NEGEM

Quantifying and Deploying Responsible Negative Emissions in Climate Resilient Pathways

Identify Member State Targets for CDR

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Executive Summary

An “equitable and fair” allocation of carbon reduction and removal targets will be necessary to achieve the transformative changes needed across the world economy, as indicated by the latest IPCC report*. Nationally determined contributions (NDCs) to the Paris Agreement did not include carbon dioxide removal (CDR) activities within its remit, and this creates uncertainty on how countries intend to take responsibility for the urgent deployment of CDR in the timeframe leading up to 2050 and beyond. The academic literature presents various theoretical frameworks for the allocation of CDR across nations based on burden-sharing principles. However, their use is not straight-forward, and there is no consensus on the “fairest” way to allocate these targets, as evidenced by the active debate in disciplines such as engineering, philosophy, economics, political science, and law.

There are many challenges associated with the allocation of CDR targets amongst regions, including questions of global equity, which needs to be addressed to gather support and consensus across all nations in a global cooperative environment. The use of burden-sharing principles may provide a starting point for country- or region-specific, negotiations by the member states from a principle of common agreement. In this light, this commentary briefly summarises classical burden-sharing principles that have been suggested in literature, namely – “Responsibility”, “Capability”, and “Equality” principles to inform the quantitative analysis of CDR deployment in Europe. Furthermore, a range of Member State-specific targets for atmospheric CO_2 removal are presented based on the application of burden-sharing principles as reported in literature. These targets inform modelling activities within work packages 4, 7, and 8 in this project, and their limitations are discussed in text. The authors of this deliverable emphasise that the CDR targets derived from burden-sharing principles only serve as an aid to analyse the deployment trajectories for the individual technologies. They should not be treated as a recommendation on the allocation of CDR quotas across EU Member States.

Overall, it was concluded that relying on any single set of principles is unlikely to be a prudent decision, owing to concerns around constrained domestic CDR potential, lack of national capabilities, and fairness. Nonetheless, a range of CDR targets are provided to support modelling activities within the project, based on burden-sharing by a) historical contribution and responsibility, b) capability to finance CDR deployment, and c) the notion of equal rights to be protected from adverse impacts of climate change. The authors also intend to explore a multi-criteria allocation approach as part of the modelling activities within Task 4.4 of work package 4 of the NEGEM project, where a mix of burden-sharing principles will be studied with a range of weighted coefficients, to generate a set of cumulative CDR targets for each European Union Member State. This will likely mirror the approach previously used by the European Commission to assign respective shares for renewable penetration across its Member States.

* https://www.ipcc.ch/assessment-report/ar6/

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Introduction

Around 131 countries, covering 73% of global greenhouse gas emissions, have adopted net-zero emissions targets for 2050 [1]. Organisations and nations that have adopted net-zero targets for this timeframe generally assume that their commitment is aligned with the Paris Agreement [2]. These commitments implicitly assume that others will also realise net-zero emissions over the same timeframe to achieve a global average net-zero by 2050. However, this approach may not be sufficiently ambitious by nations who have the capacity to transition more rapidly. For example, China's intention to achieve net-zero CO_2 emissions by 2060 necessitates a faster decarbonisation trajectory for the rest of the nations combined [2]. Naturally, these assumptions bring questions on fairness and equity to the forefront of the debate on climate policy. The United Nations Framework Convention on Climate Change (UNFCCC) introduced the principle of "common but differentiated responsibilities and respective capabilities", recognising the importance of these issues in global emissions mitigation. Moreover, the nationally determined contributions (NDCs) to the Paris Agreement offer a means to consider an equitable allocation of emissions mitigation efforts across different nations. However, it omits large-scale carbon dioxide removal (CDR) efforts, and therefore leaves open questions on the responsibility for the delivery of CDR over the course of the century [3].

