected by the green recovery investments in contrast to China and India, as recovery funding is higher in the EU than in other countries. Specifically, the NDC-LTT-GR scenario incorporating the recovery funding projects that electricity, will be increased by 84% in 2050 about 6% more than in NDC-LTT scenario. The consumption of gases, liquids, and heat is expected to decline by 1-3% below NDC_LTT levels while the reduction is even larger for solids with a 7% decline from NDC_LTT scenario.

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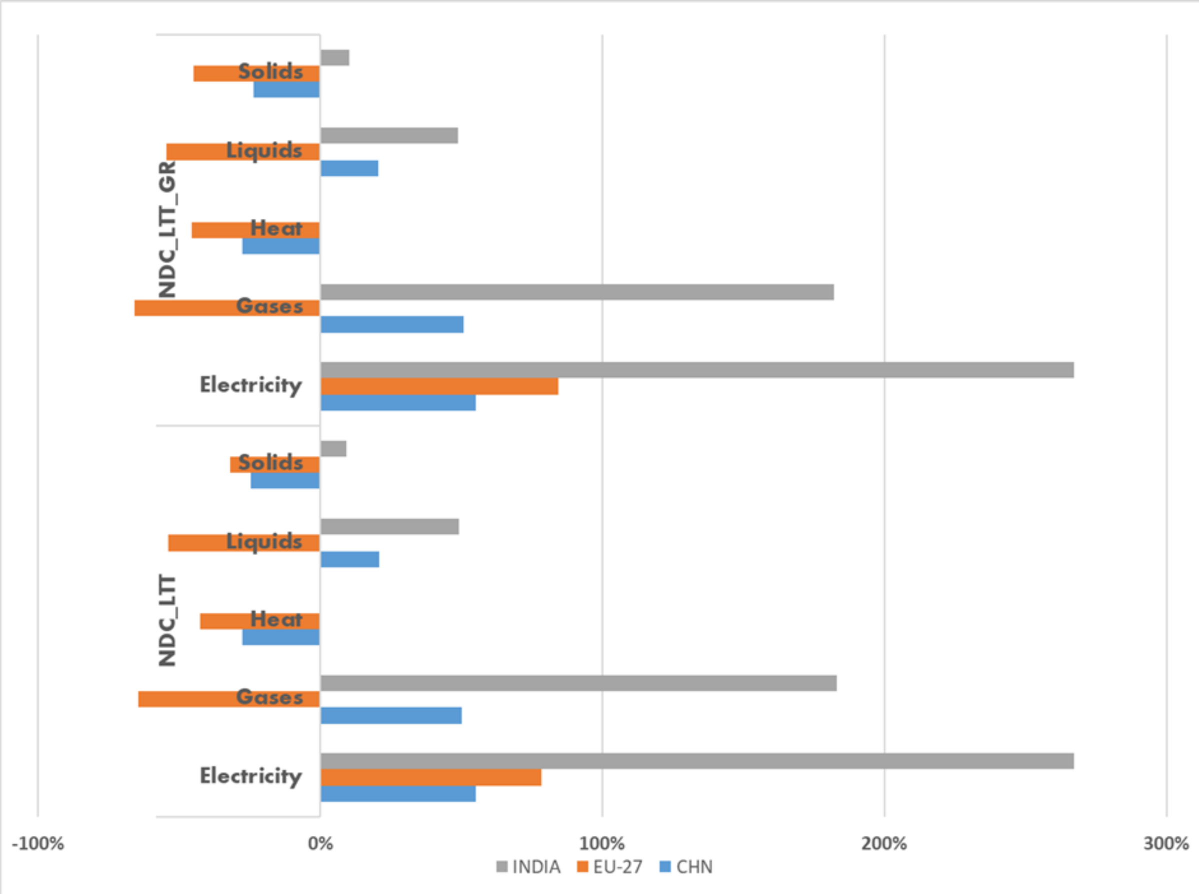

Figure 40: Differences in Final Energy by source in NDC-LTT-GR scenario and in NDC-LTT scenario (2050 compared to 2020), GCAM modelling results

In the NDC_LTT scenario, PROMETHEUS projects that China's consumption of electricity, gases and liquids will increase by 64%, 192% and 6% in the period 2020-2050, while the use of solids and heat is projected to decline by 89% and 9% respectively in 2050 compared to 2020 levels. Investments under the green recovery funding scenario (NDC-LTT-GR) reduce the consumption of gases, liquids, and solids in China, while the use of electricity is projected to increase by 3% as a result of the larger uptake of electric vehicles and heat pumps. India is projected to extensively increase the consumption of electricity, gases, and liquids by 2050 compared to 2020 levels under the NDC-LTT scenario while the consumption of solids will be reduced by 43% due to the imposition of strong climate policies to achieve its LTT target of net-zero emissions by 2070. The insertion of green recovery funding (NDC-LTT-GR) will moderate the consumption of gases and liquids and increase the consumption of electricity (compared to NDC-LTT). The EU is expected to increase the consumption of electricity by 37% under the NDC-LTT scenario, due to the projected electrification of transport and heating uses, while the consumption of solids, liquids and gases is projected to decline by 25%, 58% and 78% respectively. The green investments (NDC-LTT-GR scenario) will further increase the consumption of electricity by integrating electricity-based technologies in the transport and heating sectors (electric vehicles and heat pumps), while a further large reduction is projected for the consumption of liquids mostly from transportation sector due to the transitioning to electric vehicles (EVs) (compared to NDC-LTT).

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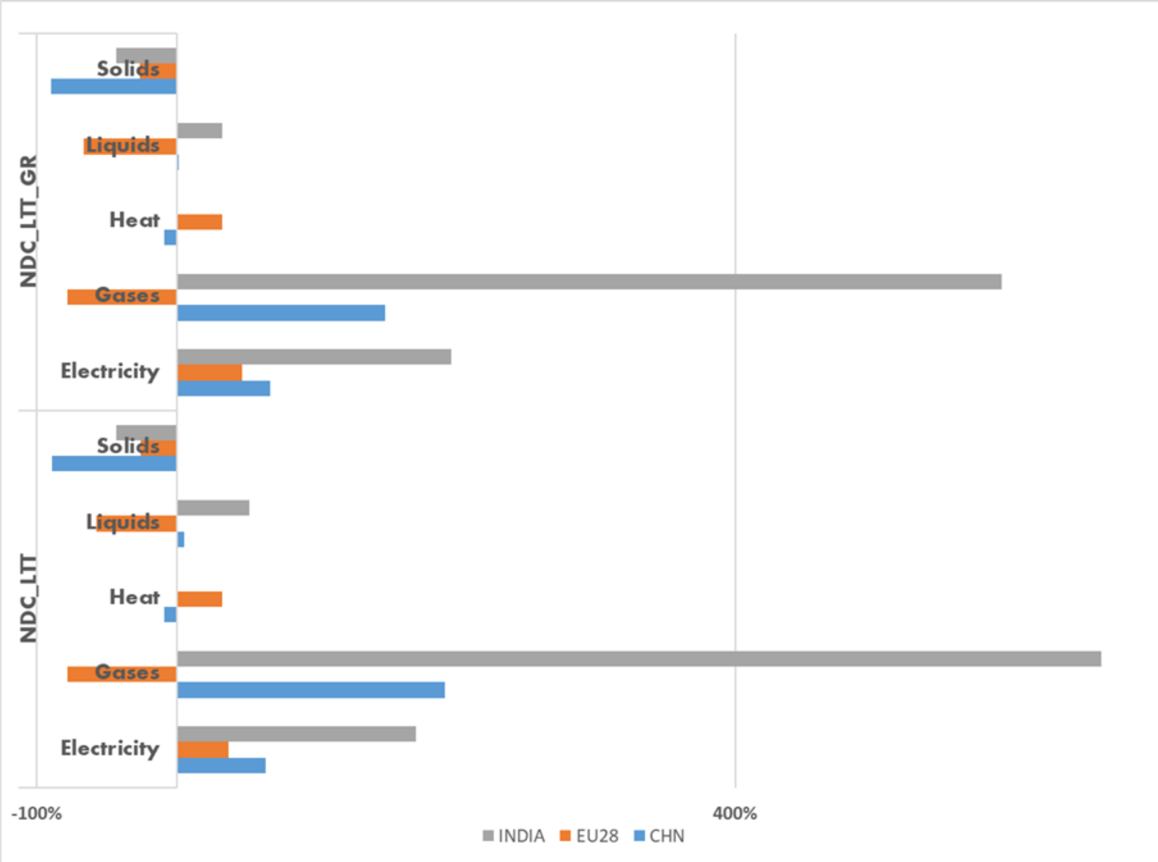

Figure 41: Differences in Final Energy by source in NDC-LTT-GR scenario and in NDC-LTT scenario (2050 compared to 2020), PROMETHEUS modelling results

In the NDC-LTT scenario, TIAM projects that the consumption of electricity, heat and gases will increase in 2050 in China by 45%, 98% and 3% respectively while the consumption of liquids and solids will reduce by 26% and 58% respectively in 2050 compared to 2020 levels. The investments under the NDC-LTT-GR scenario moderate the increase of energy use in China with gases, electricity and heat being the most affected fuels. The consumption of electricity, gases, and heat in India is set for a large growth under the NDC-LTT scenario in the 2020-2050 period, to support increasing economic activity and rising standards of living. Contrastingly, the consumption of liquids and solids is expected to decline by 16% and 2% respectively in the NDC_LTT scenario. The insertion of recovery funding (NDC-LTT-GR) would lead to further increases in the electricity consumption. The consumption of solids on the other hand is expected to further decrease by 2050 compared to 2020 under the NDC-LTT-GR scenario. The EU under the NDC-LTT scenario is expected to increase the consumption of electricity by 63% in 2050 compared to 2020 levels accompanied by a reduction of the consumption of gases, heat, liquids, and solids. The imposition of green recovery funding in the NDC_LTT_GR scenario would lead to a further reduction of solids, while the consumption of electricity, gases and heat would increase mostly to provide the energy required for the emergence of Direct Air Capture in TIAM.

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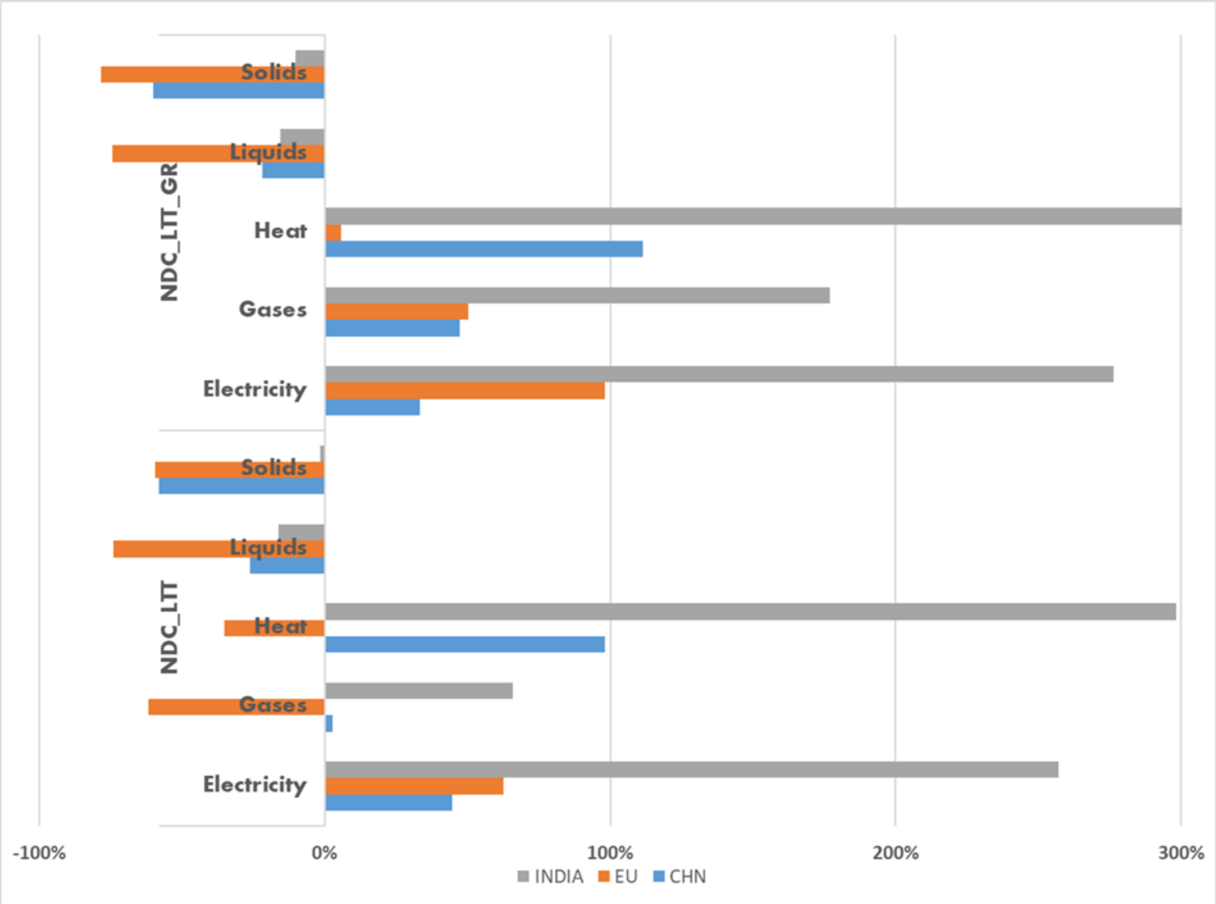

Figure 42: Differences in Final Energy by source in NDC-LTT-GR scenario and in NDC-LTT scenario (2050 compared to 2020), TIAM modelling results

Generally, the NDC-LTT scenarios promote cleaner energy sources, emphasizing sustainability and reduced energy consumption while the CP-EI scenarios tend to rely on current climate policies, resulting in less emphasis on renewable energy uptake. This is visible in the EU and China, showing reductions in final energy use and fuel shifts towards low-emission energy sources as a result of ambitious climate targets in the NDC_LTT scenario. The imposition of its LTT target only moderately reduces the increase in India's energy consumption driven by large GDP increases and rising standards of living. In all regions, the imposition of green recovery funding results in a larger shift towards clean energy sources (e.g. electricity, hydrogen) while the consumption of fossil fuels would decline.

