NEGEM

Quantifying and Deploying Responsible Negative Emissions in Climate Resilient Pathways

Quantify the socio-economic value of intra-European collaboration

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Editors/Authors: Mai Bui, Nixon Sunny, Solene Chiquier, Piera Patrizio, Niall Mac Dowell.

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1.0	15.03.2024	ICL	Mai Bui (ICL), Nixon Sunny (ICL), Solene Chiquier (ICL), Piera Patrizio (ICL), Niall Mac Dowell (ICL) / Kati Koponen (VTT)

Partners

VTT – VTT Technical Research Centre of Finland Ltd, Finland
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Executive Summary & Policy Relevant Messages

Negative emission technologies and practices (NETPs) will play a vital role in delivering the Paris Agreement's 1.5°C target. However, there are still, uncertainties about their carbon dioxide removal (CDR) potential, cost and up-scaling, as well as concerns about their side-effects and their interactions with the Sustainable Development Goals (SDGs). Particularly, deploying NETPs at large-scale will trigger significant structural changes in our economy, with important socio-economic impacts at national and regional scales.

The MONET-EU framework, developed in the previous NEGEM deliverables D7.1, D7.2 and D7.3 of WP7, is a spatio-temporal explicit modelling and optimisation framework that provide insights into the techno-economic, and bio-geophysical implications of deploying NETPs, *i.e.* afforestation/reforestation (AR), bioenergy with carbon capture and storage (BECCS), biochar, and direct air carbon capture and storage (DACCS), within the European Union (EU). This work also aims to evaluate to socio-economic impacts of deploying this extended suite of NETPs in the EU economies. This is done by combining the MONET-EU framework with the JEDI tool, to quantify key macro-economic impacts associated with the deployment of NETPs, *i.e.* direct value added (DVA) and jobs creation.

It is assumed that EU Member States must meet a cumulative CDR target of up to 81 Gt CO_2 of removal by 2100. This target is a proxy for the remaining EU carbon budget and is obtained from the IPCC P2 pathway by applying a responsibility-based burden-sharing principle, as detailed in the NEGEM deliverables 4.3 and 7.2 of WP4 and WP7, respectively.

When inter-regional supply chains are deployed, jobs can be created across multiple countries. To meet the 81 $GtCO_2$ removal target by 2100 in the EU-28, the "Cost" case study mainly relies on cheaper biomass-based NETPs such as afforestation (AF), biochar and BECCS, resulting in lower average CDR cost of \$240/tCO_2 removed. These biomass-based CDR methods are expected to increase direct value added (DVA) in the agricultural and forestry sectors. The "Jobs" case study prioritizes technical CDR methods such as DACCS which increases average CDR cost to \$529/tCO_2 removed by 2100. The "Job" scenario results in increased DVA and years of employment in economic sectors such as manufacturing, construction, utilities, and scientific R&D.

For both "Cost" and "Jobs" case studies, large-scale NETPs deployment leads to an observable growth in DVA and cumulative job years by 2100 in *all* EU-28 regions. These case studies demonstrate that inter-regional supply chains are deployed, which creates jobs across different regions. This highlights the value of intra-European collaboration in delivering EU-level CDR targets. Hence, collaboration amongst the EU member states can create economic opportunities across the different regions and industries.

This work provides further understanding on which key factors are able to contribute towards a socially equitable, financially viable, technically feasible, and ecologically sustainable pathway for NETPs deployment across Europe. Large-scale NETPs deployment will require significant changes to the structure of our economy and will likely lead to positive socio-economic impacts at the regional and national scale. A sustainable pathway to scale the NETPs portfolio in line with the CDR requirement of the 1.5°C Paris Agreement target would be to balance regional CDR objectives with affordability, whilst still enabling macro-economic growth and providing employment.

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1. Introduction

The role of negative emission technologies and practices (NETPs) has become widely acknowledged in delivering the Paris Agreement's 1.5°C objectives (COP21, 2015; IPCC, 2018, 2022). However, the global deployment levels of NETPs are currently very low, and their carbon dioxide removal (CDR) potential, cost, scaliability, side effects, and ease of monitoring, reporting and verification (MRV), public acceptance are highly debated (Fuss et al., 2018; Bui and Mac Dowell, 2022; Geden et al., 2023; Smith et al., 2023).

The deployment of NETPs will be crucial in the transition to net zero emissions at the national and regional scale. It will be needed to offset residual GHG emissions, especially those from hard-to-abate sectors such as aviation, agriculture or industry. As demonstrated in NEGEM WP4 (Tasks 4.5) and earlier WP7 (Tasks 7.3) deliverables, the levels of large-scale NETPs deployment will vary significantly across different regions, owing to differences in resources availability (e.g., water, land and biomass), climate (e.g., temperature, relative humidity) and techno-economic factors (e.g., cost of capital). Each type of NETP will contribute different economic activities (e.g., agriculture, construction, manufacturing, forestry etc.) and will not be evenly distributed across regions. Therefore, to quantitatively understand the role and value of NETPs to society, it will be important to analyse the socio-economic impacts of deploying NETPs at the national and regional scale, whilst also investigating the impacts of intra-European collaboration.

To address these important gaps, the aims of Task 7.4 of the NEGEM project are to:

1) Evaluate the socio-economic implications associated with the deployment of NETPs within the EU using the MONET-EU-JEDI framework under two different scenarios – "Cost" (minimises cost) and "Jobs" (maximises socio-ecnomic impacts) case studies.
2) Identify key factors that contribute towards a socially equitable, financially viable, technically feasible, and ecologically sustainable pathway for NETPs deployment across Europe.

To this end, this work employs the extended version of the MONET-EU framework, which includes enhanced weathering (both basalt and dunite rocks) and forestry residues as an alternative biomass feedstock for BECCS and biochar (developed in Task 7.1 and 7.2). To quantify the socio-economic impacts of NETPs deployment within the EU, this work also uses the Jobs and Economic Development Index (JEDI) tool, developed by the US National Renewable Energy Laboratory (NREL) (Jacobson et al., 2017; Patrizio et al., 2018; Patrizio et al., 2020; Patrizio et al., 2022). The hard link between the MONET-EU framework and JEDI was implemented in Task 7.3.

2. MONET-EU-JEDI framework

The MONET-EU-JEDI framework was first introduced in the D7.3 report. An overview of the MONET-EU optimisation framework is provided below.

2.1. JEDI tool

The Jobs and Economic Development Impact (JEDI) tool was initially developed in 2004 from a collaboration between the National Renewable Energy laboratory (NREL) and MRG & Associates, to quantify the macro-economic impacts associated with energy project development in the US. The initial portfolio of low carbon technologies covered in JEDI included conventional hydropower, geothermal, wind, bioenergy, coal- and natural gas power and heat generation facilities (Jacobson et al., 2017), fossil fuels with CCS and BECCS (Patrizio et al., 2018; Patrizio et al., 2020). As part of Task 7.3, the JEDI tool was expanded to integrate a broader portfolio of NETPs, including afforestation (AR), biochar, direct air capture of carbon with storage (DACCS) and enhanced weathering (EW), alongside bioenergy with carbon capture and storage (BECCS) (Chiquier et al., 2022).

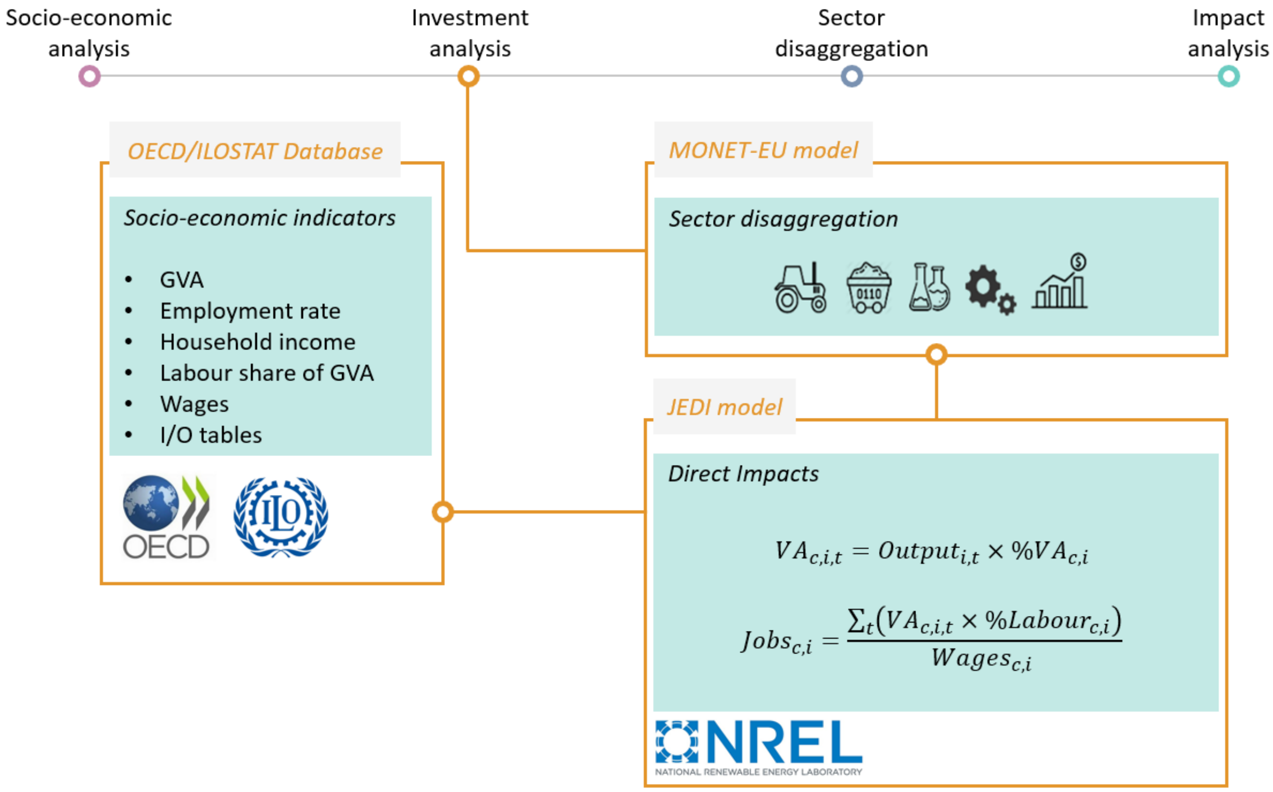

Figure 1: Framework of the Job and Economic Development Impact (JEDI) tool, adapted from (IEAGHG, 2022).

An overview of the framework of JEDI framwork is provided in Figure 1. The JEDI tool combines techno-economic details of selected NETPs with socio-economic indicators from the database for structural analysis (STAN)[1] maintained by the Organisation for Economic Co-operation and Development (OECD). The STAN database is a comprehensive tool for analyzing industrial performance at a relatively detailed level of activity across countries. It includes annual measures of output, value-added and its components, labor input, investment, and capital stock, from 1970 onwards. This allows users to construct a wide range of indicators to focus on areas such as productivity growth, competitiveness, and general structural change. STAN is primarily based on OECD member countries' annual national accounts[2], while data from national business surveys/censuses (maintained by OECD, Eurostat or compiled directly from national sources) are adopted to estimate any missing details. Many of the data points in STAN are estimated and therefore do not represent official member country submissions.