Most economic transition pathways, which limit global warming to 1.5 °C by the end of the century, rely on CDR technologies operating at different scales [4],[5]. The amount of CDR deployment varies widely across modelled scenarios, depending on the rate of near-term emissions reductions, and the desired limit on global average warming towards the end of the century [6]. The latest projections from integrated assessment models (IAMs) suggest a cumulative global CDR requirement between 348 and 1,218 Gt CO_2 by 2100 to limit warming to 1.5 °C [7]. According to the "middle-of-the-road" P3 scenario from the IPCC Special Report on Global Warming of 1.5 °C, the global cumulative CDR requirement by 2100 is 687 Gt CO_2 [7]. This requirement is influenced by the chosen scenario and its assumptions on the pace of mitigation efforts, discounting factors, etc [8]. Nonetheless, there is a lack of clarity on responsibility for CDR and the efforts required by individual nations towards meeting this global cumulative target. Table 3 (Section 2.3) of Deliverable 8.1 in the NEGEM project reported that very few concrete quantitative estimates are available on CDR potentials in EU climate strategies. Similarly, IAMs typically feature engineered greenhouse gas removal (GGR) technologies, such as bioenergy with carbon capture and storage (BECCS) [7], [9], which are generally more expensive than emissions reduction measures, and are constrained by access to significant material, energy, and bio-geophysical resources. Furthermore, there is limited evidence to suggest that there are co-benefits from their deployment, and they could, in fact, generate adverse impacts in regions where they are deployed [10], [11]. Given these considerations, the allocation of the overall CDR target is likely to be a sensitive issue and requires a great degree of cooperation amongst nations.

Burden-sharing principles have been used to derive targets for CDR in literature as a starting point, with assumed parallels between CDR and emission reduction allocations [12], [13], [14]. Studies have analysed the implications of applying widely accepted burden-sharing principles on the overall CDR requirements, where the CDR target is defined separately from that required by reduction. They have found that the overall CDR target varies significantly depending on the method used to allocate the target [3]. The most popular burden-sharing principles discussed in literature are based on "Responsibility", "Capability", and "Equality" [15],[13]. The remainder of this document summarises these principles in the context of allocating CDR targets across countries in Europe. Recent literature is used to provide indicative bounds for CDR targets in Europe, which is to be assessed further in subsequent deliverables to inform the modelling of CDR pathways in different countries. It is important to note that the authors do not endorse the use of any single burden-sharing principle, but instead indicate potentially different principles and underline their impact on CDR targets. Note that these burden-sharing principles do not account for a region's technical potential to deploy CDR technologies, and this will need to be investigated further in future work.

1 Responsibility principle

The "Responsibility" principle, as the name indicates, relates the liability for global warming with a responsibility for its solution, by accounting for both current and cumulative historical greenhouse gas (GHG) emissions in absolute terms as the measurement indicator. Whilst the underlying principle is clear and accepted, its use in the allocation of CDR targets has several challenges. There is an ongoing debate on the accounting methods used, the list of GHGs involved, and the starting dates used to count emissions, etc. These parameters can greatly influence the share of the efforts amongst countries and are likely to remain as a source of contention.

Table 1: Cumulative CDR targets based on the Responsibility principle for countries within EU-28 expressed in Gt CO_2 by the year, 2100. Source: Pozo et al. [3]. *Note that the underlying data for the measurement indicators was not provided in Pozo et al., thus additional sources are necessary to derive the CDR targets as part of the modelling activities in Deliverable 4.4.*

Country	CDR target from Pozo et al. (Gt CO_2)	CDR target using the PRIMAP dataset (Gt CO_2)	Share of total EU-28 CDR using the PRIMAP dataset (%)
Austria	9.94	2.19	1.5
Belgium	15.93	4.71	3.3
Bulgaria	5.70	1.71	1.2
Cyprus	3.82	0.10	0.1
Czech Republic	17.91	4.37	3.1
Germany	15.00	32.20	22.5
Denmark	9.65	1.70	1.2
Spain	4.38	5.58	3.9
Estonia	28.94	0.63	0.4
Finland	7.67	1.30	0.9
France	9.24	17.70	12.4
United Kingdom	18.98	29.04	20.4
Greece	4.73	1.66	1.1
Croatia	3.11	0.47	0.3
Hungary	5.85	2.15	1.5
Ireland	6.28	2.46	1.7
Italy	5.34	9.28	6.5
Lithuania	4.89	0.78	0.5
Luxembourg	27.25	0.25	0.2
Latvia	3.94	0.45	0.3
Malta	3.05	0.03	0.0
Netherlands	12.05	4.53	3.2
Poland	9.65	10.47	7.3
Portugal	3.28	1.18	0.8
Romania	4.61	4.12	2.9
Slovakia	8.77	1.43	1.0
Slovenia	4.92	0.33	0.2
Sweden	10.61	2.19	1.5
Total	266	137	100

