Iceland Liechtenstein Norway grants

Norway grants

The *Building momentum for the long-term CCS deployment in the CEE region* project is funded by Iceland, Liechtenstein and Norway through the EEA and Norway Grants Fund for Regional Cooperation.

BUILDING MOMENTUM
FOR THE LONG-TERM CCS DEPLOYMENT
IN THE CEE REGION

Assessment of current state, past experiences and potential for CCS deployment in the CEE region

Luciana Miu, Diana Nazare, Mihnea Cătuți, Constantin Postoiu, Radu Dudău

Implemented by: WiseEuropa, Bellona Europa, EPG Energy Policy Group, CIVITTA, Institute for European Integration

Supported by: EUROPEUM Institut pro evropskou politiku / Institute for European Policy

Co-financed by: NIW

Sfinansowano przez Narodowy Instytut Wolności - Centrum Rozwoju Społeczeństwa Obywatelskiego ze środków Programu Rozwoju Organizacji Obywatelskich na lata 2018 – 2030

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BUILDING MOMENTUM
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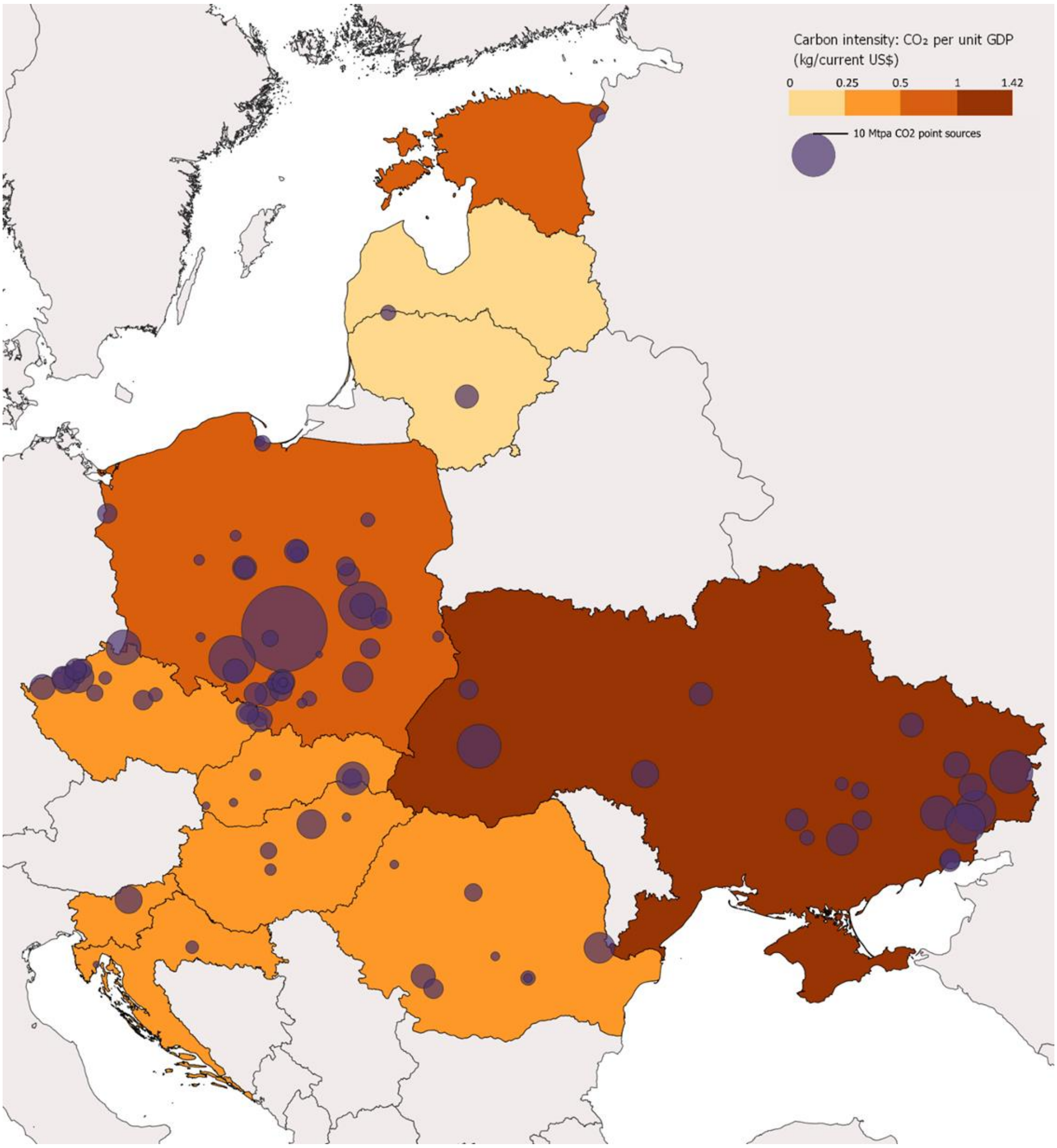