3.6 Employment impacts of global modelling results

3.6.1 Introduction

As explained in Section 2, the COVID-19 pandemic caused widespread socioeconomic disruptions, notably on employment through lengthy lockdowns, with the energy sector also being impacted as a result of disruptions in supply chains and cancelations of planned projects. Although employment levels started bouncing back as economic activities returned to pre-pandemic norms, changes induced in the labour market—i.e., permanent job losses, reduced income and working hours—pose challenges in the smooth recovery (World Economic Forum, 2023). As such, global recovery packages strongly focused on creating job opportunities vis-à-vis promoting a green recovery to both address the socio-economic impacts of the pandemic as well as accelerate decarbonisation efforts.

There are various approaches to estimating employment implications of green recovery spending and/or other

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decarbonisation measures, notably consisting of bottom-up estimations through employment factors, or top-down approaches through Input-Output tables and national accounting (Garrett-Peltier, 2017), Computable General Equilibrium modelling (Dell'Anna, 2021), and sectoral macro-econometric post-Keynesian modelling (Kiss-Dobronyi et al., 2021). Early efforts in the literature based on preliminary estimates or announced packages globally (den Elzen et al., 2022; Fragkos & Fragkiadakis, 2022; Pollitt et al., 2021; van de Ven et al., 2022) and in the EU (Koasidis et al., 2022) shed light on the possibility of exploiting employment opportunities in green investments to create jobs alongside climate action.

Here, we revisit these attempts based on the final/updated recovery packages, presented in Section 2, to estimate the potential employment opportunities within the current global climate policy context, as reflected in the current policies and the updated NDCs (along with the long-term pledges) presented in this section. Notably, we draw from the bottom-up factor-based employment accounting methodology presented in (van de Ven et al., 2022) for the energy sector. On top of these power generation and fossil fuel production jobs, we account for additional jobs created, e.g., for buildings, infrastructure, transport, based on additional sections of the recovery packages (on top of those accounted in the bottom-up approach) using employment factors per million spent from (Garrett-Peltier, 2017). Through this combination of a bottom-up and top-down approach, we can provide an estimation of jobs created by a large share of the recovery packages, disaggregating the impact of each part of the fiscal stimuli.

3.6.2 Methods

We choose the employment factor approach to estimate direct jobs associated with power generation and fuel production (i.e., fossil fuels, biomass, uranium including extraction and refining when relevant), an intuitive and effective method that applies different job intensities (i.e., employment per GW installed and operating and EJ of fuel produced) to each job category (Ram et al., 2020). The contribution of each fuel/technology to the energy mix and the total employment of the energy sector are estimated based on the aggregation of construction, extraction, manufacturing, operation, and maintenance (O&M), and refinery jobs required for the calculated amount of fuel/technology usage in each scenario by each model. Employment factors are drawn from (Rutovitz et al., 2015), a comprehensive database, commonly employed in relevant modelling analyses (e.g., (Fragkos & Paroussos, 2018; Pai et al., 2021)), further calculating a decline in employment factors/intensities based on technological and operational maturity, especially for low-carbon technologies (Ram et al., 2020).

Input-output models have also been used to estimate employment impacts of decarbonisation pathways (Su & Ang, 2015) and changes to the energy sector (Markandya et al., 2016). Here, we use the employment multipliers per $1million increase in spending developed in (Garrett-Peltier, 2017) to assess employment impacts in the broader energy and energy efficiency industries (building retrofits, public transport, and grid expansion) not covered by the bottom-up approach.

In both cases, employment impacts through I/O tables and factors in general are most relevant during the short-to-medium term as they rely on a snapshot of the economy, with static prices and production functions.

3.6.3 Results

3.6.3.1 Bottom-up impacts to the electricity sector

The employment impacts related to the power generation and fuel production sectors of CP_EI and NDC_LTT scenarios are assessed for GCAM and PROMETHEUS models at the global level. We utilise the results for capacity additions of renewable (wind, solar, hydropower, biomass, and geothermal), nuclear, and fossil fuel (coal, gas, oil) electricity technologies, the primary energy of fossil fuels source and biomass, the secondary energy of carrier liquids (oil and biofuels) in each scenario and model, as well as the employment factors in (Rutovitz et al., 2015) to estimate job implications in each sector (see Section 3.6.2.1). Capacity additions for hydropower are not represented in GCAM, and secondary fuels are not included in PROMETHEUS, meaning that the job implications calculated in this section do not account for the relevant sub-sectors missing in each model. Within this

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methodology, a core driver of job impacts in the energy sector is the capacity additions in the electricity sector, and as such electricity as a secondary energy source, both shown in Figure 43. Evidently, recovery packages have a more pronounced impact in PROMETHEUS compared to GCAM, as discussed in Sections 3.4 and 3.5, while notably in GCAM the increase in renewables in the recovery packages is minimal, and a lower amount of total electricity demand is observed through efficiency improvements by the rest of the packages (e.g., in the building sector).

Figure 43: **(a)** Absolute difference of capacity additions (GW) and **(b)** % difference of secondary electricity (EJ/yr) in Green Recovery scenarios (GR) compared to non-recovery scenarios in GCAM and PROMETHEUS; left: CP_EI_GR scenario; right: NDC_LTT_GR scenario.

Figure 44 shows the difference in direct jobs from GCAM & PROMETHEUS between scenarios with and without green recovery. In the CP_EI_GR scenario, PROMETHEUS shows an 18% increase in total electricity-related jobs in 2025 compared to the CP_EI scenario, which gradually declines to 5% in 2035, slightly increasing towards 2040 and finally resulting in a 1% increase in 2050. The peak in employment gains in PROMETHEUS occurs in 2025, where capacity additions of renewables also peak due to the implementation of green recovery packages, despite the projected decrease in fossil fuels. GCAM projects an opposite short-term effect, with a job reduction of ~1.3% until 2025, an increase of 2.2% in 2030, followed by a decline ranging between 1-1.6% post-2035 until 2050. Capacity additions in all technologies decline in 2025 in GCAM, which mainly drives the decrease in short-

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term jobs. The green recovery in both models is projected to have an immediate but short-term impact on jobs but limited effect on long-term employment. This decrease, apart from 2030 as an immediate result of the low-carbon electricity generation recovery package, is a result of the lower electricity demand in GCAM, as shown in Figure 43, because of the contents of the recovery package as a whole, which drive demand in buildings and transport down. This implies that the small number of lower job gains between the GR and the non-GR package can be easily counterbalanced in the other sectors.

The NDC_LTT_GR scenario in PROMETHEUS shows a similar positive effect of recovery packages in the short-term jobs as CP_GR, which however steeply decreases post-2035, leading to an 8% decrease in 2050. This can be attributed to the relevant decline in capacity additions, the reduction in global energy and electricity consumption (Figure 25), and further emissions cuts towards 2050 (Figure 23), indicating a slight trade-off between emissions abatement and long-term employment creation. In GCAM, on the other hand, we see a similar decrease in employment as in CP_EI_GR in 2025, which however does not rebound, remaining relatively steady until 2050, following the minimal effect of recovery packages in capacity additions in the model.

Generally, in both models we observe that the impact of the recovery packages is stronger in the CP scenarios compared to the NDC scenarios (especially in the long run), which is expected as this financial instrument is designed explicitly to assist toward immediate employment creation to address the socio-economic impact of the pandemic. However, this also implies that, without continuous effort, the acceleration of job creation observed in the implementation of the current policies along with the recovery package could also have negative effects as climate action intensifies to bridge the gap with the NDCs and the long-term pledges post-2030.

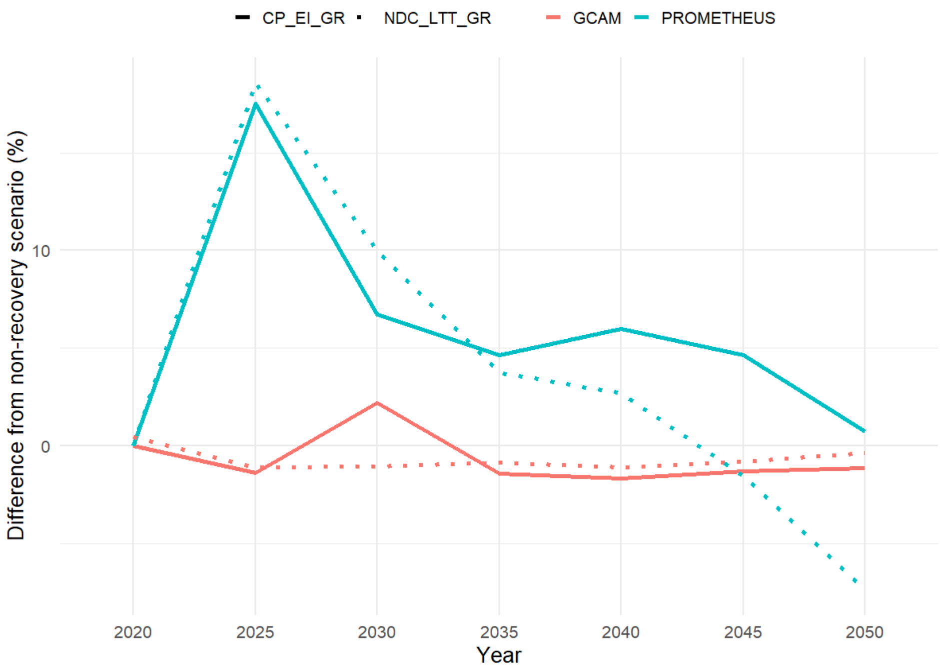

Figure 44: Employment impacts of Green Recovery scenarios (GR) as % difference compared to non-recovery scenarios in GCAM (red) and PROMETHEUS (green). Solid lines indicate CP_EI_GR scenarios and dotted lines NDC_LTT_GR scenarios.

Despite the differences between scenarios and models, in all cases a growth of the low-carbon electricity generation is observed, which is more pronounced in the NDC scenarios as a result of higher mitigation driving sectoral low-carbon jobs up. Compared to the base year (Figure 45), all scenarios in GCAM show a positive impact on employment, with CP_EI following a similar trend to CP_EI_GR and NDC_LTT to NDC_LTT_GR, respectively. However, green recovery scenarios in GCAM have an overall lower, albeit positive, effect on employment than scenarios without the green recovery funding as a result of lower demand, as previously discussed. This is in contrast to PROMETHEUS, which shows increased employment in the energy sector as a result of green recovery funding throughout all modelled years in CP scenarios and until 2045 in NDC_LTT scenarios. An employment growth between 12-26% for the power generation and fuel production can be expected by 2050 based on these

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scenarios and models (as well as the implementation of the recovery packages).

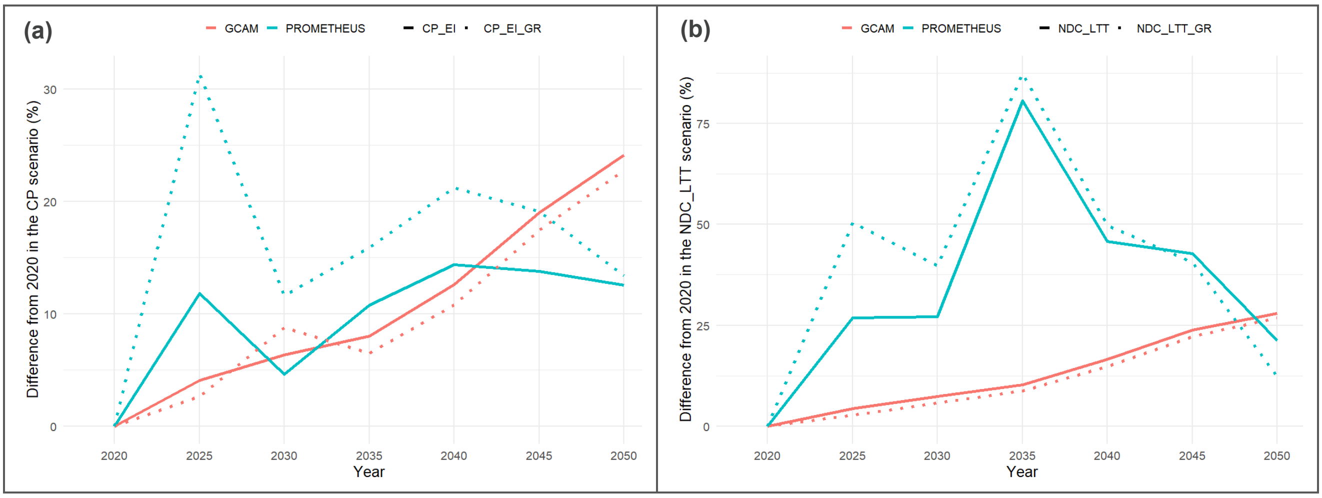
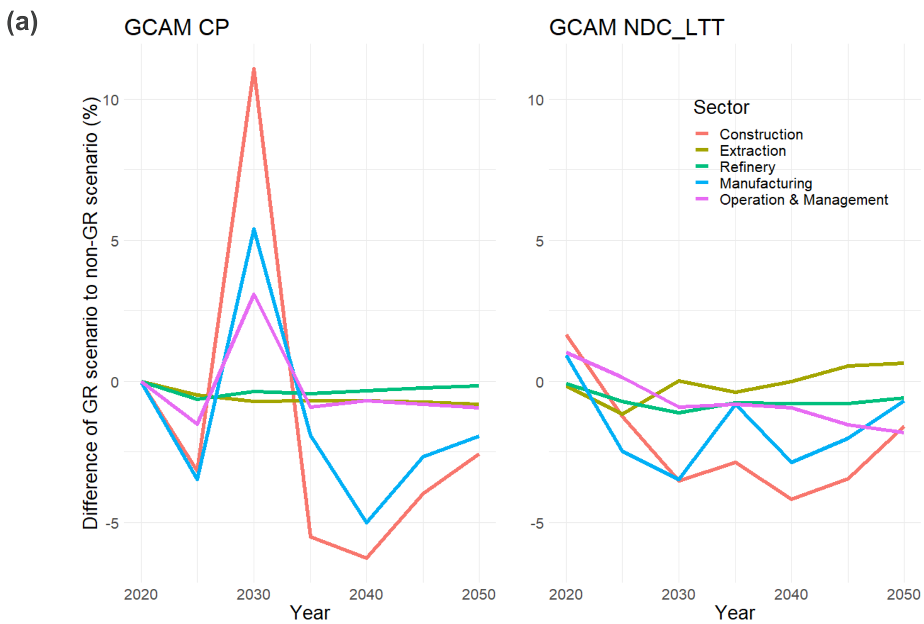


Figure 45: Employment impacts as a % difference compared to 2020 of **(a)** CP_EI scenario and **(b)** NDC_LTT scenario in GCAM (red) and PROMETHEUS (green). Solid lines indicate CP_EI_GR scenarios and dotted lines NDC_LTT_GR scenarios.