The Responsibility principle is often considered in tandem with the "Capacity" principle (see section 2) in literature as evidenced by the greenhouse development rights (GDRs) framework [16], [17]. According to Pozo et al. [3], the application of the Responsibility principle for CDR allocation results in countries such as Kuwait, Estonia, Luxembourg, United States, United Kingdom, Czech Republic, and Canada undertaking 25% of the global CDR burden of 687 Gt CO_2. Pozo et al. [3] applied the Responsibility principle, with a CO_2 emission accounting

period, 1850 – 2017 using data from the Community Emissions Data System [18] and the Global Carbon Atlas[†]. This results in the allocation of a cumulative CDR target of 266 Gt CO_2 across nations in Europe, and their results are tabulated in Table 1.

The use of the Responsibility principle to allocate the CDR target results in approximately half of the European Union (EU) CDR requirement being borne by countries such as Estonia, Luxembourg, United Kingdom, Czech Republic, Belgium, and Germany. However, it is difficult to ensure consistency when using these allocation methods as the CDR shares across the countries vary significantly depending on the underlying data and assumptions used for the calculations. Note that their results are generated based on the following performance indicator: the total GHG emissions per capita. Countries with a smaller population, and a significant relative contribution to overall GHG emissions, are responsible for delivering the majority of CDR using this metric. Thus, countries such as Kuwait, Luxembourg, and Estonia have a disproportionately larger share of the CDR target than countries such as the United States, and United Kingdom, which appears counter-intuitive given their historical emission contributions.

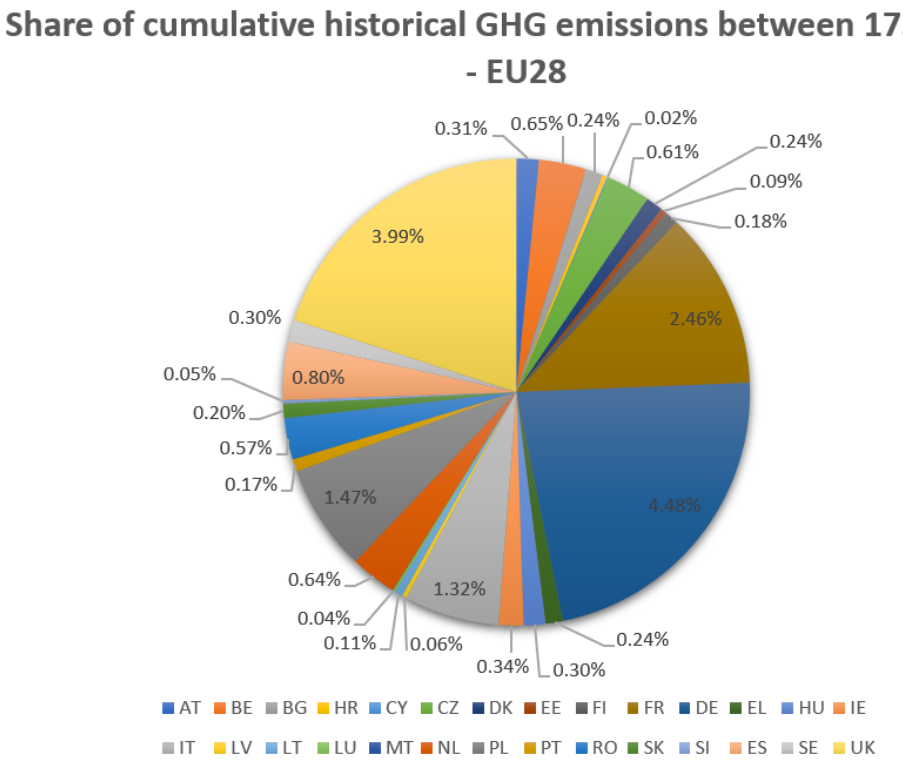

Figure 1: Shares of cumulative GHG emissions between 1750 – 2019 in countries across Europe based on the PRIMAP-hist dataset [19]. *Note that countries such as Luxembourg (LU), and Estonia (EE) have a considerably lower share of the cumulative historical GHG emissions in absolute terms and a lower the CDR target if cumulative emissions is used as the measurement indicator.*