The JEDI tool allows quantifying how much of the value in service and manufacturing products are generated in a certain country as a percentage of the capital expenditure of NETPs. The value-added

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[1] The STAN database gathers macro-economic data from national I/O databases. For more information about the STAN database, please refer to www.oecd.org

[2] National accounts are reported here: http://www.oecd.org/sdd/na/

share of production $\%VA_i$ and labor share of value-added $\%Labour_i$ of every EU Member State are broken down by economic sectors in the Appendix.

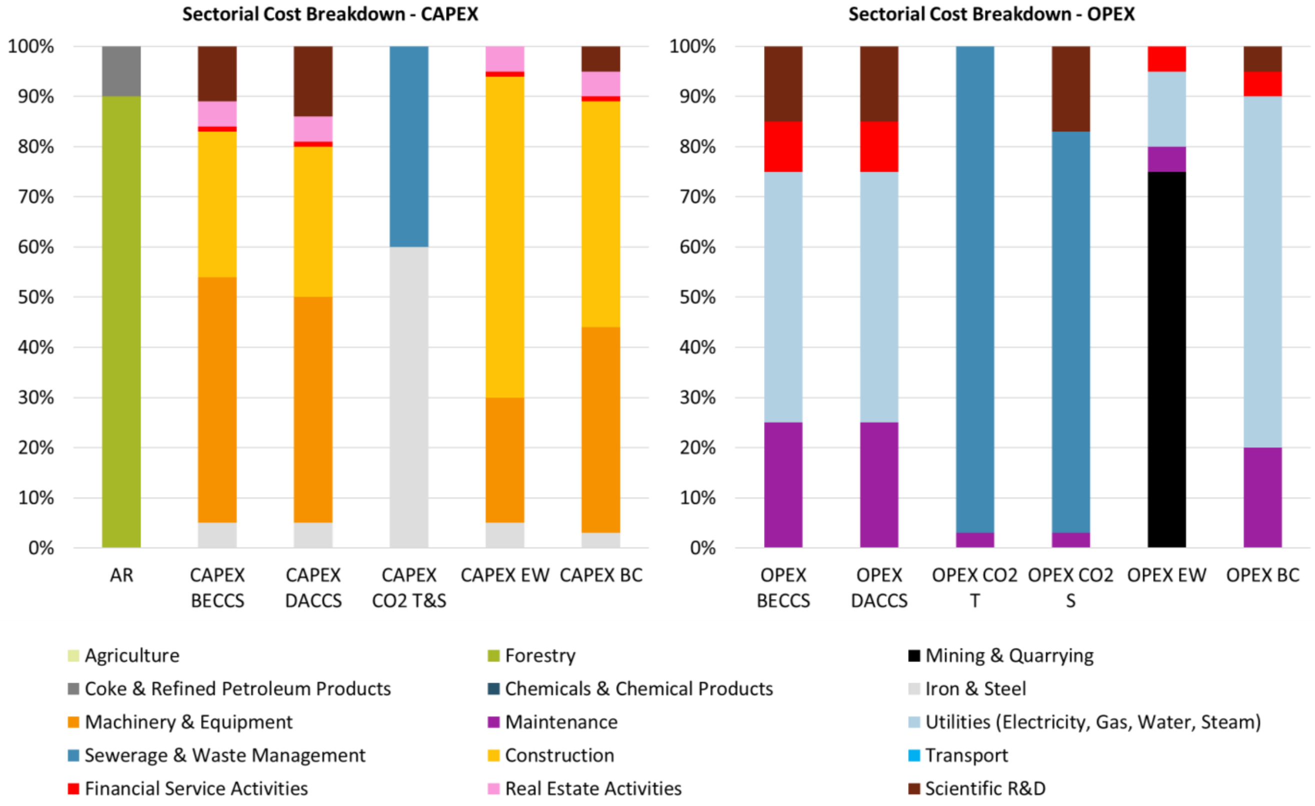

Figure 2: Sectorial cost breakdowns of the different archetypal CDR technologies, only showing the (left): CAPEX of AR, BECCS, DACCS, CO_2 Transport & Storage (T&S), EW and biochar, and (right): OPEX of BECCS, DACCS, CO_2 Transport, CO_2 Storage, EW, and biochar. There are also sector breakdowns other parts of the NETPs value chain, including energy requirements, feedstocks/inputs (e.g., seeds to grow biomass, rocks, chemicals), farming, forestry biomass, biochar/EW spreading. Each NETP's CAPEX and OPEX are broken down into different economic sectors. For instance, whilst almost most of the CAPEX of AR is allocated to the forestry sector, the CAPEX of BECCS, DACCS, EW, and biochar are broken down (in different proportions) into the iron & steel, construction, machinery & equipment, financial service activities, real estate activities, and scientific R&D sectors, and the CAPEX of CO_2 T&S is allocated to the iron & steel and sewerage management sectors.

The lifetime costs of NETPs projects are disaggregated across main manufacturing and downstream activities. The cost breakdown is allocated to the corresponding industrial sectors, considering only the share of expenditure contributing to the creation of national economic output. Key sectorial cost breakdowns of NETPs, e.g. the CAPEX and OPEX of a DAC plant, are shown in Figure 2**.**

MONET-EU includes different options for DAC technology type and energy sources, including liquid-based DAC using natural gas or low-carbon hydrogen (e.g., electrolysis with renewables), and solid sorbent-based DAC using low temperature heat or grid electricity with decarbonization trajectories according to the IPCC P2, P3 and P4 scenarios. The carbon intensity of these different options are accounted for in balance of the net CO_2 removal of the DAC plant . The DAC technology type and energy sources are also considered for the calculation the domestic value of DACCS. We distinguish between imported and domestic natural gas so that heat procurement activities are allocated to the utility sector following national energy trade statistics.

In addition to Figure 2, there is data for sector breakdowns for other parts of the NETPs value chain in MONET-EU. For instance, energy requirements involves utilities, inputs (e.g., seeds to grow biomass for BECCS and biochar, rocks for EW, chemicals for DACCS), biomass production involves agriculture and forestry, biochar/EW spreading involves machinery, equipment and maintenance. More details on the DVA and jobs distribution associated with different NETPs can be found in the Appendix.

2.2. MONET-EU optimisation framework

MONET-EU is a linear optimisation problem (LP), that determines the optimal co-deployment of CDR pathways to meet regional or national removal targets for the EU and the UK. It covers 28 countries, disaggregated into 103 regions, following the 2021 Nomenclature of Territorial Units for Statistics 1 (NUTS1) classification[3]. The CDR pathways considered in the MONET model include afforestation (AR), bioenergy with carbon capture and storage (BECCS), biochar (BC), direct air capture with carbon storage (DACCS), and enhanced weathering (EW). The key optimisation constraints of the MONET-EU framework are summarised in Figure 3 and Table 1, and include long-term CDR targets, sustainability (land and biomass supply availability, maximum water stress), feasibility (maximum deployment rates, operating lifetimes), and CO_2 storage capacity. More details can be found in the NEGEM deliverables 7.1, 7.2 and 7.3. It should be noted that the maximum deployment constraints have been reduced for BECCS, biochar, and DACCS, compared to the NEGEM deliverable 7.2, for feasibility purposes and to consider realistic/conservative build rates.

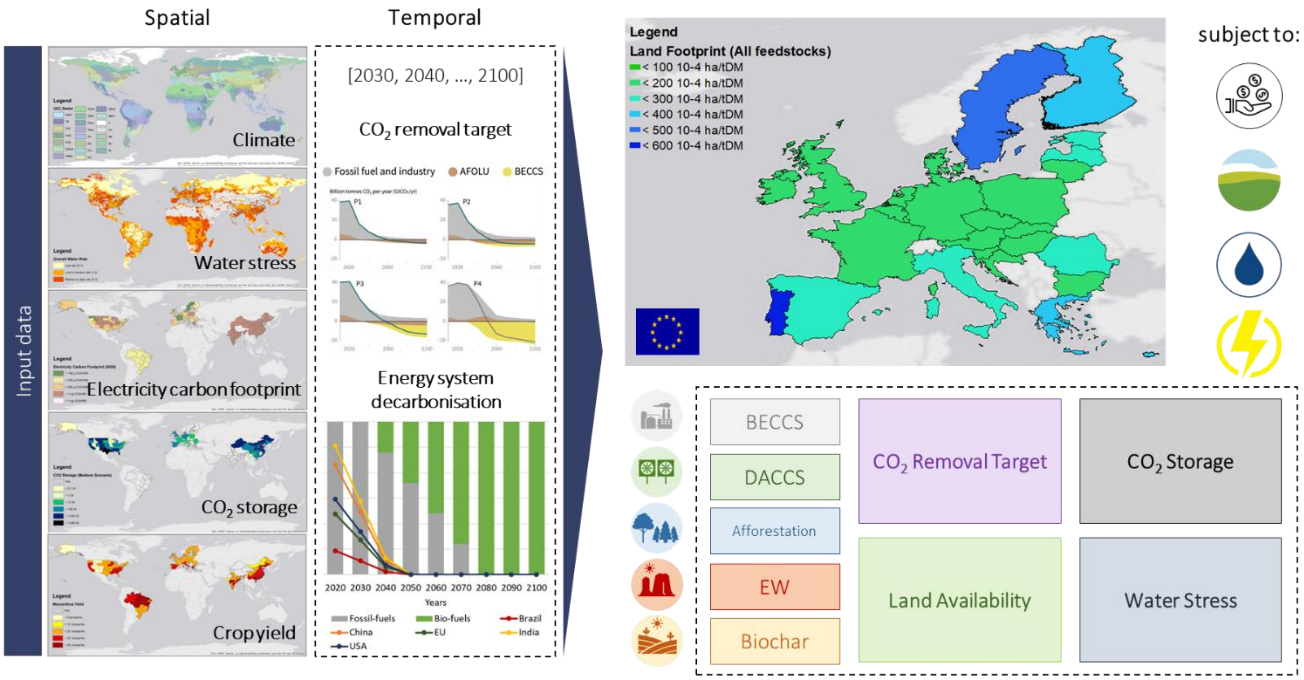

Figure 3: The Modelling & Optimisation of Negative Emissions Technologies EU (MONET-EU) modelling framework. This version of MONET covers 28 countries – the EU countries plus the UK, and is referred to as-EU28 in this study.

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[3] More information about the 2021 Nomenclature of Territorial Units for Statistics 1 (NUTS1) classifications can be found at :https://ec.europa.eu/eurostat/web/nuts/background

Table 1: Summary of the MONET-EU optimisation constraints.

	Description of the constraint	**Key elements**
CDR targets	Cumulative CDR targets for each region over the 2020-2100 period	Targets are consistent with the IPCC P3 climate mitigation scenario (Grubler et al., 2018; IPCC, 2018), and allocated nationally based on the responsibility-based burden-sharing principle (Raupach et al., 2014). Evaluated in NEGEM deliverables 4.3 and 7.2 of WP4 and WP7, respectively.
CDR deployment rates	Deployment rates reflect the maximum speed at which each CDR method can deploy.	*Project lifetime:* AR: in perpetuity BECCS/DACCS: 30 years Biochar/EW: 20 years *Maximum deployment at global scale:* BECCS: one BECCS plant of 500 MW[4]/region/yr (~ 4.5 Mt CO_2 captured/region/yr and ~ 2.7 Mt_{DM} biomass /region/yr) DACCS: same CO_2 capture capacity as BECCS (~ 4.5 Mt CO_2 captured/region/yr) Biochar: same biomass feedstock capacity as BECCS (~ 2.7 Mt_{DM} /region/yr) EW: one rock mining facility of 450,000 t rocks/ region/yr AR: 0.83%/yr of the forest area/country[5]
Sustainable land availability	Both AR, BECCS and biochar require to grow biomass, which is limited by the availability of land and water. Biomass grown for BECCS and biochar can stem from dedicated-energy crops, forestry residues or	AR is limited by the availability of ecologically viable areas with a potential for reforestation (Griscom et al., 2017). Dedicated-energy crops for BECCS and biochar are grown on marginal agricultural land (Cai et al., 2011).