Finally, we assess the impacts of all scenarios in different energy-related sectors, broken down into construction, extraction, refinery, manufacturing, and operation and maintenance (Figure 46). We find that, in GCAM (Figure 46a), all sectors face small declines following the trends observed in the aggregated results, due to reduced electricity demand. An exception is observed in 2030 with a 11% increase in construction jobs, 5% in manufacturing, and 3% in operation & maintenance, and a similar decline post-2030, highlighting the immediate effect of the packages when comparing the GR to non-GR scenarios. The effects on the NDC_LTT pathway is less pronounced. Interestingly, extraction jobs also seem to grow, as a result of increased biomass and uranium extraction that counterbalance the declines in the fossil fuel sector.



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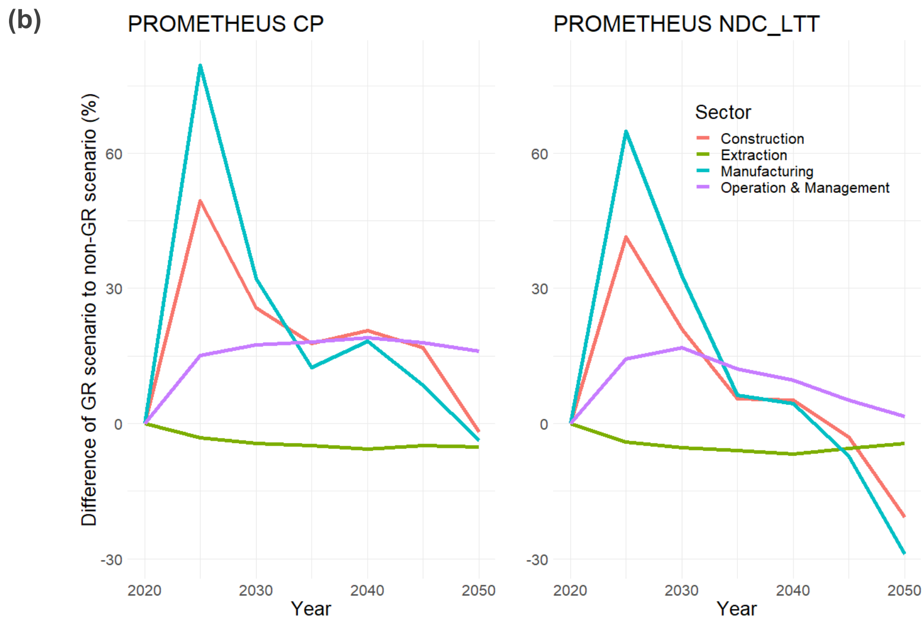

Figure 46: Employment impacts of Green Recovery scenarios (GR) per sector as % difference compared to non-recovery scenarios in **(a)** GCAM and **(b)** PROMETHEUS in construction (red), extraction (green), manufacturing (blue), and operation & maintenance (purple)

In PROMETHEUS (Figure 46b), recovery packages have a clear short-to-medium-term positive impact in all energy sectors except for extraction, which is expected given the accelatared electrification and further reduction in the consumption of petroleum products. The effect of green recovery packages on employment is more pronounced in CP scenarios compared to NDC_LTT, as the latter already includes clean energy investments and significant changes in the global energy mix. In the long-term (2050), PROMETHEUS shows a sustained positive impact on O&M, which however does not completely cancel-out the negative trend in contruction and manufacturing post-2030, further stressing the need to support construction and manufacturing jobs after the immediate positive effect of the packages to ensure that these jobs are not lost in the long run.

3.6.3.2 Top-down impacts to the energy sector

For the top-down impacts of green recovery packages on full-time equivalent (FTE) jobs, we draw from the employment multipliers provided in (Garrett-Peltier, 2017) and the sectoral classiffication of recovery packages in Section 2.3.2. We focus on the sectors not captured by the bottom-up approach in Section 3.6.3.2 and which receive a large portion of the green recovery funding namely electricty networks (4%), energy efficient buildings and industry (9%), and sustainable public transport (12%), and for which employment multipliers were available in the literature. This apparoach is thus model-agnostic, entirely depending on the size of spending per sector, and the employment multipliers of the "synthetic" clean energy industries in (Garrett-Peltier, 2017) with fixed input-output proportions. Fluctuations on these are expected based on model pathways. For example, the lower increase of the power generation sector in the GR scenarios of GCAM could be counterbalanced by slighty larger increases than those calculated in this sub-section.

Table 6: Funding allocation to different sectors and direct, indirect, and total full-time-equivalent (FTE) jobs globally

	Electricity networks	Energy-efficient-buildings & industry	Sustainable Public Transport
Billion USD_World	88.02	222.20	300.32

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Direct FTE Jobs_World	322,163	1,015,445	1,849,953
Indirect FTE Jobs_World	272,870	705,479	831,878
Toal FTE jobs_World	595,033	1,720,923	2,681,831

We fiind that, on average, green recovery packages would generate 595,000 FTE jobs towards electricity networks, 1.7 million FTE jobs towards energy efficient buildings and industry, and 2.68 million FTE jobs towards sustainable public transport globally. Considering the positive employment impact of the recovery packages found in PROMETHEUS and the slight reduction of job gains in GCAM on the electricity and fuel productions sectors, these additional jobs created from the rest of the packages can create a positive net impact on employment, when accounting for job creation in building retrofits, mass transit and freight rail, and smart grids. Future studies can shed light on fluctuations in the values of the top-down approach based on the results of each model to account for these differences (e.g., largest demand reductions in GCAM from the building sector). It should also be noted that, despite efforts to capture a wide range of sectoral employment impacts, there are still sectors not linked to job creation, such as energy affordability (in the form of subsidies mostly) that receives ~35% of green recovery subsidies globally, since such chunks of the packages are unlike to lead to job creation. This also explains recent efforts to phase out subsidies (European Comission, 2023), to avoid further losing the opprotunity of the packages having a long lasting impact on the energy sector.

3.7 Policy Recommendations - Conslusions

While dealing with the health and economic impacts of COVID-19 is crucial, governments still need to urgently address the climate crisis. Whether countries pursue green, resilient, and inclusive recovery in the wake of the COVID-19 crisis will influence the world's future for the next years. At the same time, the commitments that countries make in their climate plans (NDCs) and their Long-Term Targets (LTTs) under the Paris Agreement will also have profound implications for the low-emission transition.

The current study uses three well-established global IAMs to assess the impacts of green recovery funding on emissions and energy system development on a Current Policy and an NDC/LTT scenario context. The analysis shows that green recovery spending can reduce global emissions and accelerate the uptake of renewable energy and electric vehicles, but its effects are visible—albeit limited—in the near-term (i.e., by 2030) and uncertain, as models disagree on some of the outcomes. Green recovery funding should be accompanied with ambitious and sustained climate policies worldwide in order to pave the way towards the systemic transformation required to achieve the Paris Agreement goals. However, the implementation of green recovery can help reduce emissions globally, accelerate the deployment of low-carbon technologies, and build resilience in the energy sector, by spurring sustainable low-emission action in sectors like electricity production, transport, buildings, and industry, while providing socioeconomic benefits in terms of job creation in manufacturing, construction, and operation of clean energy technologies.

While the green recovery from COVID-19 has short-term benefits, the longer-term climate plans (LTT) of countries provide a major stimulus to reduce emissions and increase the uptake of clean energy and energy efficiency providing clear signals about what is important for the future. Building on and significantly expanding the investments made as part of the COVID recovery measures, climate action in NDCs and LTTs can help generate further emission, renewable energy, and socio-economic benefits in key sectors. Recovery packages on their own will not adequately deliver the sustained systemic transformation that the climate crisis requires, so their combination with the NDCs and LTTs is indeed critical. The assessment of green recovery packages holds significant importance, acting as a catalyst for global efforts towards boosting emission reduction and restructuring of the energy consumption towards cleaner energy sources.

Modelling results show differences across modelling frameworks (PROMETHEUS, GCAM, TIAM), which highlight

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the complexity of energy challenges and the complex interplay of climate policy with recovery funding. Green recovery packages would lead to emission reductions, especially in the current policy scenario in PROMETHEUS, driven by faster clean energy technology uptake and accelerated energy efficiency. The GCAM and TIAM models confirm PROMETHEUS results, but the impacts of green recovery packages are more limited in these models. The impact of green recovery packages is higher in countries/regions with a high share of green recovery investment (as a share of their GDP), with the EU being a clear frontrunner, with green recovery packages supporting the (over-) achievement of its 2030 and 2050 climate targets. In contrast, the impacts are projected to be relatively limited in China and India, indicating potential trade-offs between sustained economic growth and climate action. The transport and electricity production sectors exhibit the largest emission reductions triggered by large investment in renewable energy and electric vehicles included in green recovery packages. Energy consumption is projected to modestly decline due to the implementation of green recovery packages, while fuel shifts are projected with cleaner energy sources (e.g. electricity, biofuels, hydrogen) replacing the use of fossil fuels in transport, buildings, and industries. PROMETHEUS and GCAM agree on the overall trends and impacts described above, while TIAM shows increasing energy consumption as the reduction in electricity costs triggers a higher uptake of Direct Air Capture, which in turn requires large amounts of energy to operate, thus increasing final energy consumption.

The scientific analysis shows that recovery funding alone will not be sufficient to bridge the emissions gaps towards Paris. Policymakers should acknowledge and integrate diverse strategies in combination with the recovery funding tailored to the unique characteristics of each country. Green recovery funding under both current policies and long-term climate targets leads in reduced emissions, both from the energy demand and supply side, globally and in major emitters. This demonstrates the potential of recovery packages in accelerating the global energy transition, especially through increased deployment of renewable energy (solar PV and wind power), higher electrification of transport and heating uses, and accelerated energy efficiency improvements.

Recognising the sector-specific responses to recovery funding, the study underscores the necessity for tailored policies, especially for sectors like transportation, which require more targeted measures to align with decarbonisation goals. The projected increase in electricity consumption triggered by the uptake of electric vehicles and heat pumps prompts a call for careful consideration of the energy mix and technological advancements to avoid an unwanted increase in CO_2 emissions from power generation especially in countries like India with a coal-dependent power mix.

It is evident that, while recovery packages contribute to the transition to a low-carbon economy, careful allocation of funds is crucial, considering national specificities, resources, costs, and policy priorities. An emphasis on emerging and early-stage technologies signals a commitment to low-carbon innovation. However, the results also point out that recovery packages alone will fall short of filling the massive investment gap needed for a net-zero transition and only cover a small part of the emissions gap to ensure meeting the Paris Agreement temperature goals. Governments are urged to complement investment support policies with other ambitious and predictable climate policies (e.g., gradually increasing carbon prices, efficiency, and CO_2 standards, blending mandates and an array of other complementary but ambitious policies) to incentivise private funding building investors' confidence in low- and/or zero-carbon technologies and pave the way for an efficient, equitable, and sustainable future.

Countries must proactively pursue both climate action and economic recovery in the upcoming years. They need to strategically integrate recovery measures to not only strengthen their economies but also contribute to the envisioned long-term transition of the Paris Agreement, while also improving their resilience. To realise this synergy, nations should align their recovery efforts with the submission of revised, more ambitious NDCs and LTTs compatible with the transition towards a low-carbon economy. Collectively, these integrated approaches can act as crucial levers, steering us toward the long-term objectives of the Paris Agreement while fostering a resilient and equitable economy capable of creating more jobs withstanding future challenges, including those akin to COVID-19.

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Table 7: Policy Recommendations

Urgency of ambitious climate policies	The study underscores the crucial need for sustained and ambitious climate policies to achieve the required emission reductions aligned with the Paris Agreement goals. Despite the positive impact of newly legislated climate policies, these fall short, and green recovery packages alone cannot bridge the emissions gap by 2030 and 2050.
Strategic allocation of recovery funding	While a significant portion of recovery funding targets emissions from electricity generation, its effectiveness depends on complementary measures. High carbon pricing and sustained climate policies are imperative to maximise the impact of investments in clean energy technologies and ensure synergies with demand-side strategies in achieving emission reduction targets, especially in the context of increased electrification.
Sector-specific tailored policies	The sectoral analysis highlights the necessity for tailored policies, especially in sectors like transportation, where targeted measures are crucial for alignment with decarbonisation goals. Green recovery funding contributes to reduced energy consumption and limited shifts in fuel mix, but sector-specific strategies are required for a comprehensive and effective transition.
Role of green recovery in energy mix transformation	Green recovery packages lead to shifts in the global final energy mix, with a notable increase in electricity deployment, replacing fossil fuels. Governments should prioritise and incentivise the adoption of cleaner and more sustainable energy sources both in energy demand and supply side in a coordinated manner.
Accelerated electrification and reduced Fossil Fuel Dependency	Green recovery packages accelerate electrification, leading to reduced consumption of fossil fuels, particularly evident in PROMETHEUS results, with lower impacts in GCAM and TIAM. Policymakers should focus on transitioning away from fossil fuels and promoting cleaner energy alternatives, considering sectoral specificities.
Integrated approach for comprehensive energy transition	The study advocates for an integrated and comprehensive approach to energy transition. While impactful, green recovery funding should be viewed as part of a broader, holistic strategy for a systemic transformation towards a low-emission, sustainable, and more resilient society. Policymakers must integrate these packages with ambitious and robust climate policies, innovative technologies, and diverse energy solutions to effectively address the complexities of global energy challenges.