In contrast, the third column in Table 1, together with Figure 1 depicts the share of cumulative GHG emissions for each country in the EU with a start date of 1750. Note that the underlying data is derived from the PRIMAP-hist dataset v2.3 [19], and it includes emissions statistics covering GHGs such as CO_2, CH_4, N_2O, etc. The use of this dataset to derive a CDR target results in large discrepancies with the data presented in Pozo et al. [3] for

[†]Boden, T. A., Marland, G. & Andres, R. Global, Regional, and National Fossil-Fuel CO_2 Emissions (USDOE, 2017); https://doi.org/10.3334/CDIAC/00001_V2017.

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[*] Statistical Review of World Energy (BP, 2018).

countries such as Estonia, Luxembourg, owing to methodological and accounting differences. This discrepancy stems mainly from the use of cumulative total GHG emissions from each country as the indicator instead of cumulative total GHG emissions per capita. Importantly, both indicators have been used in the literature to ascribe responsibility to countries based on historical contributions to GHG emissions. However, we contend that cumulative total GHG emissions per capita is a poor indicator to allocate country-level CDR quotas, as it places the emphasis on the emissions intensity instead of the cumulative contribution to the global atmospheric carbon stock. Thus, there needs to be more attention and research focus on developing a consensus around performance indicators, emissions accounting start dates, the list of GHGs considered, etc. Importantly, allocations based on the Responsibility principle alone does not account for the capability of a country to effect large-scale CDR deployment. This may be addressed by generating a weighted set of CDR targets from accepted burden-sharing principles.

2 Capacity Principle

Section 1 noted that countries which may have a higher share of CDR target as per the Responsibility principle might not necessarily have the capabilities to achieve the necessary scale of deployment. The "Capacity" principle hinges on the notion that countries that have the capabilities to tackle the problem should contribute more to the efforts. In the context of CDR, this would imply that wealthier nations, to some degree, have a greater share of the overall CDR target. Capacity, in this context, represents the ability of an agent to fulfil a costly action of deploying CDR without a disproportionate sacrifice in welfare. The overall income per capita is usually taken as a measurement indicator for Capacity. Pozo et al. [3] used the Capacity principle to derive a cumulative CDR target of 325 Gt CO_2 by 2100 as illustrated by Table 2 below.

Table 2: Cumulative CDR targets based on the Capacity principle for countries within EU-28 expressed in Gt CO_2 by the year, 2100, allocated based on GDP per capita projections over the time horizon. Source: Pozo et al. [3].[3]. *Note that the underlying data for the measurement indicators was not provided in Pozo et al., thus additional sources are necessary to derive the CDR targets as part of the modelling activities in Deliverable 4.4.*

Country	CDR target (Gt CO_2)	Share of total EU-28 CDR (%)
Austria	17.32	5.3
Belgium	14.54	4.5
Bulgaria	4.11	1.3
Cyprus	7.07	2.2
Czech Republic	8.29	2.5
Germany	17.17	5.3
Denmark	18.80	5.8
Spain	13.45	4.1
Estonia	7.17	2.2
Finland	15.75	4.8
France	14.03	4.3
United Kingdom	11.93	3.7
Greece	12.92	4.0
Croatia	7.42	2.3
Hungary	6.63	2.0
Ireland	14.06	4.3
Italy	15.71	4.8
Lithuania	6.45	2.0
Luxembourg	23.22	7.1
Latvia	6.69	2.1
Malta	8.43	2.6
Netherlands	18.58	5.7

Poland	6.62	2.0
Portugal	11.44	3.5
Romania	4.41	1.4
Slovakia	7.61	2.3
Slovenia	10.13	3.1
Sweden	15.15	4.7
Total	325	100

Note that the term, capacity, in this context, does not indicate a nation's ability to utilise their indigenous resources to provide CDR at scale, but rather their ability to finance the deployment of CDR. Some of these nations may have the financial capability to undertake CDR and have the appropriate domestic potential to do so, whereas others may not. Thus, region-specific appraisals of CDR potential needs to be undertaken in tandem with the allocation of CDR targets to ensure wider acceptability.