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[4] We assume that a 500 MW BECCS plant has an average annual CO_2 capture capacity of 4.5 Mt CO_2, and an annual biomass feedstock capacity of 2.7 Mt_{DM} of biomass (Fajardy and Mac Dowell, 2017; Fajardy et al., 2018; Chiquier et al., 2022).

[5] The maximum annual deployment rate of AR is aligned with the IPCC P2 climate mitigation scenario (Grubler et al., 2018; IPCC, 2018), in which 0.83%/yr of the forest area is afforested in the OECD+EU region between 2020 and 2030. Among all IPCC scenarios, *i.e.* P1, P2, P3 and P4 scenarios, this is the highest afforestation rate observed for the OECD+EU region between 2020 and 2100.

	agricultural residues. Biochar and rocks (for EW) can be applied on marginal agricultural land only.	Agricultural residues for BECCS and biochar consist of wheat straw collected from harvested wheat areas (Yu et al., 2020). Forestry residues for BECCS and biochar can be collected from forest plantations (Forest Europe, 2020). All lands used for AR, BECCS and biochar are limited to areas with low water stress (Gassert, 2015; Kuzma et al., 2023).
Geological CO_2 storage availability	BECCS and DACCS store CO_2 into geological reservoirs, situated in the vicinity (*i.e.,* 100km)[6] of the BECCS and DAC plant, respectively.	EU-28: 180 Gt CO_2 (of which 78 Gt CO_2 in the UK) (Vangkilde-Pedersen et al., 2009; Vangkilde-Pedersen and GEUS, 2009; Poulsen et al., 2014; Gammer, 2015).

3. Results and discussion: Assessing the socio-economic impacts of large-scale deployment of NETPs

3.1. “Cost” and “Jobs” case studies

In this study, MONET-EU was used to evaluate the least-cost CDR portfolio — AR, BECCS, biochar, DACCS, and EW — to meet cumulative CDR targets between 2020 and 2100, in line with the Paris Agreement’s stringent 1.5°C objectives. These cumulative CDR targets, used as a proxy for the EU remaining carbon budget, are obtained from the IPCC P2 pathway by applying a responsibility-based burden-sharing principle, as detailed in the NEGEM deliverables 7.2 and 4.2 of WP7 and WP4, respectively. It is assumed that EU Member States and the UK (EU-28) must collaborate together to meet up to 81 Gt CO_2 removal by 2100. The trade of biomass among the EU Member States is permitted, i.e. EU Member States can use imported biomass from another EU Member State to deploy BECCS or biochar.

To assess the socio-economic impacts of NETPs, two optimisation case studies were evaluated using the MONET-EU optimisation constraints outlined in Table 1:

- **“Cost” case study** – minimizes the total system cost, i.e. represents the least-cost system;
- **“Jobs” case study** – maximizes the job years and direct value added (DVA) of the system.

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[6] Studies indicate that most CO_2 pipeline transport will need to be on average less than 100 km in distance (McCoy and Rubin, 2008; GCCSI, 2012; Simper, 2023). The IEA analysed the location of CO_2 emissions from power and industrial facilities in China, Europe and the US. The IEA study found that 70% of the emissions are within 100 km of potential storage (IEA, 2020). Thus, 100 km is a practical and cost-effective assumption for pipeline transport of CO_2. In contrast, there is no distance constraint on biomass transport.

These scenarios are used to demonstrate the trade-offs between cost, jobs and direct value added of NETP deployment between 2020 to 2100 in the EU-28.

3.2. Evolution of the CDR system between 2020 and 2100

The combination of NETPs deployed and the cost of CO_2 removal as the system evolves until 2100 varies significantly when comparing the “Cost” scenario (Figure 4 and Table 3) and the “Jobs” scenario (Figure 5 and Table 5).

In 2030, the “Cost” case study deploys 2.9 $GtCO_2$ of CDR and mainly deploys cheaper CO_2 removal options first, including BECCS, biochar and afforestation, whereas expensive options such as DACCS is not deployed at all (Figure 4 and Table 3). As the system evolves over time until 2100, the least-cost system continues to depend on these cheaper biomass-based CDR approaches. Although the CO_2 removal cost of DACCS is considerably greater, high levels of DACCS deployment is required between 2080 and 2100 to meet the EU-28 CDR target, owing to deployment constraints of the other CDR options (Table 1). Even though AF and biochar have lower CO_2 removal costs, the “Cost” scenario predominantly relies on BECCS, owing to the economic benefit of selling bio-electricity. In 2030, the first decade of AF cost in terms of $/$tCO_2$ removal starts high, owing to the low deployment of cumulative CO_2 removal of 0.08 and 0.05 $GtCO_2$ for the “Cost” and “Jobs” case studies relative to AR total costs (Table 3 and Table 5).

Compared to the “Cost” scenario, the “Jobs” case study deploys more CDR earlier on, with 5.1 $GtCO_2$ of removals being deployed in 2030, and CO_2 removal costs are much greater across the different CDR options (right Figure 5). Despite its higher cost, DACCS is the main CDR option deployed as the systems evolves due to the socio-economic benefits such as creating jobs and DVA. The socio-economic benefits of the “Jobs” case study will be explored further in the following section.

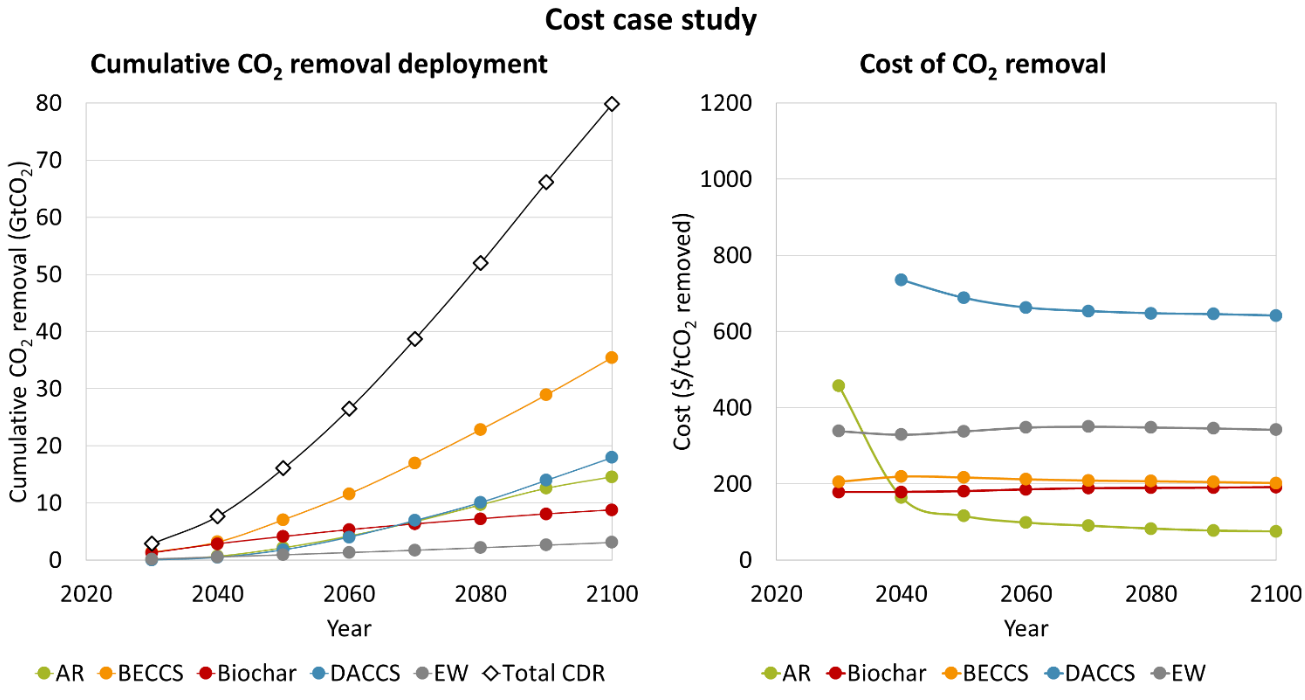

Figure 4: The “Cost” case study evolution of the CDR system, showing the contribution of different CO_2 removal technologies in terms of cumulative CO_2 removal in $GtCO_2$ and cost of CO_2 removal over time under 2100. Data values available in the Appendix Table 3 and Table 4.

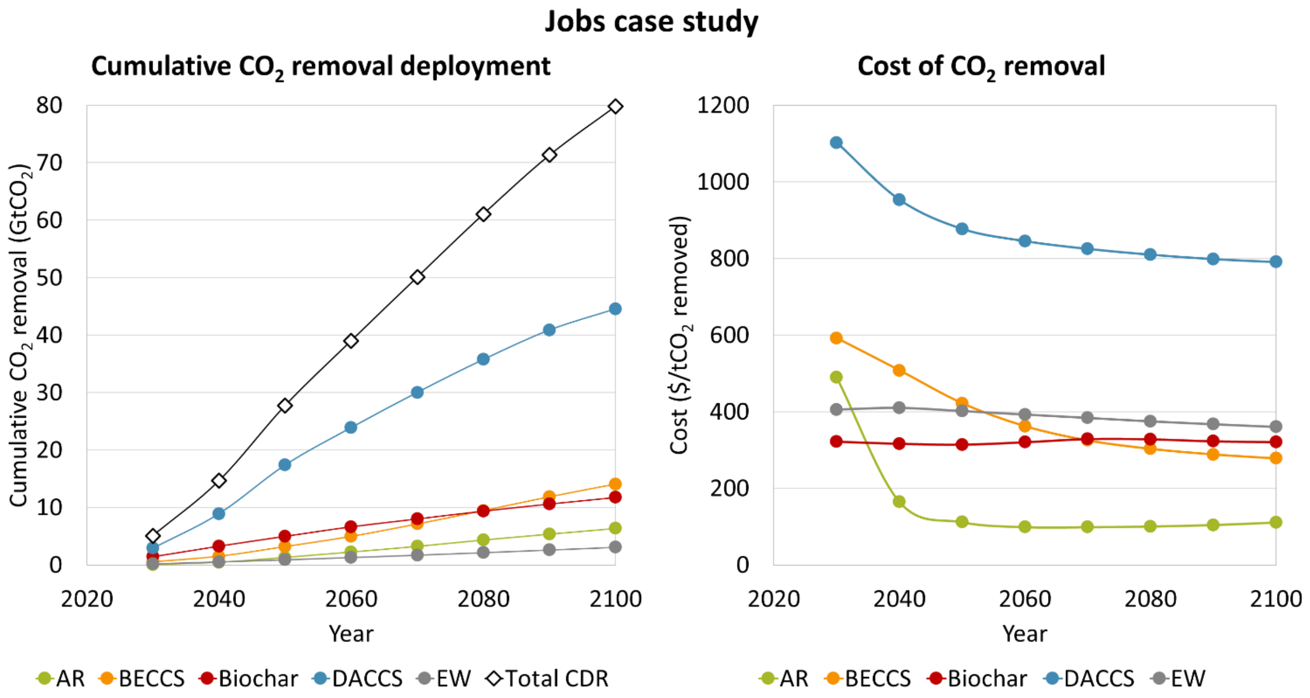

Figure 5: The "Jobs" case study evolution of the CDR system, showing the contribution of different CO_2 removal technologies in terms of cumulative CO_2 removal in $GtCO_2$ and cost of CO_2 removal over time under 2100. Data values available in the Appendix Table 5 and Table 6.