In summary, while green recovery packages present a valuable opportunity to catalyse emission reduction efforts and reshape energy consumption patterns, their success hinges on synergistic collaboration with ambitious climate policies, diversified sector-specific approaches, and an integrated vision for a sustainable and low-carbon-future. Policymakers are urged to adopt a holistic strategy, recognising the complex interactions between various sectors, and embracing innovative solutions for a resilient and climate-friendly global energy landscape.

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4 Deep dive into the National Recovery and Resilience Plan of Greece

4.1 Introduction

Greece's energy and climate strategies are strategically oriented towards achieving net-zero greenhouse gas (GHG) emissions by 2050. For the time being, its pivotal policy framework is the National Energy and Climate Plan (NECP) that was adopted in 2019, which delineates policy directions until 2030 (Ministry of Environment and Energy, 2019). Embedded within the NECP are explicit energy and climate targets and complementary measures aimed at positioning Greece on a trajectory towards net-zero emissions. Further consolidating Greece's commitment to climate action, the National Climate Law, enacted in May 2022, outlines ambitious GHG emission reduction targets compared to the 2005 levels, i.e., -55% by 2030, -80% by 2040, and ultimately culminating in achieving net-zero GHG emissions by 2050 (Hellenic Republic, 2022). Notably, this legislation articulates crucial measures, including the phaseout of lignite-fired generation by 2028 and the ambitious expansion of renewable energy sources (RES). The revised draft NECP, in accordance with the European Commission's (EC) new energy and climate objectives (and in particular with the updated EU targets for 2030 as part of the EC's Fit-for-55 package), was publicly presented in January 2023 (Hellenic Ministry of Environment and Energy, 2023c) and initially submitted to the EC for review, while the updated and revised draft NECP was prepared and re-submitted to the EC at the beginning of November 2023 (Hellenic Ministry of Environment and Energy, 2023a). The final version of the revised NECP is expected to be presented in June 2024.

Complementing these efforts, the "Greece 2.0" National Recovery and Resilience Plan (NRRP) aims to transform the economy, institutions, and society of Greece (Hellenic Republic, 2023a) and increase its resilience to such shocks as the COVID-19 pandemic. It seeks to transition towards a more outward-looking, competitive, and environmentally friendly economic model. It also aims to significantly reduce the informal economy and establish a robust and inclusive social safety net. The NRRP addresses implications of the pandemic by providing significant funding to the energy sector's activities and reforms, with a specific focus on the energy transition. The NRRP supports Greece's energy transition and is in line with the objectives of the European Green Deal, the 2030 climate targets, and the aim for climate neutrality by 2050. It allocates a total of 37.5% of the expected cost towards climate-related actions. The plan aligns with the strategic aims of the NECP, and the specific targets established by it. It also includes the EC's recommendations regarding the utilisation of the Recovery and Resilience Facility (RRF). Furthermore, the NRRP aligns with both national and territorial Just Transition Plans, considering the imperative of facilitating a fair and equitable transition during the lignite phaseout, as well as addressing the issue of energy poverty, which is particularly important in Greece.

In this context, modelling work is needed to better understand the short- and long-term impacts of the announced recovery packages (investments and reforms) proposed by the NRRP in terms of future economic, as well as energy- and emission-related, developments. The question of whether economic recovery plans and their announced recovery packages can potentially be used as opportunities to foster low-carbon transitions has been regarded as an issue of high concern for policymakers from national governments and the EC. Here, we seek to answer the following research question (RQ):

RQ: "What are the short- and long-term impacts of the investments and reforms related to the energy transition in the Greek residential and power sectors, as outlined by the NRRP, according to the transition pathways derived from sectoral models?"

4.2 Pillars and components of the NRRP

The Greek government opted to apply for the highest amount of funds available through the RRF, comprising both grants (€17.8 billion) and loans (€12.7 billion). The utilisation of the RRF resources is frontloaded, aligning with the underlying reasoning of the RRF Regulation: over 80% of the overall expenses associated with the NRRP have been planned to occur by the end of 2024; however, the actual implementation is challenging and may lead

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to delays. The NRRP consists of a comprehensive set of 175 measures, with 108 of them focusing on investments and the remaining 67 dedicated to reforms. It is organised around four main pillars: (i) "Green transition", (ii) "Digital transformation", (iii) "Employment, skills, and social cohesion", and (iv) "Private investment and transformation of the economy". These pillars are further divided into a total of 18 components (Table 8). In summary, the plan includes significant investments in energy networks and renewable energy (and storage), improving the energy efficiency of dwellings, promoting sustainable transportation, enhancing high-capacity networks and connectivity, digitising both the public and private sectors, improving education, implementing effective labour market policies, providing training and skill development for the workforce, improving social services, and enhancing healthcare.

Table 8: Structure of the Greek NRRP pillars and components. Source: (Hellenic Republic, 2023b)

Pillars and components		Funds allocated	
		€ billion	% of total
1	Green transition	6.2	33.6
1.1	Power-Up	1.2	6.5
1.2	Renovate	2.7	14.7
1.3	Recharge and refuel	0.5	2.8
1.4	Sustainable resource use, climate resilience and environmental protection	1.8	9.5
2	Digital transformation	2.2	11.8
2.1	Connect	0.5	2.8
2.2	Modernise	1.3	6.9
2.3	Digitalisation of businesses	0.4	2.0
3	Employment, skills, and social cohesion	5.2	28.2
3.1	Increasing job creation and participation in the labour market	0.8	4.2
3.2	Education, vocational education, training, and skills	2.3	12.5
3.3	Improve resilience, accessibility, and sustainability of health care	1.5	8.1
3.4	Increase access to effective and inclusive social policies	0.6	3.3
4	Private investment and transformation of the economy	4.9	26.5
4.1	Making taxes growth-friendly and improving tax administration	0.2	1.0
4.2	Modernise public administration	0.2	1.0
4.3	Improve the efficiency of the justice system	0.3	1.4
4.4	Strengthen the financial sector and capital markets	0.0	0.1
4.5	Promote research and innovation	0.4	2.4
4.6	Modernise and improve resilience of key economic sectors	3.7	20.3
4.7	Improve competitiveness and promote private investments and exports	0.1	0.3
	Total [10]	18.4	100.0
	RRF loan facility (not allocated)	12.7	

4.2.1 The "Green Transition" Pillar

The NRRP reforms and investments required to meet Greece's climate and environmental targets and handle the challenges and possibilities arising from the "Green Transition" pillar have been organised into four components,

[10] Note that the total exceeds the maximum financial contribution to Greece (net of expenses) by approximately €0.6 billion. It is not clear whether the discrepancy will be covered through the RRF loan facility or by national resources.

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which promote social welfare, economic and social resilience, and job creation:

→ **I. "Power up"**: This component's objective is to contribute to climate and energy targets through a series of investments that improve the resilience, capacity, and energy storage of the electricity system, enabling for higher penetration of RES in the energy mix. Electricity interconnections between the islands and the mainland are prioritised, particularly the connection of the Cyclades islands to the mainland's grid. These investments aim to lower energy costs and prices, phase out oil-fired power generation, and boost the islands' ability to sustain RES generation. Moreover, "Power up" implements reforms to safeguard the "RES-CHP Account's" financial stability and long-term viability, as well as to expedite the licencing process for new RES plants. This component will assist Greece's national goal for phasing out lignite by 2028 through the implementation of integrated support measures, including socioeconomic and environmental rehabilitation measures, for the redevelopment of affected areas, ensuring a just transition.

→ **II. "Renovate"**: This component includes reforms and investments that promote building renovation and energy efficiency upgrades, urban and spatial planning implementation, and the development of strategic "green" urban regeneration projects. With regards to the existing building stock's renovation, residential, commercial, industrial, and public buildings, as well as social infrastructure, will be upgraded with the goal of increasing energy efficiency. More specifically, the energy renovation programme for residential buildings will contribute up to 15% of the respective NECP target (60,000 households). Furthermore, a new action plan will be implemented to combat energy poverty with a particular focus on most vulnerable groups. In terms of urban planning, the expected reforms and investments will strengthen the urban ecosystem by modernising the legal framework for policy and promoting sustainable growth initiatives. Finally, this component aims to support the implementation of strategic, green, urban regeneration projects around the country.

→ **III. "Recharge and refuel"**: This component introduces reforms that allow for the installation and operation of EV charging infrastructure. It also encourages the investments needed to lay the groundwork for attaining the NECP target of 30% share of electric vehicles in the domestic market by 2030. The NRRP will specifically assist the construction of at least 8,000 charging points in key urban and suburban locations, as well as other publicly accessible points of interest across the country. The component also intends to support electrification of public transport by replacing old high-emission buses with electric ones and by providing incentives for the usage of battery electric vehicles as taxis. Furthermore, it will help to create industrial production units in innovative domains and technologies, such as e-mobility, hydrogen production, and carbon capture and storage. Finally, it facilitates the twin transition (green and digital) by introducing and implementing new digital technologies and by supporting low-carbon innovation.

→ **IV. Sustainable use of resources, climate resilience, and environmental protection**: This final component consists of three sets of actions that contribute to the "EU Taxonomy Regulation" objectives. The first set of actions contributes to waste management by adhering to waste hierarchy and circular economy principles and to water resource protection by implementing water-saving measures, to installing digital meters and remote-control systems, to building infrastructure for water management and wastewater treatment, and to implementing reforms that promote efficient and sustainable use of water resources. The second set of actions tries to protect the environment through reforestation initiatives and biodiversity conservation efforts, notably encompassing the restoration of more than 16,500 hectares of degraded forest ecosystems throughout Greece and considerably contributing to the National Reforestation Plan. The third set of actions focuses on strengthening and modernising the civil protection framework, as well as addressing climate change issues, as Greece is seriously affected by the rising severity and frequency of climate-related disasters and extreme events.

4.3 Working approach

To explore the short- and long-term impacts (i.e., emissions, technology capacity, and macroeconomic implications) of the NRRP packages and the respective investments related to the energy transition in the Greek residential and power sectors, and to provide answers to the overarching RQ presented above, we use two energy

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system models: a demand-side management model and an energy system optimisation model. The employed models, the sectoral deep-dives, and the scenario definitions are shortly presented in the subsections below. For more information on the models' characteristics, the case study's specifications, the simulated scenarios, and the models' parameterisation, we refer to IAM COMPACT Deliverable 4.9 "European sub-national deep dives", Section 4 ("Deep dive into Greece's National Energy and Climate Plan").

4.3.1 Modelling framework

We use two energy system models developed by the Technoeconomics of Energy Systems Laboratory (TEESlab) Modelling (TEEM) suite—namely, (a) a dynamic high-resolution demand-side management model and (b) an electricity supply system linear optimisation model. A short presentation of each model's characteristics is presented below.

4.3.1.1 DREEM

The Dynamic high-Resolution dEmand-sidE Management (DREEM) model is a fully-integrated energy demand and demand-side management simulation model, focusing on the building sector, which expands the computational capabilities of existing Building Energy System (BES) and demand-side models, by not only calculating energy demand, but by also assessing the benefits and limitations of demand flexibility, primarily for main end-users (consumers/citizens), and then for other energy system actors involved (e.g., suppliers, retailers, DSOs, TSOs, etc.) (Stavrakas & Flamos, 2020).

The main premise behind the development and the use of the DREEM model has been that, to have a more active participation to the energy transition, end-users first need to become more aware of the benefits from investing in new energy products and services. In this context, the novelty of the model lies in its potential to be used in a wide range of applications, not only to assess the existing technological infrastructure, but also to support the development of business models and regulatory innovations, which maximise the value of energy products and services, and monetise them, to fairly compensate end-users and other energy market actors. Overall, the DREEM model:

- Embodies key features towards the simulation of renewable energy, energy efficiency, and other demand-flexibility actions, like demand response, in the building sector.
- Builds on the concept of modularity consisting of multiple components, each of which is composed of additional modules, allowing for more flexibility in terms of possible system configurations and computational efficiency (high time resolution and quick simulations) towards a wide range of scenarios, to study different aspects of end-use and of the energy transition.
- Provides the ability to incorporate future technological breakthroughs in a detailed manner, such as the inclusion of heat pumps or electric vehicles, in view of energy transitions envisioning the full electrification of the heating and transport sectors.
- Produces outputs for a group of buildings, for example a neighbourhood, a district, a municipality, or an energy community.
- Serves as a basis for modelling domestic energy demand within the broader field of local, regional, and national energy systems in different geographical/climate and socioeconomic contexts. Currently the model's spatial resolution is mainly limited to EU Member States but, given the availability of historical data/observations the model can be expanded beyond the EU.

All the modules of the model are developed using the "Buildings" library, which is an open-source, freely available Modelica library for building energy and control systems. Alongside the Modelica models, Python scripts have been developed to model parts of the model's components, and to enable the interface with the Dymola simulation

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environment. The DREEM model is available open access under the "GNU AFFERO GENERAL PUBLIC LICENSE[11]" and is available on GitHub[12].

4.3.1.2 OSeMOSYS-GR

The Open Source energy MOdelling SYStem (OSeMOSYS) is an open-source energy system model generator used to determine the least-cost pathway by minimising the discounted cost of the electricity system while optimising the capacity and generation of each technology to meet the exogenous final energy demand (Howells et al., 2011). Here, we use OSEMOSYS-GR, a model developed in the context of IAM COMPACT to accurately model the Greek power system developments towards 2050. In OSEMOSYS-GR, the electricity supply system is represented by importing and extraction technologies, fossil-fired power plants using lignite, natural gas, oil, RES technologies (i.e., hydro, wind onshore and offshore, solar PV, biomass, geothermal), electricity storage (i.e., battery and pumped hydro), hydrogen production and consumption (namely electrolysers and fuel cells), transmission, and distribution systems, as well as interconnections with neighbouring countries.