In the calculations, Pozo et al. use real data for the GDP per capita based on purchasing power parity and population in 2010, while for later periods they are forecasted independently. The countries' GDPs are projected according to the Shared Socioeconomic Pathway 2 narrative (SSP2, middle-of-the-road scenario), which considers two time spans and three income groups [20],[21]. They assume 1.4%, 4.0% and 3.7% annual average GDP per capita growth for high-income, middle-income, and low-income countries, respectively, between 2010 and 2040, and 0.9%, 1.9% and 3.3% growth rates, respectively, onwards. For projections on population, they use the mean scenario from the United Nations World Population Prospects [22] for the whole policy horizon. The use of the Capacity principle leads to almost 40% of the EU CDR target being fulfilled by countries such as Luxembourg, Denmark, the Netherlands, Austria, Germany, Finland, and Sweden. Note that assigning CDR targets purely based on a nation's capabilities to finance the investment is unlikely to achieve fairness as a country might be very capable of undertaking CDR but might also have contributed very little historically. Hence, a more pragmatic approach is needed.

3 Equality principle

The "Equality" principle notes that every individual should have the same right to be protected from adversity. Thus, leading to a CDR requirement which is usually allocated on a per capita basis. Hence, countries with larger populations will ultimately be responsible for the majority of CDR deployment, irrespective of their overall contribution to global GHG emissions, and their capacity to effect deployment. However, countries that have higher populations, together with less available land area, may experience significant increases in the price of land owing to the land use change impacts of some CDR options, and this is unlikely to be politically acceptable, nor feasible. For such reasons, this principle is less widely accepted relative to those discussed earlier as it shifts the bulk of the burden onto countries that do not necessarily have the capability to achieve these targets. Table 3 summarises the CDR target amongst nations in Europe. Pozo et al. used historical data for the year, 2010, and the mean scenario from the United Nations World Population Prospects to describe the population growth for the subsequent years along the policy horizon [22]. Note that the use of the Equality principle leads to a considerably lower share of the global CDR target being met by the EU-28 – 32.9 Gt CO_2 by 2100.

Table 3: Cumulative CDR targets based on the Equality principle for countries within EU-28 expressed in Gt CO_2 by the year, 2100. Source: Pozo et al. [3].

Country	CDR target (Gt CO_2)	Share of total EU-28 CDR (%)
Austria	0.58	1.8
Belgium	0.86	2.6
Bulgaria	0.33	1.0
Cyprus	0.09	0.3
Czech Republic	0.65	2.0
Germany	5.15	15.6
Denmark	0.44	1.3
Spain	2.77	8.4
Estonia	0.07	0.2
Finland	0.41	1.2
France	4.86	14.8
United Kingdom	5.25	15.9
Greece	0.61	1.9
Croatia	0.21	0.6
Hungary	0.51	1.5
Ireland	0.41	1.2
Italy	3.51	10.7
Lithuania	0.15	0.5
Luxembourg	0.06	0.2
Latvia	0.09	0.3
Malta	0.03	0.1
Netherlands	1.16	3.5
Poland	1.92	5.8
Portugal	0.55	1.7
Romania	1.00	3.0
Slovakia	0.31	0.9
Slovenia	0.12	0.4
Sweden	0.83	2.5
Total	32.9	100

4 Discussion and future work

In theory, countries can fulfil their CDR obligations by deploying CDR domestically (which may not be the least cost solution, but may be more sustainable), or they may pay for CDR elsewhere. Some countries may have the capacity to deliver more than their national obligations for CDR (and wish to be a supplier), whereas others may fail to meet their targets (and wish to be a purchaser). The use of the burden-sharing principles discussed in the earlier sections does not account for a region's technical potential to deploy technologies. Thus, further region-specific appraisals are needed to derive the technical potential for CDR in each country, by accounting for the carbon removal efficiencies of each CDR technology, and the permanence of the carbon removed.