Current context and opportunities for CCU and CCS in Central and Eastern Europe

CCS4CEE Work Package 3 – Summary Report

October 2021

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List of acronyms and definitions

€	euro
$	dollar
ACROPO	Romania's Regulatory Authority for Offshore Petroleum Operation in the Black Sea
anthracite	a hard and compact type of coal, considered the highest rank of coal, with the highest energy density and the fewest impurities
BASTOR	Baltic Sea Storage of CO_2 (project name)
bischofite	a hydrous magnesium chloride mineral belonging to the halides family, generally found mixed with other minerals in salt basins, but rarely found at high concentrations in bischofite-rich rocks (including in the Poltava region of central Ukraine)
black coal (bituminous coal)	a relatively soft coal containing bitumen (asphalt), ranked higher in quality than lignite but lower than anthracite
blast furnace	a type of metallurgical furnace used for smelting to produce metals, generally pig iron
blue hydrogen	hydrogen produced from methane using steam methane reforming (SMR) and capturing the CO_2 from the process
CAPEX	capital expenditure
Carbon Border Adjustment Mechanism	a measure proposed by the European Commission, which would require importers in the EU to pay for carbon certificates on products imported from outside the EU, equivalent to the amount that would have been paid if the goods had been produced in the EU under the current carbon pricing regime
carbon intensity	a measure of how much CO_2 emissions are produced per a specific unit (e.g. $ of GDP)
CASTOR	CO_2, from Capture to Storage (project name)
CC	carbon capture

CCfD	carbon contracts for difference; a financing instrument by which governments guarantee investors in climate-friendly technologies and practices a fixed price which rewards CO_2 emissions reductions above the current price levels in the EU ETS
CCS4CEE	The "Building Momentum for the Long-Term CCS Deployment in the CEE Region" project
CCU	carbon capture and utilization
CCUS	carbon capture, utilization and storage
CCS	carbon capture and storage
CCS-ready	an installation has demonstrated that suitable storage sites are available, transport is technically and economically feasible and retrofit for CO_2 capture is technically and economically feasible, if sufficient market incentives in the form of a CO_2 price threshold are reached.
CCS Readiness Index	a measure developed by the Global CCS Institute (GCCSI) to quantify policy, legal, storage and stakeholder interest factors regarding CCS in various countries
CEE	central and Eastern Europe
CHP	combined heat and power
CO_2	carbon dioxide
CO_2-eq	CO_2-equivalent, a unit used to standardize the impact of greenhouse gas emissions, representing the number of metric tons of CO_2 emissions with the same global warming potential as one metric ton of any greenhouse gas
coal seam	a banded deposit of coal visible within layers of rock
concession	in this report, a concession refers to a permit granted for geological exploration or mining
Connecting Europe Facility	an EU funding instrument which targets connective infrastructure projects in the areas of transportation, energy and digital