3.3. Socio-economic impacts of NETPs deployment

Table 2 and Figure 6 presents a comparison of key results for the two case studies evaluated for this study. To achieve 81 Gt CO_2 removal by 2100 in the EU-28, the "Jobs" case study required 120% higher total system costs compared to the "Cost" case study. However compared to the "Cost" case study, the DVA was double and the cumulative number of job years was 133% greater for the "Jobs" case study.

Table 2: Comparison of key socio-economic performance indicators for the deployment of CO_2 removal in the EU-28 for the "Cost" and "Jobs" case studies.

	Cost case study	**Jobs case study**
Total system cost by 2100 ($ trillion)	19.2	42.2
Direct value added, DVA ($ trillion)	9.29	18.5
Cumulative number of job years between 2020 – 2100 (million)	119	277
Average cost of CO_2 removal by 2100 ($/t$CO_2$ removed)	240	529
Average DVA by 2100 ($/t$CO_2$ removed)	116	232
Average number of job years by 2100 ($/Mt$CO_2$ removed)	1488	3470

Note: the number of job years does not represent the number of people but rather the years of employment required to deliver the scenario.

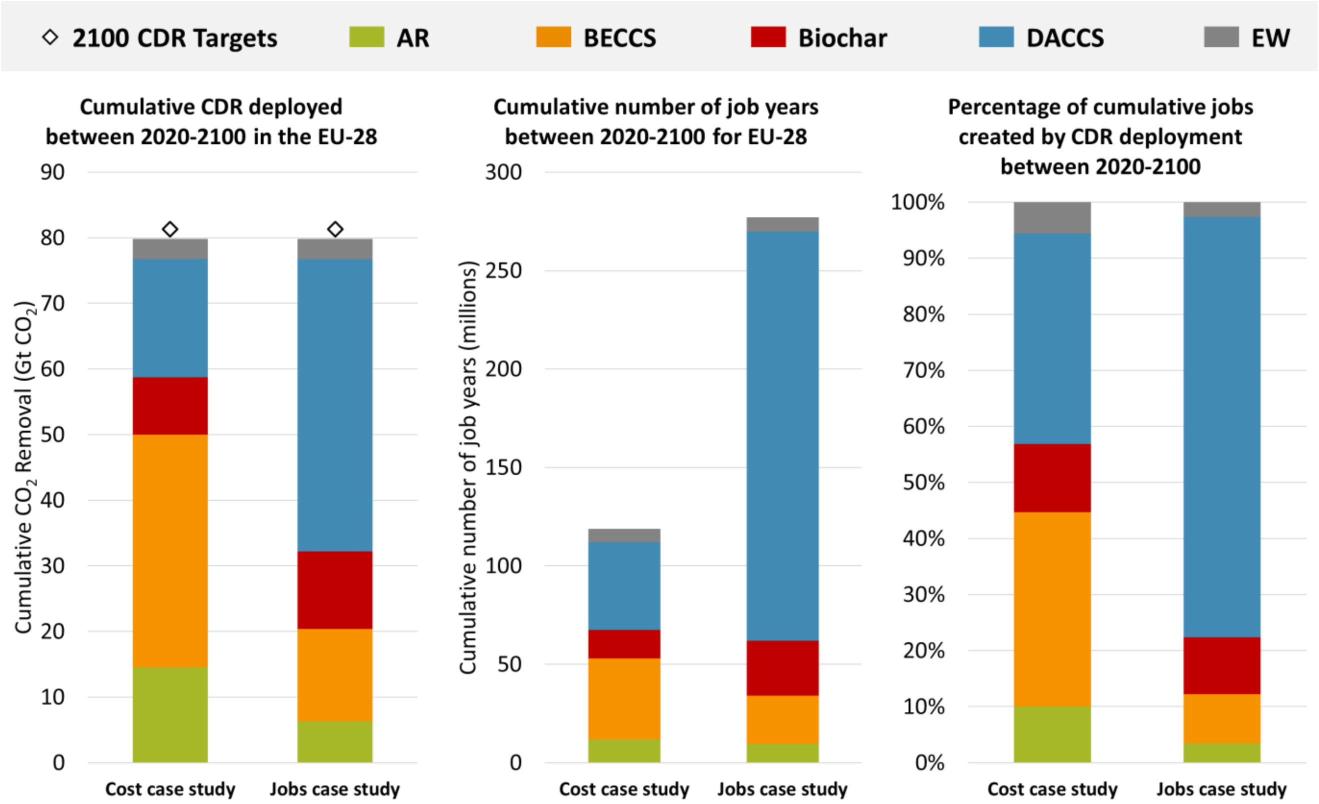

Figure 6: Comparison of key indicators for the deployment of CO_2 removal in the EU-28 for the "Cost" and "Jobs" case studies.

The "Cost" scenario relies on the deployment of biomass-based CO_2 removal options such as BECCS and afforestation, resulting in an average cost of CO_2 removal of \$240/tCO_2 removed by 2100. The "Jobs" scenario predominantly deploys DACCS, leading to a much higher average cost of CO_2 removal by 2100 of \$529/tCO_2 removed. Consequently, the reliance on BECCS in the "Cost" scenario results in fewer cumulative number of job years compared to the "Jobs" scenario, which deployed significantly higher levels of DACCS (Table 2 and Figure 6). Compared to other CDR options, DACCS consumes much more energy and large-scale CO_2 removal requirements means significant infrastructure changes. Subsequently, for a given cumulative CO_2 removal requirement, DACCS deployment triggers a considerable growth in cumulative number of jobs years compared to BECCS (Figure 6 and Figure 9). DACCS stimulates job and DVA growth in sectors such as utilities, manufacturing and construction (Figure 9).

3.4. Regional analysis of socio-economic impacts

The socio-economic impacts of CDR deployment at a national level across the EU-28 countries is summarized in Figures 7, 8 and 9. Figure 7 shows the distribution of CO_2 removal technologies in 2100 across different EU-28 countries for the case studies. Of the EU-28 countries considered in this analysis, the regions with the highest cumulative CO_2 removal targets for 2100 include Germany (18.2 GtCO_2), the UK (16.3 GtCO_2), France (10.0 GtCO_2), Poland (6 GtCO_2) and Italy (5.4 GtCO_2).

Similar observations can be made across both the "Cost" and "Jobs" scenarios (Figure 7). For instance, some countries are unable to meet their 2100 CDR targets. To meet their national-level 2100 CDR targets, Belgium, Ireland and the UK would require additional removal of 1.0 GtCO_2, 0.3 GtCO_2 and 0.1 GtCO_2, respectively.

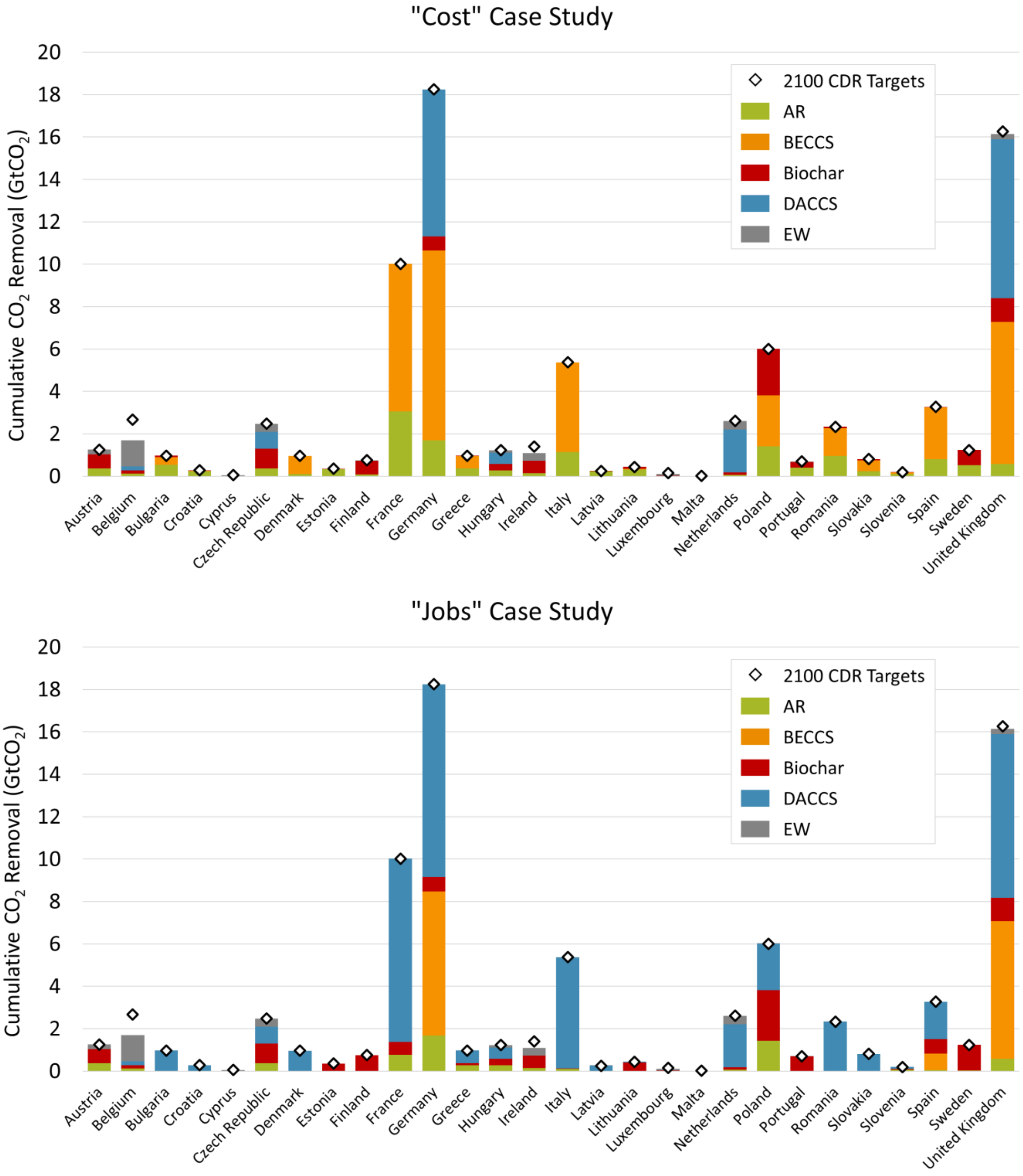

Figure 7: Cumulative CO_2 removal in 2100 for each EU Member State, broken down by NETP deployed, for two optimization scenarios: (top) "Cost" case study, and (bottom) "Jobs" case study. The EU 2100 CDR targets, used here as a proxy for the EU carbon remaining budget, are also shown (black diamonds).