The authors propose 4 distinct scenarios for modelling CDR technologies together based on quotas derived from burden-sharing principles. It is important to consider them together as it helps to explore a range of potential CDR deployment trajectories, thereby identifying critical paths and commonalities to fast-track the rollout of technologies. A technology modeller should first start with their assumptions on the overall global CDR requirement over the period to the year, 2100. Following which, the share of EU CDR can be calculated (using Table A1 in the Appendix), and the percentage shares in Tables 1, 2, and 3, can be used to allocate the overall CDR quota across EU Member states in scenarios 1, 2, and 3, respectively. The last scenario proposes a hybrid

approach where equal weighting is given to the responsibility and capacity principles.

Figure 2 (from Pozo et al. [3]) present an estimate of the domestic CDR potential (focusing on BECCS, reforestation, and DACCS) against CDR targets generated by the three equity principles, indicating that there is insufficient domestic potential to meet the targets as determined by the Responsibility and Capability principles, but sufficient potential to meet the demands generated by the Equality principle. However, this assessment needs to be expanded to include other relevant CDR options such as biochar, soil carbon sequestration, and enhanced weathering, amongst others, and this will be the focus of various activities in work packages 3, 4, 7 and 8 of the NEGEM project.

The GDRs framework is an example of a framework which seeks to balance the obligations assigned to nations based on a combination of their responsibility (contribution to the problem) and their capacity (ability to pay) [17]. The 'Responsibility and Capacity Indicator (RCI)' introduced in the GDRs framework is purported to compute a "fair share" of the global obligation for every nation. Equal weightings have been given to both the Responsibility and Capacity principle on account of the widely held view that in order to protect the global ecosystem, those who pollute more should contribute more, and those who are wealthier should contribute more, and those who have the greatest need should be supported [23]. The GDR framework also uses the concept of the "development threshold" which is used to differentiate individuals who are nominally exempted from obligations, owing to low incomes. In general, it is not entirely clear if the assignment of equal weightings for both the Responsibility-derived targets, and Capacity-derived targets, is a fair approach. Furthermore, the choice of a "development threshold" value requires justification and regular updating to be relevant.