4.3.2 Sectoral deep-dives

In this section, we provide current and future trends with regards to the energy transition in the Greek residential and power sectors. The core of Greece's energy transition agenda revolves around scaling up RES generation, with particular emphasis on wind (both onshore and offshore) and solar PV sources. At the same time, there is a deliberate focus on electrifying energy demand, notably in space and water heating and cooling as well as in transportation. A cross-sectoral commitment to enhancing energy efficiency underscores the broader goals outlined in the NECP and associated policy documents. While there is a concentrated effort to decrease dependence on lignite and oil, imported natural gas assumes a significant role (Karamaneas et al., 2023), particularly in electricity generation, building heating and industrial applications. In the wake of the Russian invasion of Ukraine and the ensuing escalation of gas prices, the Greek government is reassessing the role of natural gas as part of the updated and revised draft NECP. Despite the uncertainties surrounding specific plans for natural gas, there are discernible actions taken to curtail gas demand in all sectors, including increased support for RES and energy-efficiency measures. Simultaneously, there are contrasting indications such as planned investments to expand the gas network (naftemporiki, 2023) and even extract domestic natural gas, revealing an intricate and evolving landscape as Greece navigates the complex challenges of the global and European energy context.

4.3.3 Energy transition in the Greek residential sector

The recent updates on the EU energy policy landscape, which include the gradual phase out of fossil-fuel boilers in buildings, the reduction of the EU's dependence on natural gas, the accelerated uptake of energy-efficiency investments, and the creation of a new parallel Emission Trading System (ETS) on heating fuels in the buildings sector, affect directly the Member States' planning on the energy transition in the building sector (European Commission, 2021, 2022). It is in this context that Greece is also amending its NECP, which is expected to be published by June 2024.

Regarding the residential sector, which is considered critical for the achievement of Greece's energy transition and security objectives, as it is one of the major consuming sectors (almost 25% of final energy consumption), the first NECP back in 2019 aimed for the energy-efficiency upgrade (in part or in full) of 60,000 households annually, by 2030, as well as for the increase of natural gas consumption, and thus the country's energy dependency (Ministry of Environment and Energy, 2019).

Considering the above, the "Renovate" component of the NRRP can contribute to the achievement of the targets

[11] https://www.gnu.org/licenses/agpl-3.0.txt
[12] https://github.com/TEESlab-UPRC/DREEM

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set by the current NECP. More specifically, investments focused on the energy renovation of residential buildings are expected to contribute by up to 15% to the NECP target for the energy-efficiency upgrades in the residential sector, while the overall budget allocated for these actions is around €1.081 billion. The "Renovate" component consists of several investments focused on renovations in different sectors (Table 9):

Table 9. Funding instruments and financing mechanisms focused on renovations in the building sector under the "Renovate" component of the Greek National Recovery and Resilience Plan.

Sector	Short description	Budget allocated (€ million)
Energy renovation on residential buildings ("Saving at home")	Enhance the uptake of energy efficiency actions in the residential sector, with the aim of saving energy by at least 30%. It includes several energy efficiency interventions such as windows replacement, thermal insulation, and the upgrade of heating systems (e.g., use of heat pumps, etc.).	1,081
Energy and entrepreneurship	Enhance the uptake of actions to improve the energy efficiency of small and medium enterprises with the aim of saving at least 30%. The investments include measures such as building energy upgrades, energy upgrading of production processes, heat recovery systems within production processes, installation of "smart" energy systems, electric vehicles, etc.	450
Energy upgrade of public sector buildings and energy infrastructures of public entities	Renovations and energy upgrade of public infrastructure and buildings, energy upgrade of public lighting, with the partnership of the private sector.	200

4.3.4 Energy transition in the Greek power sector

The Greek power sector is currently undergoing structural transformations, marked by a shift towards a more sustainable, low-carbon, and diversified energy mix. In 2022, the total capacity for electricity production in Greece reached approximately 21.5 GW, with fossil fuels accounting for 42% and RES comprising the remaining 58% (IEA, 2023). Specifically, among conventional sources, natural gas accounts for 58% (5.2 GW) of fossil-fuel capacity. Notably, renewables are predominantly sourced from wind energy, contributing 4.5 GW (36% of RES), while solar PV and hydro (both large and small- scale) also play a substantial role in the electricity supply from RES (IEA, 2023).

Greece has limited capacity for interconnections and heavy reliance on imported fuels for electricity production (Kleanthis et al., 2022). The country has set ambitious climate and energy policy goals, including decarbonisation in the power sector by decommissioning its lignite power plants by 2028. Natural gas had been considered as an intermediate transition fuel to help phasing out lignite-fired generation before 2021 (Ministry of Environment and Energy, 2019). The 2022 energy crisis with the huge increase in international gas prices pushed back the Greek lignite phase out plans and forced the Greek government to reevaluate the role of natural gas in the national energy system.

Aiming to create a carbon-neutral power sector, the national energy planning emphasises the use of variable renewable energy (VRE), i.e., onshore wind, offshore wind, and solar PV, for power generation. Greece recently made important improvements to its RES electricity generation support schemes to increase VRE deployment rates. The country is also working on shortening the time required to licence and permit VRE, electricity infrastructure, and electricity storage projects. According to the revised draft NECP, the target is to have a cumulative capacity of 69 GW of VRE by 2050 (Hellenic Ministry of Environment and Energy, 2023b), a twelvefold increase compared to the installed capacity in 2020.

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Considering the above, the "Power up" component of the NRRP can contribute to the achievement of the VRE and storage capacity targets set by the current NECP, as it consists of measures focused on VRE and storage capacity growth (Table 10).

Table 10. The measures focused on renewable energy and storage capacity expansion under the "Power up" component of the Greek National Recovery and Resilience Plan.

Type of measure	Measure	Technology	Short description	Budget allocated (€ million)	Total capacity
Investment	Support of the installation of storage systems to enhance RES penetration.	Electricity storage (i.e., batteries, pumped hydro)	Installation of electricity storage capacity (700 MW) besides the long duration "Amfilochia" pumped hydro storage.	450	1.38 GW
Reform	Restructuring and enhancement of the "RES-CHP Account's" revenues following the Covid-19 contractionary impact on the account's balance.	VRE (i.e., wind onshore and solar PV)	Development and integration of at least 1 GW of new VRE capacity per year from 2023 until 2025, facilitated by the proposed reforms.	New investments will be indirectly triggered by increasing investor confidence and facilitating new RES projects financing. The reforms aim to accelerate the doubling of the installed capacity of RES in view of the lignite phase-out.	3 GW
Reform	Simplification of licensing procedure for RES.				

4.3.5 Scenario design

In this section, we present the application of the DREEM and OSeMOSYS-GR models to the case of Greece in terms of the scenarios that the models were used to simulate. In the following subsections, a short overview of the scenario design in this study is presented.

4.3.5.1 DREEM

Our study seeks to explore the energy transition of the Greek residential sector towards 2050, simulating six different scenarios (Table 11). "Scenario 1", "Scenario 2", "Scenario 3", and "Scenario 4" are based on the current NECP renovation rate goal of 60,000 renovations/year. More specifically, "Scenario 1" is based on the 2019 NECP targets mainly focusing on using natural gas as a transition fuel, while "Scenario 2", "Scenario 3", and "Scenario 4" are focused on investing in electrification (especially with heat pumps), differing in the timing of the natural gas phaseout beginning (2036, or 2031, or 2023, respectively). On the other hand, in "Scenarios 5" and "Scenarios 6", a reverse engineering approach is applied so that DREEM calculates the exact renovation rate required to achieve decarbonisation in the Greek residential sector by 2050 and 2040 (more ambitious target), respectively.

For all scenarios, further investigation is conducted regarding the environmental and economic impacts of investing in either natural gas or electrification. Economic impacts include, among others, fuel, renovation, and parallel ETS costs.

Table 11. Transition scenarios in the Greek residential sector by 2050.

Scenarios	Period	Interventions foreseen
1. "Existing national planning"	(2023-2030)	Annual natural gas penetration according to the current NECP 2030 targets (15.1% of total consumption). Annual heat pump penetration in order to achieve a 300% increase in heat pump installations.

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	(2031-2035)	Substitution of new natural gas boilers with heat pumps.
	(2036-2050)	Phaseout of the remaining natural gas boilers with heat pumps.
2. "Focusing on electrification #1"	(2023-2050)	60,000 oil boilers substitutions with heat pumps.
	(2036-2050)	Phaseout of the existing natural gas installations with heat pumps.
3. "Focusing on electrification #2"	(2023-2050)	60,000 oil boilers substitutions with heat pumps.
	(2030-2050)	Phaseout of existing natural gas installations with heat pumps.
4. "Interdependence from natural gas"	(2023-2050)	Phaseout of existing oil and natural gas boilers with heat pumps.
	Reverse engineering scenarios	
5_a. "Decarbonisation by 2050: Focusing on natural gas by 2030"	(2023-2030)	Annual natural gas penetration according to the current NECP 2030 targets (15.1% of total consumption). The remaining houses substitute their oil boilers with heat pumps.
	(2031-2050)	Phaseout of existing oil and natural gas boilers with heat pumps.
5_b. "Decarbonisation by 2050: Focusing on electrification"	(2023-2050)	Substitution of oil and natural gas boilers only with heat pumps.
6_a. "Decarbonisation by 2040: Focusing on natural gas by 2030"	(2023-2030)	Annual natural gas penetration according to the current NECP 2030 targets (15.1% of total consumption). The remaining houses substitute their oil boilers with heat pumps.
	(2031-2040)	Phaseout of existing oil and natural gas boilers with heat pumps.
6_b. "Decarbonisation by 2040: Focusing on electrification"	(2023-2040)	Substitution of oil and natural gas boilers only with heat pumps.

For all the scenarios under study, and after consulting with representatives from the Greek Ministry, it is assumed that all dwellings built before 2010 and with substituted heating technology are also renovated through envelope/window upgrades, as follows:

- **Before 1981:** Exterior wall insulation and window upgrades.
- **During the period 1981-2010:** Exterior wall insulation.

To evaluate the effectiveness of the NRRP's objectives about the uptake of renovations in the residential sector, we compare the NRRP's funding with the renovation costs derived from the DREEM model up until 2030.

4.3.5.2 OSeMOSYS-GR

We explore least-cost capacity expansion and electricity mixes that lead to a carbon-neutral power sector in Greece, according to key input assumptions, as these have been partially articulated in the revised draft NECP (Hellenic Ministry of Environment and Energy, 2023d). For this modelling exercise, we used the power sector emission target provided by the updated and revised draft NECP, i.e., decarbonisation in the power sector is achieved by 2040 (Hellenic Ministry of Environment and Energy, 2023a). All examined scenarios include the current national energy system planning with regards to phasing out lignite by 2028 and the short-term reinforcement of power interconnections with Albania, North Macedonia, Bulgaria, Italy, and Cyprus. With regards to electricity imports from the neighbouring countries, it is assumed that net electricity exports are achieved before 2050 and complete electricity independence (i.e., zero electricity imports) is achieved by 2050. Considering the above, we build the scenarios' baseline specifications. Additionally, we simulate the recovery measures as exogenous capacity additions for low-carbon technologies with OSeMOSYS-GR. In total, we define three scenarios

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that differ in terms of the simulated recovery measures. This allows us to evaluate the effectiveness of the NRRP's objectives about the short-term uptake of VRE and electricity storage in the Greek power sector.

The green recovery scenarios studied are:

- "**NDC_LTT**": Baseline scenario following the CO_2 emission and RES expansion targets articulated in the revised draft NECP. Specifically, energy-related CO_2 emissions should be reduced by 89% and 100%, by 2030 and 2040, respectively, compared to the 2005 levels. Furthermore, RES should become the dominant source of power generation, accounting for about 80% and 93.5% of the net electricity generation in 2030 and 2050. This scenario focuses on capacity expansion of VRE, electricity storage, and electrolysers for hydrogen production. Other RES technologies included in this scenario are geothermal, biomass, and hydro. The achievement of natural gas phaseout happens before the decarbonisation of the power sector (2040) due to the high adoption rate of green technologies.
- "**NDC_LTT_GR_21**": This scenario builds on the baseline and includes the "Support of the installation of storage systems to enhance RES penetration" measure (see Table **12**) for short-term electricity storage capacity expansion, as presented in the 2021 NRRP's "Power-up" component (Hellenic Republic, 2021).
- "**NDC_LTT_GR_23**": This scenario builds on "NDC_LTT_GR_21" and includes two additional measures: "Restructuring and enhancement of the RES-CHP Account's revenues following the COVID-19 contractionary impact on the Account's balance" and "Simplification of licensing procedure for RES" (see Table 10) for short-term VRE capacity expansion, as presented in the updated 2023 NRRP's "Power-up" component (Hellenic Republic, 2023b).

4.3.5.3 Model parameterisation

Before starting model-based scenario analysis, input assumptions used in the two models have been updated to match the specifications provided by Deliverable D4.3 ("Broad scenario logic") of the IAM COMPACT project. Specifically, technology data (e.g., capital costs, fixed and variable operating and maintenance costs, efficiencies, capacity factors, etc.) in the residential and power sectors have been retrieved from the EU Reference Scenario 2020 database (European Commission et al., 2021) and the IEA's "World Energy Outlook 2022" report (IEA, 2022). Moreover, price projections for fossil fuels were also visually extracted from the "World Energy Outlook 2022" report (IEA, 2022).

Specifically, DREEM was used to parameterise and simulate the energy demand in the Greek residential sector towards the different energy transition scenarios presented in Table **12**. To do so, several parameters were considered such as the various climate and weather data across Greece, the different building characteristics across the Greek residential sector based on the dwellings' construction period (here, we used data derived from the "TABULA" database[13], an online tool that contains information about the national typologies of buildings in different European countries classified per climate zone and construction period), and several occupancy and activity profiles using historical and statistical data regarding occupancy and activity patterns in Greece, which are connected with the use of Heating, Ventilation, and Air-conditioning systems (HVAC) and appliances. The type of HVAC systems, the chosen appliances, their daily use, and their characteristics are based on statistical data at the national level (Hellenic Statistical Authority, 2020). Finally, to investigate the environmental and economic impacts of each scenario, DREEM also received as inputs several factors related to technological costs, energy, and carbon prices, as well as emission factor values for the case of Greece.