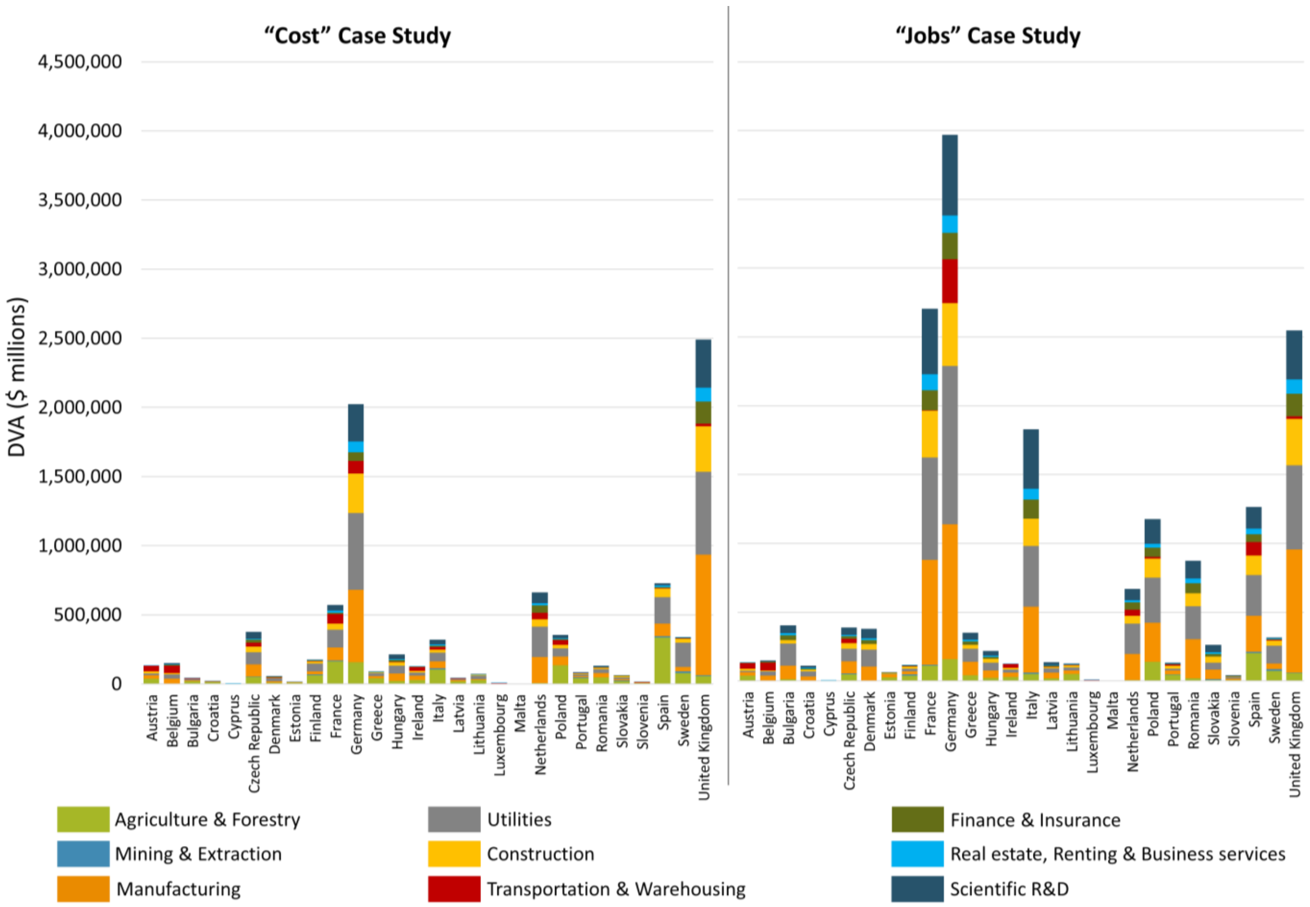

Figure 8: Direct value added (DVA) for CDR deployment in the EU-28 by 2100 for the (left) "Cost" and (right) "Jobs" case studies.

As biochar and rocks for enhanced weathering (EW) can only be applied on marginal agricultural land, deployment of biochar and EW is limited to some regions. Enhanced weathering (EW) is deployed in countries with rock and marginal agricultural land availability, which includes Belgium, the Netherlands, Czech Republic and Ireland. Biochar is deployed in most EU-28 countries such as Poland, the UK, Czech Republic, Germany and Austria. Importantly, for both case studies, large-scale NETPs deployment provides socio-economic benefits to *all* EU-28 regions (including Malta) in terms of observable growth in DVA and cumulative job years.

By 2100 in the "Cost" case study, biomass-based CDR (i.e., BECCS, AF and biochar) is deployed across the EU-28 countries. Some countries only deploy BECCS and AF, including France, Italy, Romania and Spain. Deployment of DACCS occurs in the countries with the highest CDR targets (i.e., Germany and the UK) and those with limited biomass or land availability (e.g., the Netherlands). By 2100 in the "Jobs" case study, DACCS is deployed in almost all of the EU-28 countries, displacing biomass-based pathways.

In Figures 8 and 9, deployment of biomass-based CDR methods are expected to increase direct value added (DVA) in the agricultural and forestry sectors. The DVA and cumulative job years (Figures 8 and 9) for the different EU-28 countries in the "Cost" case study is roughly proportional to the cumulative CO_2 removal targets (Figure 7). The "Jobs" case study prioritizes technical CDR methods such as DACCS, resulting in increased DVA and cumulative number of job years in economic sectors such as manufacturing, construction, utilities, and scientific R&D. Although CDR delivered by DACCS deployment in Bulgaria is much lower than the UK, the cumulative job years associated with manufacturing in Bulgaria is comparable to the UK. This suggests that inter-regional supply chains are being deployed, creating jobs across different countries and highlighting the value of intra-European collaboration in delivering EU-level CDR targets.

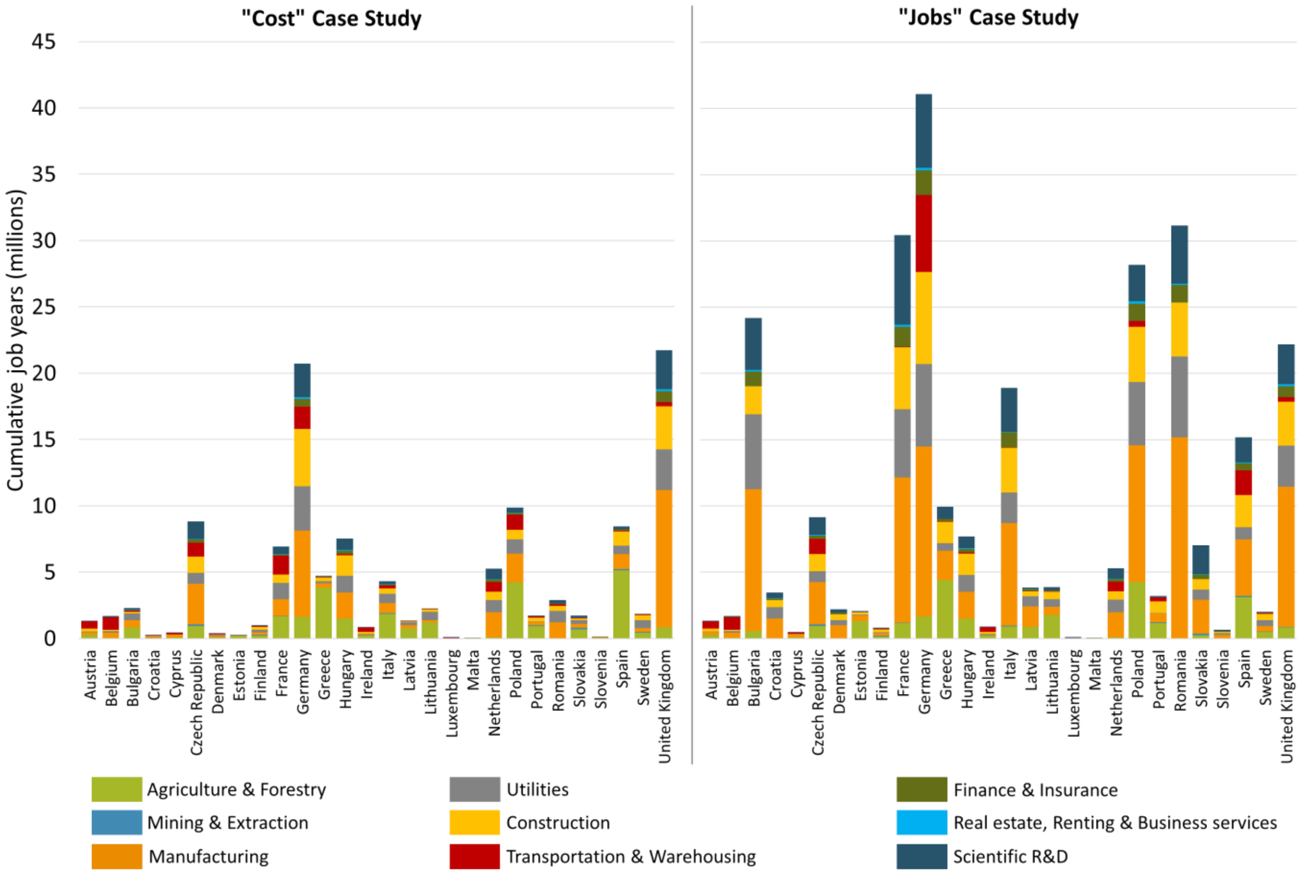

Figure 9: Cumulative number of job years created by CDR deployment between 2020 to 2100 in the EU-28 for the (left) "Cost" case study, and (right) "Jobs" case study. Note: the number of job years does not represent the number of people but rather the years of employment required to deliver the scenario.

4. Conclusions

Negative emission technologies and practices (NETPs) has become widely acknowledged as essential to delivering the Paris Agreement's 1.5°C objectives. The previous work on NEGEM WP4 and WP7 explored the technical potential of NETPs based on availability of resources (e.g., water, land and biomass), climate (e.g., temperature, relative humidity) and techno-economic factors (e.g., cost of capital). This study for Task 7.4 aims to analyse the socio-economic impacts of deploying NETPs at the national and regional scale, whilst also investigating the impacts of intra-European collaboration under two main scenarios – "Cost" (minimises cost) and "Jobs" (maximises socio-economic impacts) case studies.

To meet the 81 $GtCO_2$ removal target by 2100 in the EU-28, the "Cost" case study mainly relies on biomass-based NETPs such as afforestation (AF), biochar and BECCS, which leads to lower average CDR costs for the system of $240/$tCO_2$ removed. These biomass-based CDR methods are expected to increase direct value added (DVA) in the agricultural and forestry sectors. In contrast, the "Jobs" case study prioritizes technical CDR methods such as DACCS which increases average CDR cost to \$529/tCO_2 removed by 2100. Deploying more DACCS results in increased DVA and years of employment in economic sectors such as manufacturing, construction, utilities, and scientific R&D.

For both “Cost” and “Jobs” case studies, large-scale NETPs deployment provides socio-economic benefits to *all* EU-28 regions in terms of observable growth in DVA and cumulative job years. There is also evidence of inter-regional supply chains are being deployed, creating jobs across different countries and highlighting the value of intra-European collaboration in delivering EU-level CDR targets. Thus, international collaboration amongst the EU member states can create economic opportunities across different regions and sectors.

This work provides further understanding on which key factors are able to contribute towards a socially equitable, financially viable, technically feasible, and ecologically sustainable pathway for NETPs deployment across Europe. Large-scale NETPs deployment will require significant changes to the structure of our economic and will likely lead to positive socio-economic impacts at the regional and national scale. A sustainable pathway to scale the NETPs portfolio in line with the CDR requirement of the 1.5°C Paris Agreement target would be to balance regional CDR objectives with affordability, whilst still enabling macro-economic growth and providing employment.