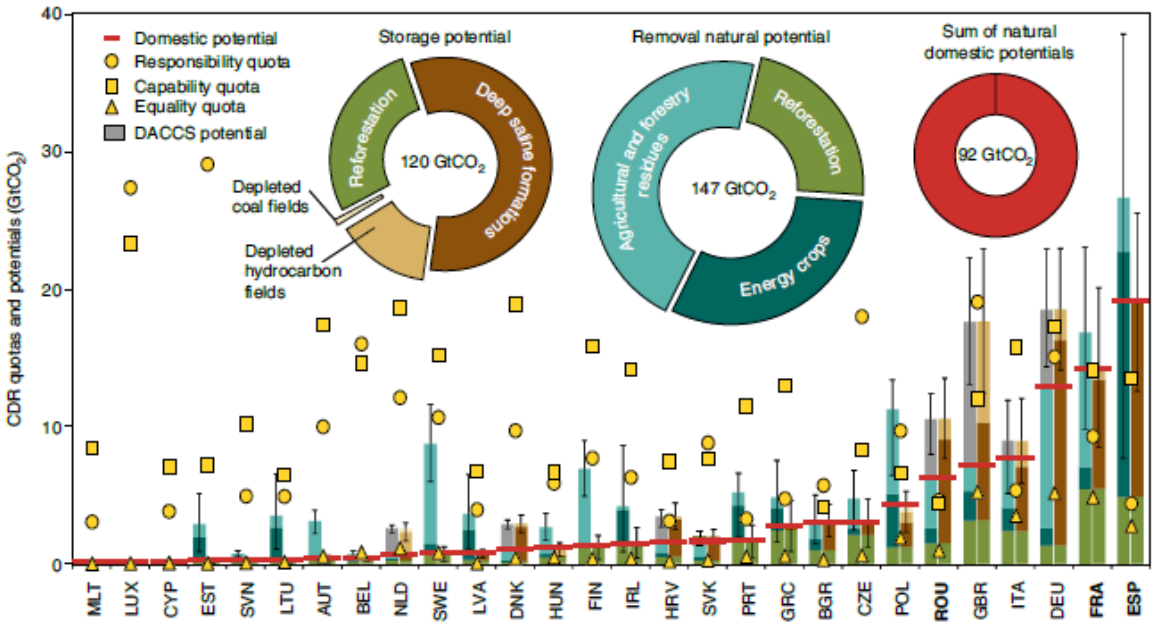

Figure 2: A comparison between the targets derived from burden-sharing principles, domestic CO_2 removal and storage potentials in each EU country. Source: Pozo et al. [3]. *National CDR targets are depicted with different markers (circles for Responsibility, squares for Capability and triangles for Equality). The domestic CDR potential for each EU member state is given by the vertical bars, where the left-hand side stacked bars denote removal potential (BECCS, reforestation, and DACCS) and the right-hand side stacked bars provide the CO_2 storage potential. Countries are sorted in increasing order of their natural domestic potential considering the most limiting factor between removal and storage (depicted by a horizontal red line). Country labels correspond to the official ISO3 code abbreviations. Error bars depict the conservative and optimistic scenarios for both removal and storage potentials in each.*

It is also important to note that application of different burden-sharing principles across regions in the world lead to differences in the share of the (687 Gt CO_2) global target being owned by a region. This highlights the need to

have agreements on "accepted principles" that can be used by national bodies and governments to start negotiations. Here, multi-criteria allocation methods may be used to derive weighted targets based on burden-sharing principles. However, the relative importance of each principle, and their weighting coefficients are inherently subjective. Thus, the authors do not recommend the use of any single burden-sharing principle or weighting method to support policymaking. But there is value in exploring different combinations of weighting coefficients to derive a range of CDR targets. This allows the modeller to identify deployment patterns that are similar across all burden-sharing allocation methods to inform policy and decision-making. For instance, this approach was used by the European Commission to allocate a 20% increase in the renewable energy generation across the member states, where the liability for the problem, and the ability to pay, were both considered [24]. The weightings used to allocate the targets for renewable energy generation is not directly transferable and should be explored in more detail.

The 4 scenarios proposed in this deliverable are intended to be used in the modelling work within WP 4, 7, and 8. They allow demand-driven mathematical models to explore the cost, and environmental implications of different levels of CDR being "owned" by EU-28. Note that the authors recommend the use of these 4 scenarios, together with different global CDR targets, potentially derived from the IPCC scenarios. This will generate several sets of results, which can be analysed to inform policy decisions on the value of different technologies and policy measures. It is important to note that the application of burden-sharing principles via these scenarios leads to diverging shares of effort by the EU Member States, allowing a wide range of circumstances to be explored. These results can inform Member State negotiations on CDR quotas, provided timely engagement with the policymakers.

For preparing this report, the following deliverable/s have been taken into consideration:

D#	Deliverable title	Lead Beneficiary	Type	Dissemination level	Due date (in MM)
D8.1	Stocktaking of scenarios with negative emission technologies and practises. Documentation of the vision making process and initial NEGEM vision	VTT	R	PU	8
D4.3	Identify Member state targets for CDR	ICL	R	PU	17

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5 Appendix

Table A1: Scenarios based on burden-sharing principles and the respective CDR share "owned" by the EU-28 as part of a global CDR target.

Scenario label	Scenario description	Share of global CDR by EU-28 CDR (%)
1	Responsibility-based	21[‡]
2	Capacity-based	47[§]
3	Equality-based	4.7
4	Equal weighting to Responsibility and Capacity	34

[‡] This percentage share is derived from the EU's cumulative GHG contribution over the period 1750 – 2019, based on data from the PRIMAP-hist dataset.

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