4.4 Results

This section presents and discusses short- and long-term impacts of the investments and reforms related to the

[13] https://webtool.building-typology.eu/#bm

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energy transition in the Greek residential and power sectors.

4.4.1 Evaluating the effectiveness of the National Recovery and Resilience Plan in boosting energy efficiency in the Greek residential sector

Overall, modelling outcomes provide projections on the energy consumption by fuel, the total energy savings achieved, the annual and cumulative carbon footprint, and the annual and cumulative ETS-relevant, fuel, and renovation costs in the Greek residential sector under different transition scenarios by 2050. In this study, our analysis focuses primarily on the renovation costs derived in each scenario to examine the effectiveness of the NRRP's allocation of funds. More specifically, we present the annual and the total renovation costs towards the short-term energy transition, i.e., 2030, aiming to understand whether the currently allocated national funding is supposed to meet the renovation objectives.

Figure 47 presents the annual renovation costs for "Scenario 1", "Scenario 2", "Scenario 3", and "Scenario 4", i.e., the scenarios that are based on the current NECP renovation rate (60,000 dwellings to be renovated annually). Note that "Scenario 2", "Scenario 3", and "Scenario 4" lead to the same annual renovation costs, as they follow the same trend until 2030. Moreover, Table 12 and Figure 48 present the total renovation costs for each scenario, the allocated budget for energy-efficiency renovations based on the NRRP, and the NRRP's contribution to the renovation costs of each scenario. The allocation of the NRRP's funding follows a "split" rule, i.e., 2/3 of the overall funding by 2025, and 1/3 by 2030 in line with the other model-based transition scenarios presented in Section 3. Results show that, in all four scenarios, the NRRP covers the target of contributing to the 15% of the NECP's target by 2030 regarding energy upgrades in the Greek residential sector. The modelling results point to a subsidy rate for renovations that is broadly consistent with the "Saving at Home" programmes (20-50%). A caveat is that these are economy-wide numbers and tailored analysis is required to identify the economic impacts by location, income, building age, etc.

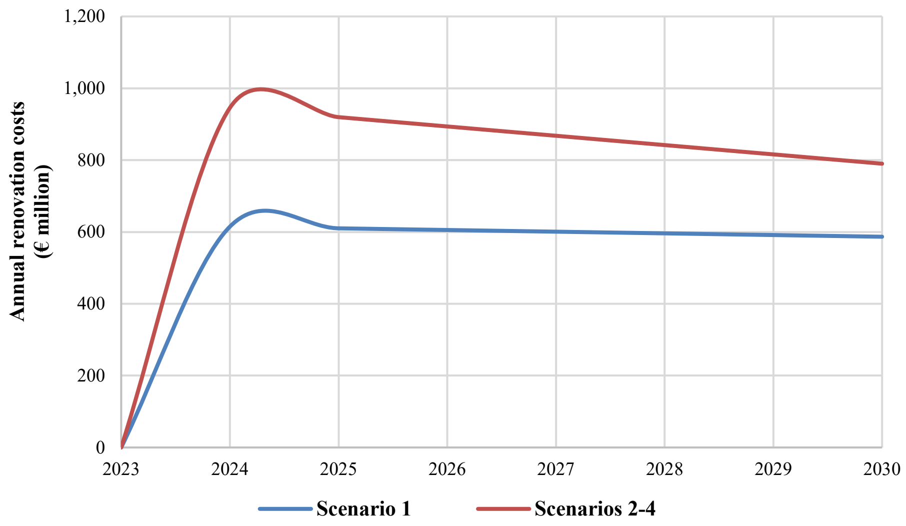

Figure 47: Annual renovation costs (€ million) for "Scenario 1", "Scenario 2", "Scenario 3", and "Scenario 4", as derived from the DREEM model.

Table 12. Total renovation costs by 2030 (€ million) for "Scenario 1", "Scenario 2", "Scenario 3", and "Scenario 4", and national allocated budget based on the National Recovery and Resilience Plan along with its contribution to each scenario under study.

	Renovation costs by 2025 (€ million)	**NRRP budget by 2025** (€ million)	**NRRP's contribution**	**Renovation costs by 2030** (€ million)	**NRRP budget by 2030** (€ million)	**NRRP's contribution**
"Scenario 1"	1,225	720.7	58.8%	4,205	1,081	25.7%

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"Scenarios 2-4"	1,865		38.6%	6,074		17.8%

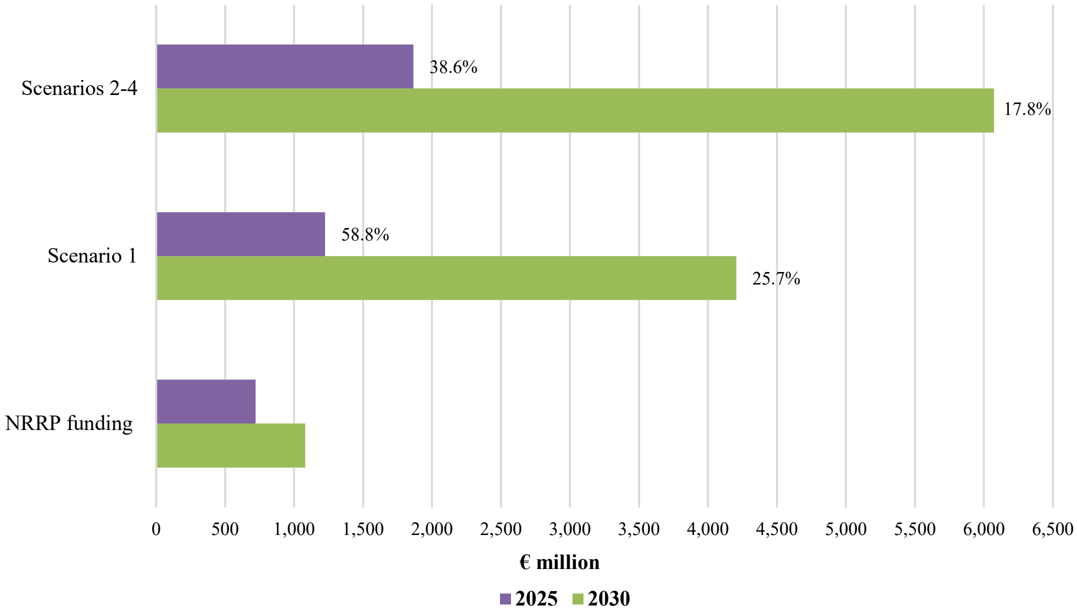

Figure 48: Total renovation costs by 2030 (€ million) for "Scenario 1", "Scenario 2", "Scenario 3", and "Scenario 4", and national allocated budget based on the National Recovery and Resilience Plan along with its contribution to each scenario under study.

As a next step, we proceed with the same analysis for the scenarios that expand the current NECP renovation rate and are formulated through a reverse engineering approach, i.e., the scenarios focused on achieving decarbonisation by 2050 and 2040, respectively ("Scenario 5_a", "Scenario 5_b", "Scenario 6_a", and "Scenario 6_b"), in the Greek residential sector.

Modelling outcomes from the DREEM model show that, to achieve decarbonisation in the Greek residential sector by 2050, around 100,000 dwellings should be renovated on average, annually (which corresponds to roughly a 2.5% annual renovation rate on average); while, to achieve decarbonisation by 2040, around 145,000 dwellings should be renovated annually (or roughly a 3.5% annual renovation rate, which is considerably higher than current and projected future renovation rates in EC scenarios). Figure 49 presents the annual renovation costs for "Scenario 5_a" and "Scenario 5_b" (decarbonisation scenarios with an increased annual renovation rate of 2.5%, i.e., ~100,000 renovations/year) and "Scenario 6_a" and "Scenario 6_b" (decarbonisation scenarios with an increased annual renovation rate of 3.5%, i.e., ~145,000 renovations/year). Moreover, Table 13 and Figure 50 present the total renovation costs for each scenario, the allocated budget for energy-efficiency renovations based on the NRRP, and the NRRP's contribution to the renovation costs of each scenario. Again, the allocation of the NRRP's funding follows a "split" rule, i.e., 2/3 of the overall funding by 2025, and 1/3 by 2030.

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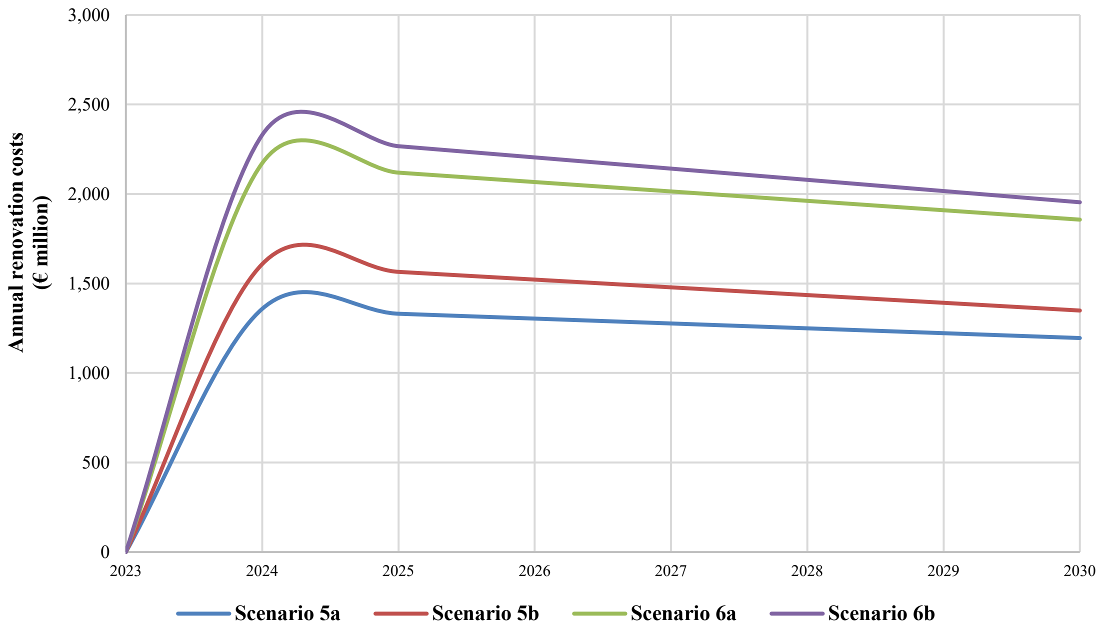

Figure 49: Annual renovation costs (€ million) for "Scenario 5a", "Scenario 5b", "Scenario 6a", and "Scenario 6b", as derived from the DREEM model.

Table 13. Total renovation costs by 2030 (€ million) for "Scenario 5_a", "Scenario 5_b", "Scenario 6_a", and "Scenario 6_b", and national allocated budget based on the National Recovery and Resilience Plan along with its contribution to each scenario under study.

	Renovation costs by 2025 (€ million)	**NRRP budget by 2025** (€ million)	**NRRP's contribution**	**Renovation costs by 2030** (€ million)	**NRRP budget by 2030** (€ million)	**NRRP's contribution**
"Scenario 5_a"	2,689	720.7	26.8%	8,938	1,081	12.09%
"Scenario 5_b"	3,173		22.7%	10,350		10.44%
"Scenario 6_a"	4,291		16.8%	14,099		7.67%
"Scenario 6_b"	4,596		15.7%	14,992		7.21%

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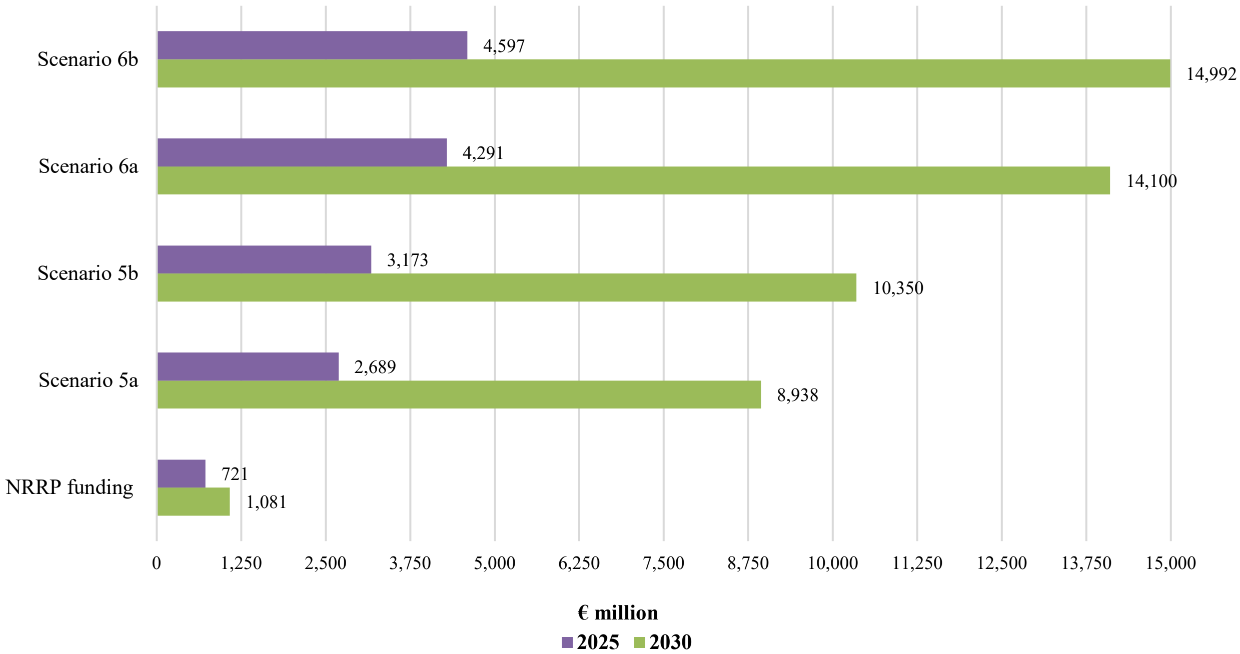

Figure 50: Total renovation costs by 2030 (€ million) for "Scenario 5_a", "Scenario 5_b", "Scenario 6_a", and "Scenario 6_b", and national allocated budget based on the National Recovery and Resilience Plan along with its contribution to each scenario under study.