To prepare this report, the following deliverable has been taken into consideration:

D#	Deliverable title	Lead Beneficiary	Type	Dissemination level	Due date (in MM)
D1.1	Justification of NETPs chosen for the NEGEM project	ETH	Report	CO	6
D1.2	Comprehensive sustainability assessment of terrestrial biodiversity NETPs	ETH	Report	PU	12
D4.1	NETP database	ICL	Excel spreadsheet	PU	9
D4.2	Bio-geophysics database	ICL	Excel spreadsheet	PU	12
D4.3	Identify Member state targets for CDR	ICL	Report	PU	18
D7.1	Develop MONET-EU	ICL	Report	PU	12
D7.2	Extended MONET-EU	ICL	Report	PU	18
D7.3	Link MONET-EU and JEDI	ICL	Report	PU	25

Appendix: JEDI tool

Key outputs

Key outputs of JEDI are *gross value added (GVA)*, the value of an industry's production to the country of analysis, and *employment creation.* These metrics are calculated for different industrial activities and economic sectors, based on the sectorial indexing of the International Standard Industrial Classification (ISIC)[7]. The following indicators are extracted from STAN for the calculation of *direct impacts*:

- $\%VA_i$ Value added share of production: Value added contributed by each sector *i* relative to total production. The GVA is a widely recognized macroeconomic variable that measures the contribution to the Gross Domestic Product (GDP) made by individual producers, industries, or sectors in a country. It provides an indication of the production structure of a given sector, and allows to measure the value that each industrial activity adds to the domestic economy.

- $\%Labour_i$ Labor share of value added: Amount of labor compensation within the value added created by a given industry. It is used to calculate the total earnings generated within a certain economic activity.

- Wages: this indicator is used to calculate the number of jobs created by a given industry.

Value added and jobs created in a given industry *i* are proportional to the output produced by technology *t* in that sector[8].

$$VA_{i,t} = Output_{i,t} * \%VA_i$$

$$Jobs_i = \sum_t \left(VA_{i,t} * \%Labour_i\right) / _{Wages_{i_i}}$$

Overall, the JEDI tool allows to specify how much of the value in service and manufacturing products are generated in a certain country as a percentage of the capital expenditure of NETPs. The $\%VA_i$ and $\%Labour_i$ of every EU Member State are broken down by economic sectors in Figures A.1-3.

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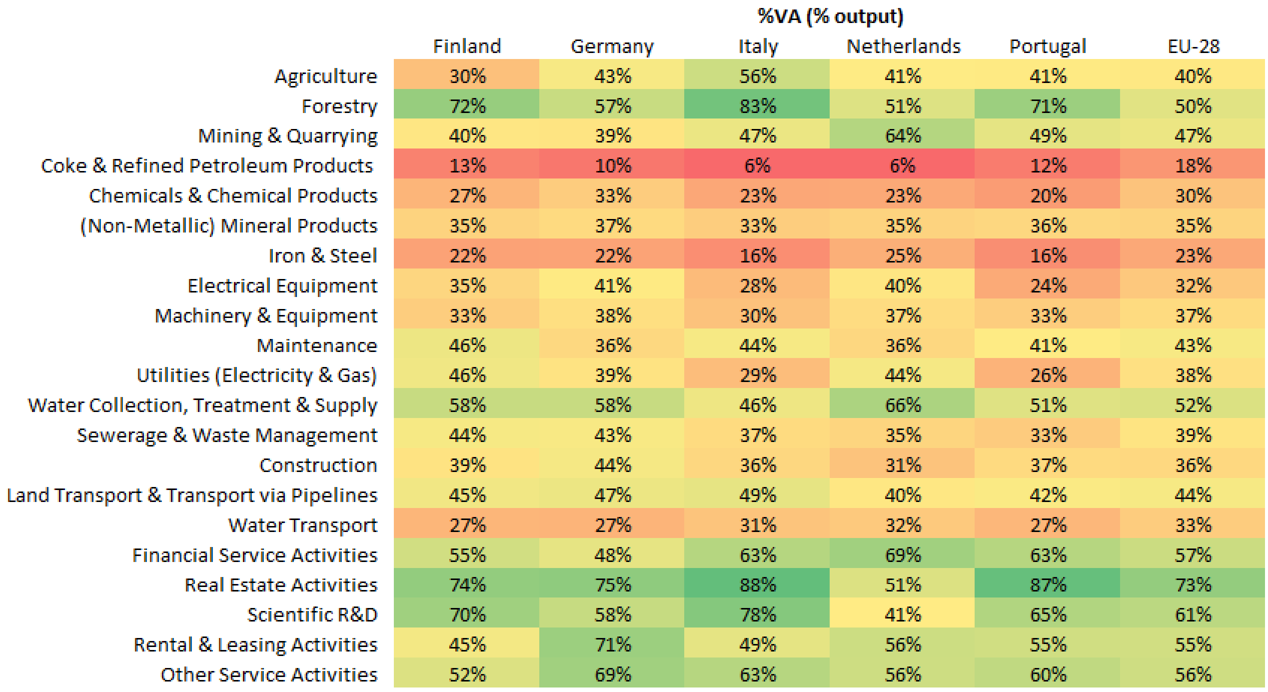
[7] More information about International Standard Industrial Classification codes can be found at https://unstats.un.org/unsd/publication/seriesm/seriesm_4rev4e.pdf

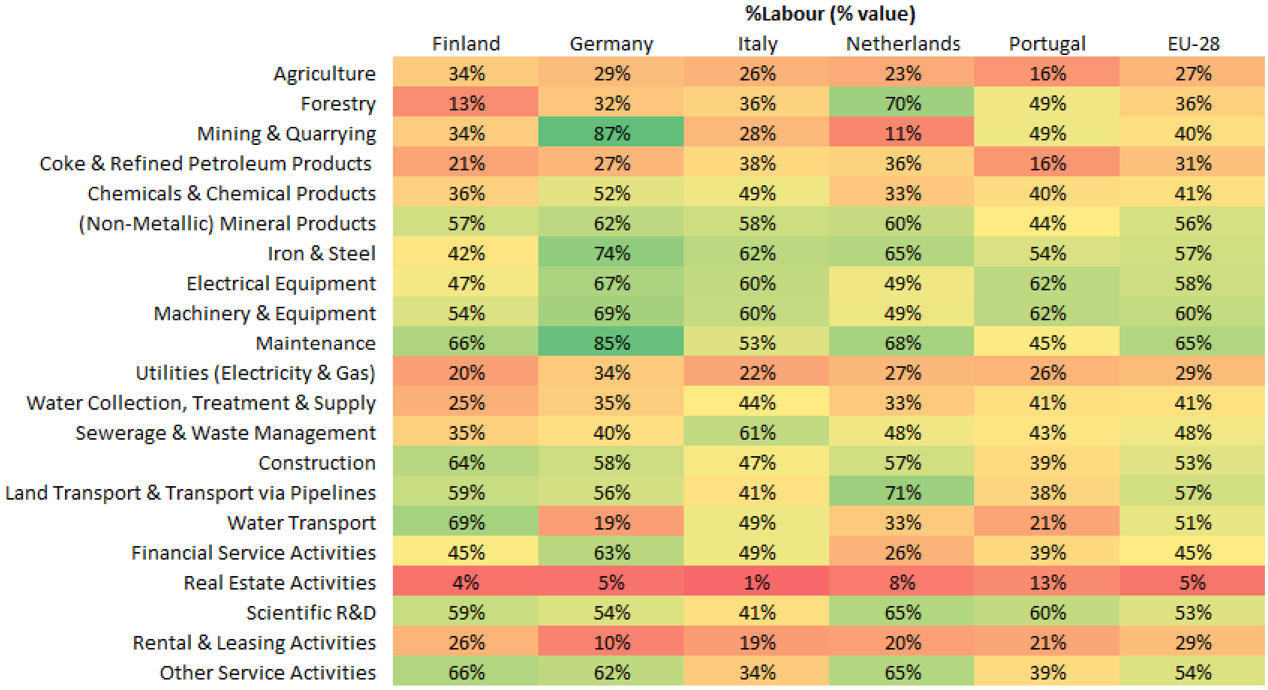
[8] Therefore, I-O methodology assumes that all estimates are linear and proportional. Value added, earnings, and jobs, are then simply proportional to certain output.

Data from the OECD/ILOSTAT database



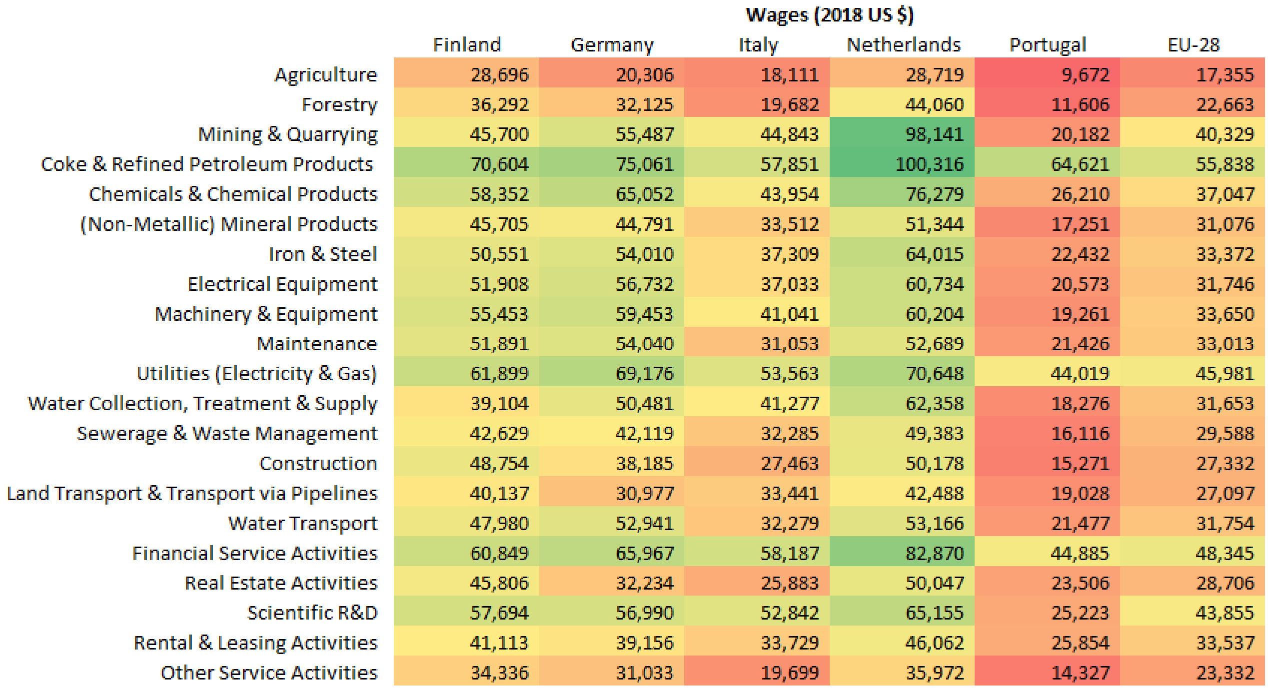
	%VA (% output)					
	Finland	Germany	Italy	Netherlands	Portugal	EU-28
Agriculture	30%	43%	56%	41%	41%	40%
Forestry	72%	57%	83%	51%	71%	50%
Mining & Quarrying	40%	39%	47%	64%	49%	47%
Coke & Refined Petroleum Products	13%	10%	6%	6%	12%	18%
Chemicals & Chemical Products	27%	33%	23%	23%	20%	30%
(Non-Metallic) Mineral Products	35%	37%	33%	35%	36%	35%
Iron & Steel	22%	22%	16%	25%	16%	23%
Electrical Equipment	35%	41%	28%	40%	24%	32%
Machinery & Equipment	33%	38%	30%	37%	33%	37%
Maintenance	46%	36%	44%	36%	41%	43%
Utilities (Electricity & Gas)	46%	39%	29%	44%	26%	38%
Water Collection, Treatment & Supply	58%	58%	46%	66%	51%	52%
Sewerage & Waste Management	44%	43%	37%	35%	33%	39%
Construction	39%	44%	36%	31%	37%	36%
Land Transport & Transport via Pipelines	45%	47%	49%	40%	42%	44%
Water Transport	27%	27%	31%	32%	27%	33%
Financial Service Activities	55%	48%	63%	69%	63%	57%
Real Estate Activities	74%	75%	88%	51%	87%	73%
Scientific R&D	70%	58%	78%	41%	65%	61%
Rental & Leasing Activities	45%	71%	49%	56%	55%	55%
Other Service Activities	52%	69%	63%	56%	60%	56%

Figure 10: Sectorial value added share of production (%VA) for five illustrative EU Member States, and for the EU (average).



	%Labour (% value)					
	Finland	Germany	Italy	Netherlands	Portugal	EU-28
Agriculture	34%	29%	26%	23%	16%	27%
Forestry	13%	32%	36%	70%	49%	36%
Mining & Quarrying	34%	87%	28%	11%	49%	40%
Coke & Refined Petroleum Products	21%	27%	38%	36%	16%	31%
Chemicals & Chemical Products	36%	52%	49%	33%	40%	41%
(Non-Metallic) Mineral Products	57%	62%	58%	60%	44%	56%
Iron & Steel	42%	74%	62%	65%	54%	57%
Electrical Equipment	47%	67%	60%	49%	62%	58%
Machinery & Equipment	54%	69%	60%	49%	62%	60%
Maintenance	66%	85%	53%	68%	45%	65%
Utilities (Electricity & Gas)	20%	34%	22%	27%	26%	29%
Water Collection, Treatment & Supply	25%	35%	44%	33%	41%	41%
Sewerage & Waste Management	35%	40%	61%	48%	43%	48%
Construction	64%	58%	47%	57%	39%	53%
Land Transport & Transport via Pipelines	59%	56%	41%	71%	38%	57%
Water Transport	69%	19%	49%	33%	21%	51%
Financial Service Activities	45%	63%	49%	26%	39%	45%
Real Estate Activities	4%	5%	1%	8%	13%	5%
Scientific R&D	59%	54%	41%	65%	60%	53%
Rental & Leasing Activities	26%	10%	19%	20%	21%	29%
Other Service Activities	66%	62%	34%	65%	39%	54%

Figure 11: Sectorial labour share of value added (%Labour) for five illustrative EU Member States, and for the EU (average).



	Wages (2018 US $)					
	Finland	Germany	Italy	Netherlands	Portugal	EU-28
Agriculture	28,696	20,306	18,111	28,719	9,672	17,355
Forestry	36,292	32,125	19,682	44,060	11,606	22,663
Mining & Quarrying	45,700	55,487	44,843	98,141	20,182	40,329
Coke & Refined Petroleum Products	70,604	75,061	57,851	100,316	64,621	55,838
Chemicals & Chemical Products	58,352	65,052	43,954	76,279	26,210	37,047
(Non-Metallic) Mineral Products	45,705	44,791	33,512	51,344	17,251	31,076
Iron & Steel	50,551	54,010	37,309	64,015	22,432	33,372
Electrical Equipment	51,908	56,732	37,033	60,734	20,573	31,746
Machinery & Equipment	55,453	59,453	41,041	60,204	19,261	33,650
Maintenance	51,891	54,040	31,053	52,689	21,426	33,013
Utilities (Electricity & Gas)	61,899	69,176	53,563	70,648	44,019	45,981
Water Collection, Treatment & Supply	39,104	50,481	41,277	62,358	18,276	31,653
Sewerage & Waste Management	42,629	42,119	32,285	49,383	16,116	29,588
Construction	48,754	38,185	27,463	50,178	15,271	27,332
Land Transport & Transport via Pipelines	40,137	30,977	33,441	42,488	19,028	27,097
Water Transport	47,980	52,941	32,279	53,166	21,477	31,754
Financial Service Activities	60,849	65,967	58,187	82,870	44,885	48,345
Real Estate Activities	45,806	32,234	25,883	50,047	23,506	28,706
Scientific R&D	57,694	56,990	52,842	65,155	25,223	43,855
Rental & Leasing Activities	41,113	39,156	33,729	46,062	25,854	33,537
Other Service Activities	34,336	31,033	19,699	35,972	14,327	23,332

Figure 12: Sectorial wages (expressed in 2018 US $) for five illustrative EU Member States, and for the EU (average).

Socio-economic impact of NETPs

Here, we present a non-exhaustive selection of the socio-economic impacts of NETPs, based on the combination of the JEDI tool with the MONET-EU framework, as presented above.

Direct value-added

Figure 13 shows the different economic sectors that benefit from the deployment of each of the NETPs considered in this deliverable, in the UK (selected for illustrative purpose). For example, AR contributes the most to the forestry sector, with the added GVA accounting for 41% of its total cost. The deployment of biochar and BECCS, when using energy-dedicated crops, *e.g.* Miscanthus, contributes mostly to the agricultural sector (12–20% of BECCS's total cost). For biochar, this accounts for 58% of the total added GVA whereas, for BECCS, it only accounts for a third (34%). The economic sectors of machinery & equipment, maintenance, construction, utilities, and waste management benefit the most from BECCS deployment, accounting for 43% of BECCS's total added GVA. The deployment of DACCS (both archetypes) also generates GVA in the machinery & equipment, maintenance, utilities, and construction sectors (24–25% of DACCS's total cost), but also in the scientific R&D sector, with 5–6% of DACCS's total cost. Finally, EW is the only NETP that contributes to the mining & quarrying sector, with 10% of the total cost, which is more than a quarter of EW's total added GVA (27%).

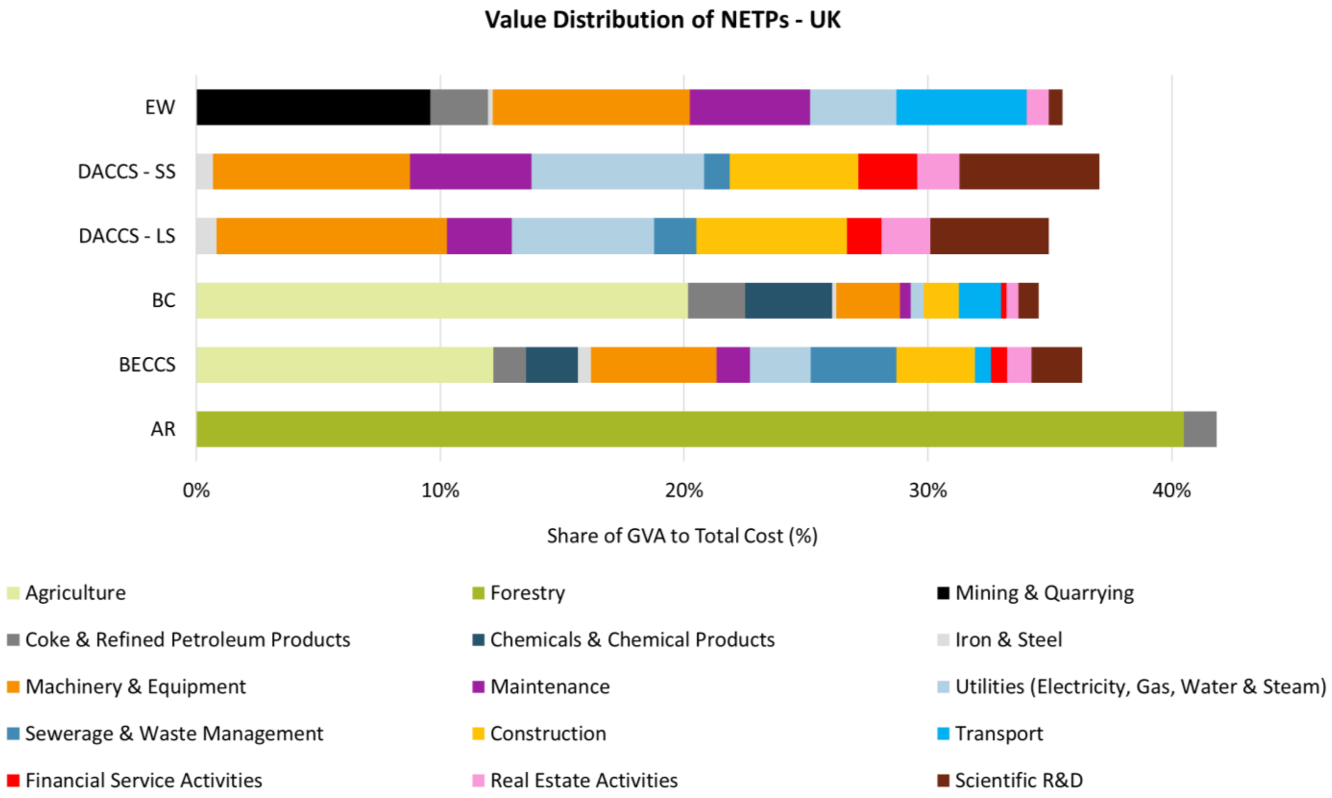


Figure 13: Variation of GVA distribution of different NETPs in the UK. From bottom to top: AR, BECCS, biochar, liquid solvent DACCS, solid sorbent DACCS, and EW. Costs are expressed in 2018 US$.

Thus, whilst land-based NETPs are expected to increase GVA in the agricultural and forestry sectors, engineered NETPs are more likely to increase GVA in economic sectors such as machinery & equipment, maintenance, construction or utilities, or even R&D.

Direct jobs created

Figure 14 highlights that the distribution of jobs created with the deployment of NETPs can vary significantly from one EU Member State to another, and from one economic sector to another. For example, most jobs are consistently created in the forestry sector when AR is deployed (98–99% of total jobs). However, when BECCS is deployed, it appears that the share of jobs created in the transport sector varies significantly from one country to another, and from a BECCS's configuration to another: If local biomass, *i.e.* forestry residues here, is used, then fewer jobs are created then if imported biomass is used, *i.e.* from Portugal or Italy here. Note that the import of forestry residues benefits the most to the transport sector if biomass comes from Portugal (35% of total jobs), whereas it benefits the most to the forestry sector if biomass comes from Italy (30% of total jobs). This is because the forestry sector generates significantly more GVA and jobs in Italy than in Portugal. As also shown in Figure 14, the deployment of solid sorbent DACCS contributes to a greater share of jobs created in the construction sector in Germany than in the Netherlands (22% versus 11% of total jobs), but to a greater share of jobs created in the R&D sector in the Netherlands than in Germany (33% versus 17% to total jobs). Also, the deployment of EW using basalt rocks benefits overall to the same economic sectors in Finland and Portugal. Note that employments in the mining & quarrying sector benefit slightly more from the deployment of EW in Portugal than in Finland (26% versus 20% of total jobs), owing to its higher employment share in Portugal than in Finland.