In the case of "Scenario 5_a", "Scenario 5_b", "Scenario 6_a", and "Scenario 6_b", the current NRRP's funding does not meet the target of covering at least the 15% of the annual renovations required to achieve decarbonisation by either 2050, or 2040. The deviation from this target and the necessary increase in the NRRP's funding are presented in Table 14. It becomes apparent that, if Greece strives to be more ambitious and meet the EU's objectives for a decarbonised building sector by 2050 at the latest, a significant increase in funding for the renovation of buildings will be needed. More specifically, the current NRRP's funding will need to increase by at least 19%, to achieve decarbonisation by 2050 (19% if the focus is on investing in natural gas as a transition fuel and 30% if the focus is on an alternative transition pathway based on electrification and diffusion of heat pumps). If the target is to achieve decarbonisation by 2040, the allocated funding to renovate buildings should be almost doubled (49% increase if the focus is on investing in natural gas as a transition fuel and 52% if the focus is on an alternative transition pathway based on electrification and diffusion of heat pumps).

Table 14. Deviations from the current National Recovery and Resilience Plan's target (i.e., 15%) and necessary increase in order to boost energy efficiency in the Greek residential sector, as derived from the results of the DREEM model for "Scenario 5_a", "Scenario 5_b", "Scenario 6_a", and "Scenario 6_b".

	Renovation costs by 2030 (€ million)	**Money needed to cover the 15% target by 2030** (€ million)	**NRRP's budget by 2030** (€ million)	**Deviation** (€ million)	**Necessary increase in the current NRRP's budget**
"Scenario 5_a"	8,938	1,341	1,081	259.7	**19%**
"Scenario 5_b"	10,350	1,552		471.5	**30%**
"Scenario 6_a"	14,099	2,115		1,034	**49%**
"Scenario 6_b"	14,992	2,249		1,168	**52%**

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4.4.2 Evaluating the effectiveness of the National Recovery and Resilience Plan in boosting RES and storage capacity expansion in the Greek power sector

We present modelling results from OSeMOSYS-GR in terms of short- and long-term impacts related to primary energy, CO_2 emissions, capacities, and investments.

4.4.2.1 Power generation mix

Across all scenarios there is a consistent pattern of a 100% reduction in electricity generation from biomass, lignite, gas, and oil used for electricity generation by 2040, signifying a complete phaseout of these traditional energy sources and complete dominance of renewable energy in the power mix. In the "NDC_LTT" and "NDC_LTT_GR_21" scenarios, solar energy demonstrates a remarkable growth with a 1189% increase in generated electricity by 2050 (0.202 EJ) compared to 2021 levels (0.015 EJ). This underscores a substantial shift towards solar energy as a pivotal component of Greece's energy supply mix. Wind also exhibits a significant expansion. According to the "NDC_LTT" and "NDC_LTT_GR_21" scenarios, electricity generation from wind energy increases by 1002% in 2050 (0.349 EJ) compared to 2021 levels (0.032 EJ). This signals a strong trajectory towards the increased adoption of wind power, both onshore and offshore, in Greece. Figure 51 presents the power generation mix per source and scenario for the years 2025, 2030, 2035, 2040, 2045, and 2050.

The cross-comparison of the scenarios reveals significant differences in fossil-fuel use in the short-term and similarities in RES exploitation in the long term. Specifically, in 2025, we observe a 54.5% reduction in the electricity produced by lignite in the "NDC_LTT_GR_23" scenario compared to the "NDC_LTT" and "NDC_LTT_GR_21" scenarios. In the same year, the reduction in electricity generation from natural gas in the "NDC_LTT_GR_23" scenario compared to the "NDC_LTT" scenario is 14.1%. The reduction of fossil-fuelled electricity generation is offset by the increase in power produced by renewable energy as electricity demand is exogenous in this modelling framework. We find that primary energy from solar and wind in 2025 increases by 24.4% and 10.1%, respectively, when comparing the "NDC_LTT_GR_23" scenario with the "NDC_LTT" scenario. In 2050, the impacts of the recovery measures are negligible, considering that electricity generation from solar and wind are almost the same for all scenarios under study.

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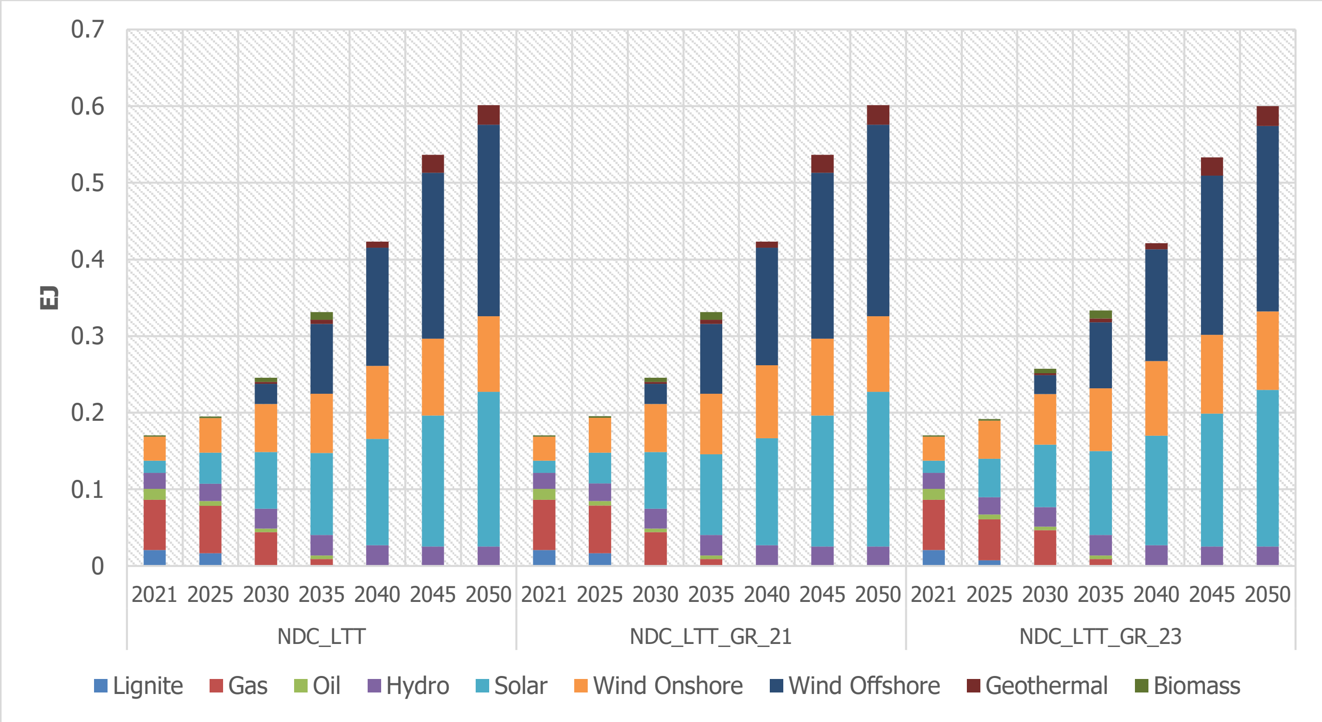

Figure 51: Least-cost annual power generation mixes for "NDC-LTT", "NDC_LTT_GR_21", and "NDC_LTT_GR_23" scenarios.

4.4.2.2 CO_2 emissions

The short-term impacts on fossil-fuel use for power generation entail a significant CO_2 emission reduction. The "NDC_LTT_GR_23" scenario achieves 30.3% fewer CO_2 emissions in 2025 compared to the "NDC_LTT" scenario. This is translated into 85.5% and 43.4% CO_2 emission reductions compared to the CO_2 emissions in 2005 and 2021, respectively. This large emission reduction is mostly due to the displacement of lignite and gas by solar and wind in the electricity mix. However, this improved performance in terms of CO_2 emissions is discontinued in 2030 onwards due to the absence of additional recovery measures. We also see that the complete phaseout of fossil fuels (exogenous for lignite and endogenous for natural gas and oil) leads to decarbonisation in the power sector by 2040, so differences across scenarios in the long term would be limited. Figure 52 presents the CO_2 emissions from power generation per scenario for the years 2025, 2030, 2035, and 2040.

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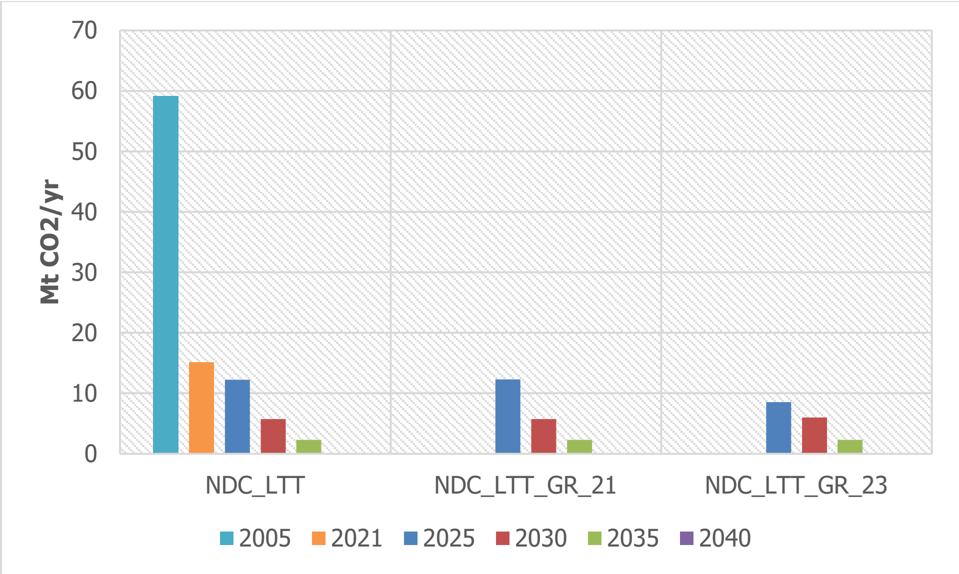

Figure 52: CO2 emissions from power generation over 2005-2040 for the "NDC-LTT", "NDC_LTT_GR_21", and "NDC_LTT_GR_23" scenarios.

4.4.2.3 Electricity capacity

Modelling results show an increase in electricity capacity by 2050 in all the three scenario variants, projecting a growth of approximately 108 GW compared to the 2021 levels, dominated by solar PV installations and wind power—both onshore and offshore. This finding signifies higher total electricity capacity requirements than those articulated by the updated and revised draft NECP (~82 GW increase from 2021 until 2050). This difference shows that, to create a fully renewable capacity mix, more ambitious RES targets will be required. In line with the EU's goals, results also project a complete phaseout of lignite-fired electricity capacity post-2025 (in 2025 there is ca. 2.5 GW capacity, which then becomes zero). After 2040, remaining fossil gas and oil power plants (ca. 5.5 GW) are only used as cold reserves, not contributing to the power generation mix. In the "NDC_LTT" scenario, solar power capacity increases by 36.3 GW in 2050, compared to 2021 levels (Figure 53). Similarly, wind and geothermal power are expected to contribute significantly, with increases of 27.7 GW (19.7 GW offshore and 8 GW onshore wind) and 7.9 GW, respectively, by 2050 compared to 2021 levels. The high increase of geothermal capacity is owing to the lack of dispatchable power plants that can generate dependable power to consistently meet demand considering that gas plants will not operate after 2037. In the "NDC_LTT_GR_23" scenario, solar and wind power increase by 36.8 GW and 27.5 GW from 2021 until 2050. The small differences between the two scenarios are due to the frontloaded capacity expansion that takes place between 2023 and 2025 in the "NDC_LTT_GR_23" scenario. Notably, hydrogen increases its capacity in 2050 by 14.2 GW compared to 2021 levels, having a larger role on the evolving energy landscape mostly to provide seasonal storage to the RES-dominated system. In contrast, hydro capacity displays a modest increase of 0.8GW, which signals the planning focus on VRE capacity expansion and the development stagnation of hydro projects in Greece.

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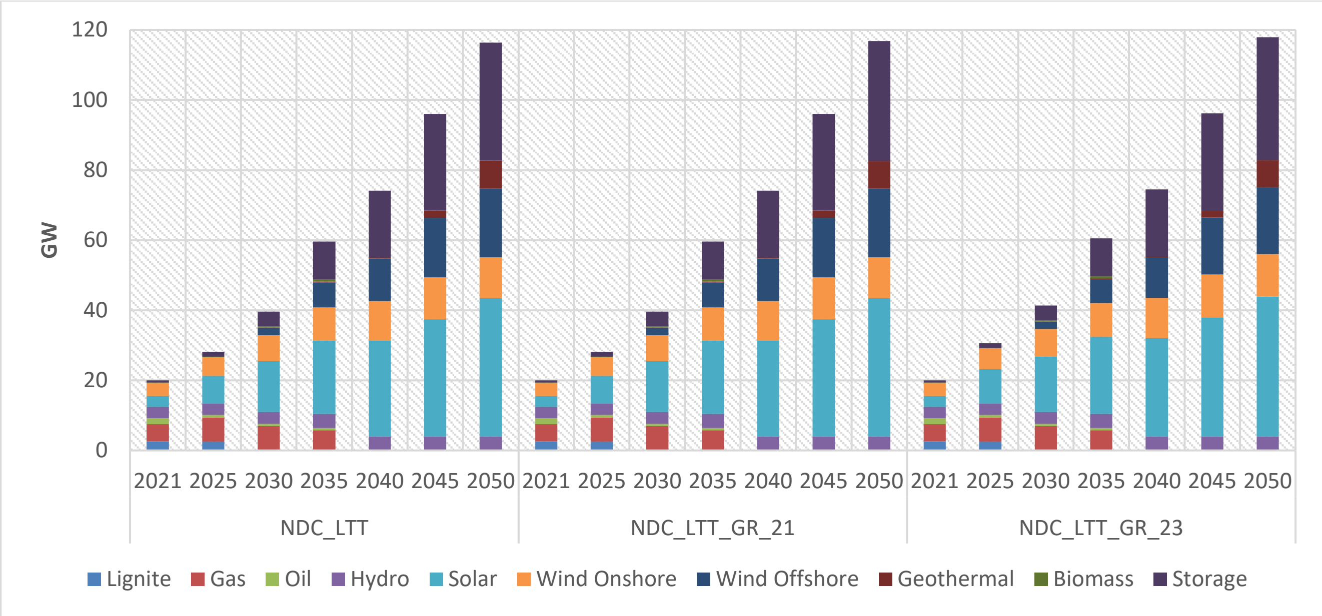

Figure 53: Electricity capacity (in GW) for the "NDC-LTT", "NDC_LTT_GR_21", and "NDC_LTT_GR_23" scenarios.

Figure 54 shows the changes in electricity capacity by technology in 2025 and 2050 across the three scenario variants. While overall trends align, a slight difference in solar electricity capacity shares can be observed, emphasising the impact of scenario assumptions on specific RES outcomes. Specifically, solar capacity in 2025 has a 28% share in total electricity capacity in the "NDC_LTT" and "NDC_LTT_GR_21" scenarios, while in the "NDC_LTT_GR_23" scenario its share is projected to increase to 32%. In 2050, all scenarios project almost the same share for solar electricity capacity in the total capacity mix (~29%) with wind accounting for 23% and electricity storage for 25%.

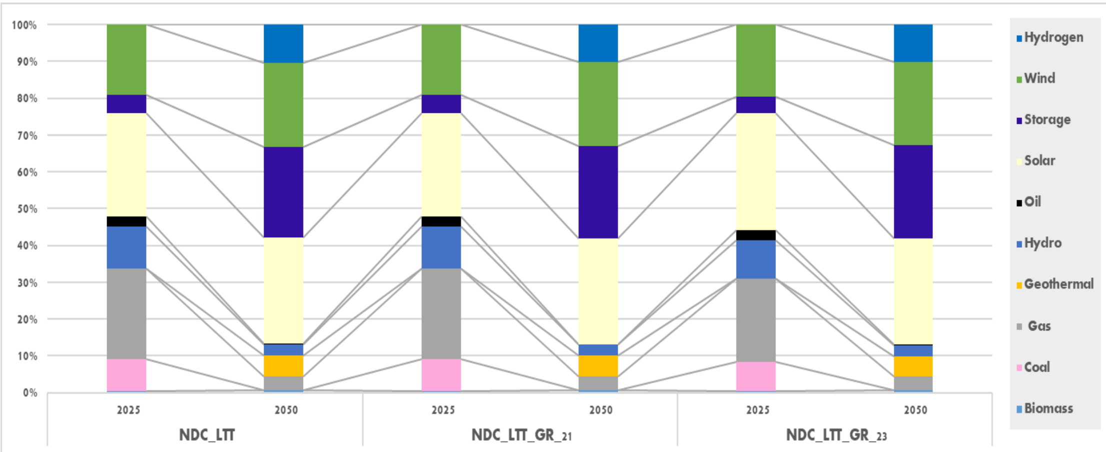

Figure 54: Changes in 2050 compared to 2025 in electricity capacity mix for the "NDC-LTT", "NDC_LTT_GR_21", and "NDC_LTT_GR_23" scenarios.

4.4.2.4 Investments in electricity supply

The energy investment landscape in Greece will undergo noteworthy changes as overall investments in the electricity supply will increase by 71.9% in 2050 compared to the 2025 levels. This is particularly evident in wind energy investments, which are projected to increase by 416% in 2050. Wind electricity experiences substantial investment growth, averaging a total of 2 billion USD annually, indicating increased focus on and funding in this sector. This significant increase in wind energy investments is, to a large extent, due to the development of offshore wind projects, which have much higher capital costs than onshore wind projects. Furthermore,

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geothermal electricity investments surge to about 0.8 billion USD on average. Similarly, investments in solar energy sources are projected to surpass 0.6 billion USD on average annually, benefiting from the large reduction in PV capital costs. Investments in electricity storage will reach an average of 1.2 billion USD on a yearly basis, with the larger share of this cost being attributed to batteries, whose long-term capacity needs are much higher that pumped hydro. Finally, investments in electrolysers overcome an average of 0.3 billion USD annually, which will be required to meet the increasing hydrogen demand towards 2050. Our results suggest a significant shift in investment towards RES, particularly in wind and solar electricity, which also reflects on the country's commitment to cleaner and sustainable energy solutions.

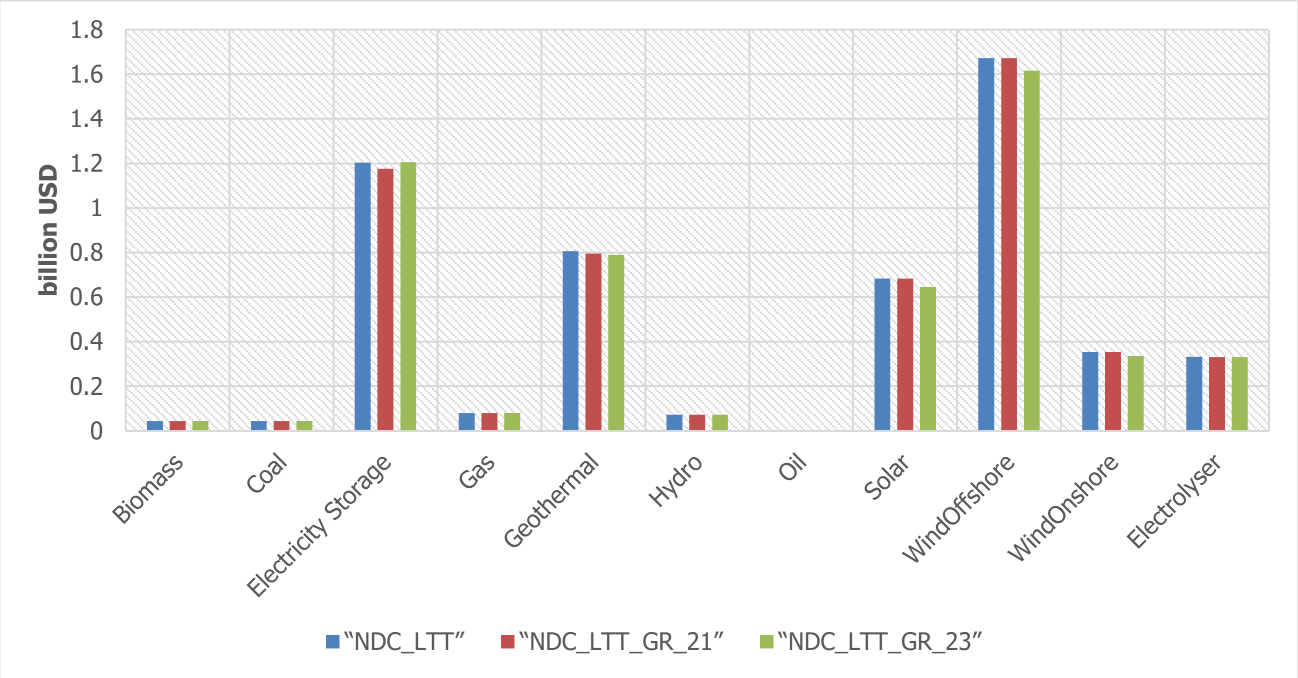

Figure 55: Average annual investment per technology for the "NDC-LTT", "NDC_LTT_GR_21", and "NDC_LTT_GR_23" scenarios over 2025-2050

It should be noted that throughout the simulation period (2023-2050) there are small investments in hydropower (~2 billion USD cumulatively), since the hydro potential has been already exploited to a great extent and the strict environmental constraints prevent its further development in Greece. According to current national energy planning, another 1.2 billion USD and 2.2 billion USD will be invested by 2025 in one lignite and three natural gas plants. Investments in oil-based electricity are absent, in line with climate objectives and due to the expanded grid interconnections of islands with the mainland limiting the need for diesel-fired plants. Overall, the proposed investments and reforms of the NRRP considered in the "NDC_LTT_GR_23" scenario will lead to monetary savings amounting to 3.6 billion USD compared to the "NDC_LTT" scenario, with most of them being realised in the short term. Table 15 presents the monetary savings achieved for six selected years of the modelling horizon. As shown in the table, the investment savings due to the announced NRRP recovery measures are larger in the short run.

Table 15. Investment savings from the implementation of recovery measures for VRE and storage capacity expansion in the Greek power sector.

Year	Total investments without recovery measures (Million USD)	Investment savings with recovery measures (Million USD)	Investment savings with recovery measures (% of total investments)
2025	3,005	113,3	3.77
2030	5,476	211,1	3.39
2035	5,040	161,7	3.21
2040	5,136	104,8	2.04

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2045	4,286	105,8	2.47
2050	5,186	44,7	0.48

4.5 Discussion and Conclusions

Overall, modelling results show that the current NRRP's funding can play an important role in the short term, if targeted towards the expansion of key RES technologies such as heat pumps and VRE, but will not have significant impacts in the long-term decarbonisation pathways of the Greek power and residential sectors, and thus private investments will be required to cover the lack of public funding. In this regard, a strategic private investment plan that complements the NRRP with specific objectives and concrete evaluations of private investment benefits in terms of added value, job creation, and environmental impacts should be developed. As suggested by our cost calculations, the NRRP seems much more important in the residential sector compared to the power sector, where low-carbon options (i.e., wind onshore and solar PV) are already cost competitive with fossil-fuel technologies. Of course, additional research should examine the key issues and challenges related to the Greek energy transition, such as just transition in areas affected by the lignite phaseout (i.e., Western Macedonia and Megalopolis), energy poverty and vulnerable households, energy prices, market reforms, etc., as well as look into transport and industry, which were not investigated in this study and have the most hard-to-abate segments like aviation, shipping, steel making, cement, etc.

4.5.1 Energy transition in the Greek residential sector

Our work focused on the short-term renovation costs foreseen in different transition scenarios to examine the effectiveness of the NRRP's funding. We find that the NRRP funding is adequate to meet the target of contributing to the 15% of the NECP's target by 2030 regarding the energy upgrade of dwellings (60,000 renovations/year). However, in the case of decarbonisation scenarios by 2050 and 2040 (requiring 100,000 and 145,000 renovations/year required, respectively), we see that the current NRRP's funding does not meet the target of covering the 15% of renovations. Consequently, to support Greece in delivering on the 2030 saving targets, significant contribution from private funding sources will be needed. Furthermore, targeted policy measures enabling the mobilisation of private investments in energy efficiency should be developed and innovative financing mechanisms and private financial products for energy efficiency—and especially the renovation of existing buildings and the massive uptake of heat pumps—should be promoted (European Commission, 2023).

In this direction, one-stop-shops can be effective at raising awareness of the technical and financing options as well as providing a combination of technical and financial assistance for energy efficiency renovations in the residential sector. One-stop-shops may directly provide financing for a project through consumer or business loans, mortgages, asset-based financing, etc. or function as an intermediary, connecting consumers with public or private financiers. They can also bring multiple households with similar retrofit needs together, thus acting as project aggregators, creating economies of scale, reducing the administrative and quality-assurance burden for individual owner-occupiers, and enabling standardisation of projects for financial investors and enhancing the overall "bankability" of such projects. Furthermore, financial institutions in Greece may offer energy efficiency lending products that fulfil the needs of various types of clients in the residential market segment, providing prospective clients with a wide variety of options. Finally, on-bill and on-tax financing are forms of innovative home-based financing, in which mechanisms are established to transfer debt repayment obligations from the previous to the following owner by linking debt to the property itself. Mechanisms can also be implemented to allow tenants to contribute to loan repayments through an additional fee on the property's tax, or energy bill, which can be partially or completely offset by reduced energy consumption.

4.5.2 Energy transition in the Greek power sector

We find that the investments and reforms of the NRRP can imply a significant short-term reduction in fossil-fuel use and CO_2 emissions from the power sector due to the increased deployment of renewable energy. However, the long-term impacts of the NRRP's recovery measures on primary energy and emissions are negligible, as in all

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scenarios the electricity sector is nearly decarbonised by 2040. We also observe that the recovery package for VRE and storage capacity expansion will lead to minor monetary savings, mostly in the short run. This leads us to the conclusion that significant private funds should be mobilised and current policy mechanisms for the deployment of renewable electricity generation (e.g., feed-in premiums, contracts for differences, investment subsidies, power purchase agreements, etc.) should be strengthened to achieve the ambitious RES electricity penetration and CO_2 emission reduction targets. In this regard, the NRRP's reform envisioned for the RES-CHP Account is crucial to ensure that the account is sufficiently funded in a transparent and sustainable manner to maintain investors' confidence. In addition, the government should monitor the impacts of the NRRP's reform regarding the RES licencing procedure to ensure they lead to faster project deployment in a transparent manner, as the renewable industry has indicated that large complex fossil projects have been awarded licences in much shorter timeframes than simpler renewable energy projects.

A key shortcoming of the NRRP appears to relate to the lack of any reference to the strengthening of the manufacturing industry of energy systems and components, considering that their domestic production and export creates more employment opportunities and expertise domestically compared to the mere installation (and operation) of RES capacity. According to the Institute of Energy for South-East Europe (IENE), manufacturing of energy components generates a greater number of direct jobs than those created during the installation, operation, and maintenance phase of RES projects (Stabolis & Terzidou, 2021). As such, there is a significant concern that decarbonisation in the power sector may not create a sufficient number of employment opportunities when jobs in the entire value chain of technologies are considered. This also applies to the percentage of domestic added value derived from the installation of photovoltaic and wind technologies, but also batteries, electrolysers, and heat pumps. If Greece fails to substantially increase the percentage of domestic added value in the development of RES units, most future investments will contribute to the growth of imported energy components and will be directed towards foreign countries (e.g., China for imported PV panels and batteries, Denmark for wind turbines), while Greece will only reap benefits during the installation and operation phases. Therefore, considering the large, anticipated investments, it is imperative that the increase of the domestic added value of green projects be prioritised, such as the ongoing Green HiPo project that aims at the manufacturing fuel cells and electrolysers for the production of power and green hydrogen in Western Macedonia, by encouraging local production of a significant proportion of the components and equipment, hence fostering the creation of highly trained jobs.

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