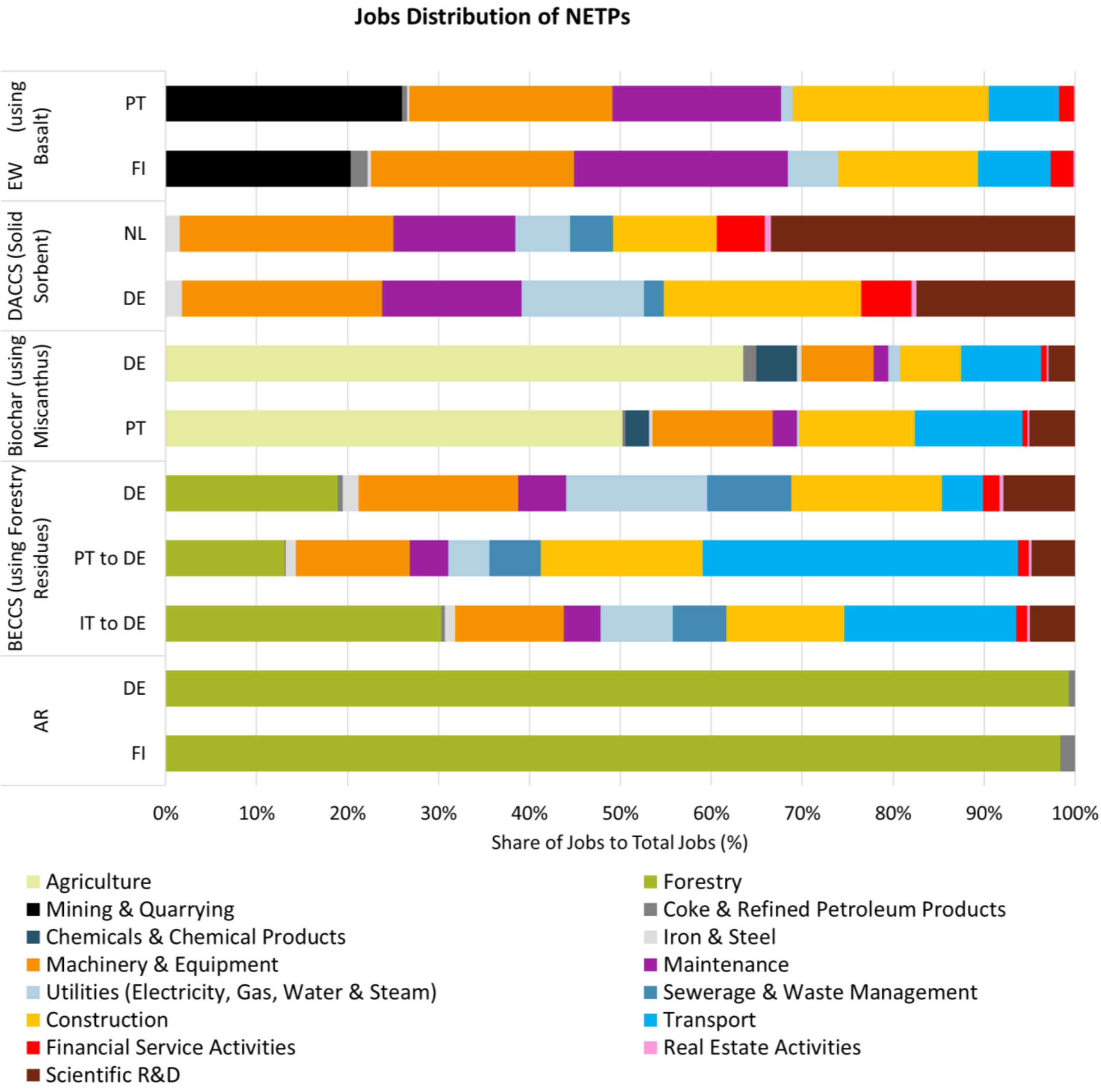


Figure 14: Variation of created jobs distribution of NETPs in different EU Member States. From bottom to top: AR in Finland (FI) and Germany (DE); BECCS using forestry residues in Germany, with supply chains from Italy (IT), Portugal (T) and Germany; Biochar using Miscanthus in Portugal and Germany; solid sorbent DACCS in Germany and in the Netherlands (NL); and EW using basalt rocks in Finland and Portugal. Note that these five illustrative EU Member States have been selected for illustrative purposes only, based on their different economic sectorial structures.

Importantly, when inter-regional supply chains are deployed, jobs can be created across multiple countries, as illustrated in Figure 15.

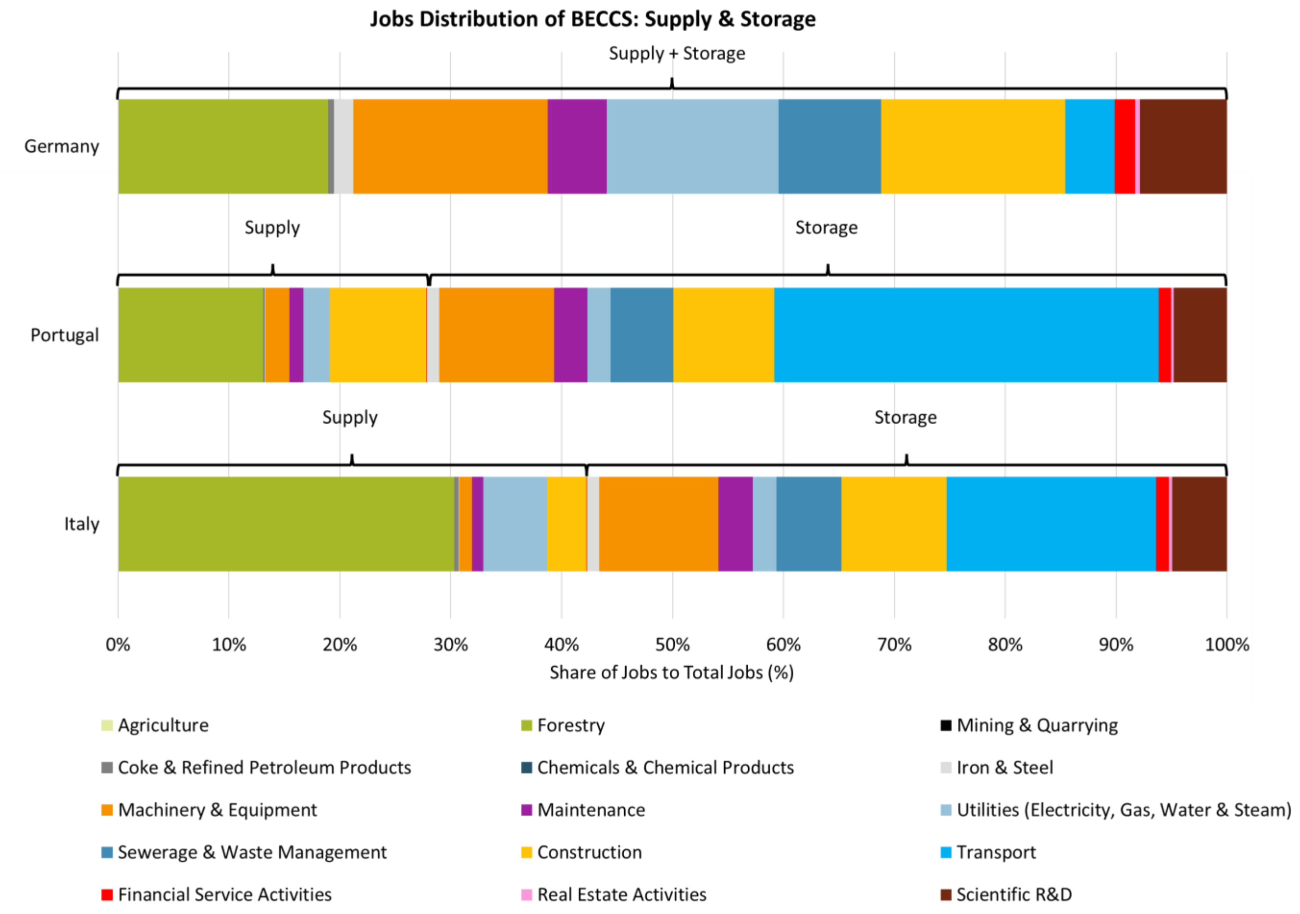


Figure 15: Variation of created jobs distribution of BECCS for different configurations in different EU Member States. From bottom to top: Imported biomass from Italy to Germany; Imported biomass from Portugal to Germany; Local biomass from Germany.

Comparison of results from the Jobs and Cost case studies

Table 3: "Cost" case study – Evolution of the EU-28 CDR system in terms cumulative CO_2 removal for the different CO_2 removal technologies up until 2100. Results presented in Figure 4.

	Cumulative CO_2 removal ($GtCO_2$)					
Year	**AR**	**Biochar**	**BECCS**	**DACCS**	**EW**	**Total**
2030	0.08	1.26	1.37	0.00	0.17	2.9
2040	0.71	2.84	3.17	0.45	0.53	7.7
2050	2.19	4.12	7.07	1.78	0.92	16.1
2060	4.24	5.32	11.59	4.02	1.31	26.5
2070	6.75	6.32	16.99	6.93	1.73	38.7
2080	9.68	7.22	22.83	10.09	2.17	52.0
2090	12.56	8.07	28.90	13.99	2.62	66.1
2100	14.55	8.76	35.42	17.98	3.10	79.8

Table 4: "Cost" case study – Evolution of the EU-28 CDR system in terms of average cost of CDR (\$/tCO_2 removed) for the different CO_2 removal technologies up until 2100. Results presented in Figure 4.

	Cost of CO_2 removal (\$/tCO_2 removed)				
Year	**AR**	**Biochar**	**BECCS**	**DACCS**	**EW**
2030	165	179	219	736	330
2040	116	181	217	689	338
2050	98	186	212	663	348
2060	90	189	209	654	350
2070	83	189	207	648	348
2080	77	190	205	646	346
2090	75	192	202	642	342
2100	165	179	219	736	330

Table 5: "Jobs" case study – Evolution of the EU-28 CDR system in terms cumulative CO_2 removal for the different CO_2 removal technologies up until 2100. Results presented in Figure 5.

	Cumulative CO_2 removal (GtCO_2)					
Year	**AR**	**Biochar**	**BECCS**	**DACCS**	**EW**	**Total**
2030	0.05	1.43	0.53	2.90	0.17	5.1
2040	0.44	3.28	1.49	8.92	0.52	14.6
2050	1.28	4.99	3.18	17.38	0.90	27.7
2060	2.22	6.65	4.96	23.91	1.29	39.0
2070	3.22	8.02	7.13	30.04	1.71	50.1
2080	4.34	9.38	9.45	35.76	2.15	61.1
2090	5.36	10.62	11.86	40.89	2.61	71.3
2100	6.35	11.76	14.07	44.56	3.08	79.8

Table 6: "Jobs" case study – Evolution of the EU-28 CDR system in terms of average cost of CDR (\$/tCO_2 removed) for the different CO_2 removal technologies up until 2100. Results presented in Figure 5.

	Cost of CO_2 removal (\$/tCO_2 removed)				
Year	**AR**	**Biochar**	**BECCS**	**DACCS**	**EW**
2030	490	322	592	1103	405
2040	165	316	508	954	410
2050	112	314	422	877	401
2060	99	320	362	846	392
2070	99	329	325	825	384
2080	101	328	303	810	375
2090	104	323	289	799	368
2100	111	321	278	791	361

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