DAC	direct air capture of CO_2: a process of capturing CO_2 directly from the ambient air and generating a concentrated stream of CO_2 for storage or utilization.
demonstrator project	a generally larger-scale non-commercial project used to demonstrate a concept or technology
EC	European Commission
EEA	European Economic Area
EOR	enhanced oil recovery; a class of techniques used to extract oil which could not have been extracted otherwise
EGR	enhanced gas recovery; a class of techniques used to extract natural gas which could not have been
EIA	Environmental Impact Assessment, a procedure that ensures that the environmental implications of decisions are taken into account before decisions are made, carried out for projects on the basis of Directive 2011/92/EU (known as 'Environmental Impact Assessment' – EIA Directive)
ENOS	ENabling Onshore CO_2 Storage in Europe (project name)
EPG	Energy Policy Group
EU	European Union
EU-27	EU Member States as of 1st January 2021 (excluding the United Kingdom)
EU-28	EU Member States until 31st December 2020 (including the United Kingdom)
EU CCS Directive	the EU directive on the geological storage of CO_2, Directive 2009/31/EC, which regulates aspects of carbon storage, and to a lesser extent carbon capture and transport
EU ETS	EU Emissions Trading System; an EU-wide system by which sources of GHG emissions are obliged to pay for a permit for each tonne of GHG they emit above a certain allocation level. Permits can be traded between emitters.

EUA	EU Allowances, a form of carbon allowance used as the main currency in the EU ETS.
Eurobarometer	surveys on a variety of topics conducted by the European Union on Member State respondents
expanded EU ETS	all emissions sources larger than 1 Mt CO_2/year which are either subject to the EU ETS or which would be subject to the EU ETS but are located in Ukraine (this term is used for the purpose of this report only)
fracking	a drilling technology used for extracting oil, natural gas or other underground resources by fracturing the rocks surrounding deposits of these resources
fuel combustion emissions	emissions generated by the burning of fuels (including for energy production and transportation)
g	gram
GCCSI	Global CCS Institute
GDP	Gross Domestic Product
GEO	Government Emergency Ordinance (Romania)
GHG	greenhouse gases
Gt	gigatonnes
GVA	Gross Value Added
GW	gigawatt
hard coal	in this report, “hard coal” is equivalent to bituminous coal
hydrocarbon reservoirs	deposits of oil or natural gas
IEA	International Energy Agency
IED	the EU’s Industrial Emissions Directive, Directive 2010/75/EU on industrial emissions, the main EU instrument regulating pollutant emissions from industrial installations

implementing decree	for the purposes of this report, an implementing decree refers to a regulation of national governments specifying the key practical aspects involved in conducting CCS projects (in particular CO_2 storage), following the transposition of the CCS Directive
Innovation Fund	a €20-billion EU funding programme (running between 2020 and 2030), focused on the demonstration of innovative low-carbon technologies (one of its four areas of focus is CCS)
IPPU	industrial processes and product use (or process emissions)
ISPE	Institute for Studies and Power Engineering (Romania)
kg	kilograms
km	kilometres
kt	kilotonnes
kWh	kilowatt-hour
large emitter	for the purpose of this report, large emitter refers to an emissions source with more than 1 Mt CO_2-eq in emissions in the most recent year of data (2020 for EU countries and 2019 for Ukraine)
lignite (brown coal)	a type of coal formed from naturally compressed peat, considered one of the lowest ranks of coal due to its relatively low heat content
mineral carbonation	a process of immobilizing CO_2 in naturally occurring minerals, such as those occurring in basaltic rocks
Mt	megatonnes
Mtpa	megatonnes per annum
MW	megawatt
MWh	megawatt-hour
NACE	Nomenclature of Economic Activities, a pan-European classification system that groups organisations according to their business activities
NAMR	Romania’s National Agency for Mineral Resources

NECP	National Energy and Climate Plan, integrated plans which Member States were required to submit to the EU by the end of 2019, outlining a plan to meet EU energy and climate targets for 2030
net zero emissions	achieving a balance between the greenhouse gas emissions put into the atmosphere and those taken out
NGO	non-governmental organization
OG	Ordinance of Government (Croatia)
pig iron	an intermediate product in the production of steel, obtained by smelting iron ore in a blast furnace
pilot project	a non-commercial, usually small-scale implementation generally used to prove the viability of a technology
proactive stakeholder	defined in this report as a stakeholder actively supporting the deployment of CCS (the main focus of this report is CCS, therefore stakeholders who are solely engaged with CCU are not defined as proactive)
process emissions	emissions generated by industrial processes, for example the chemical reactions involved in the calcination of limestone to produce cement
NIMBY	"Not-In-My-Backyard", referring to a reticent attitude towards projects being developed in close proximity to individuals' residences
R&D	research and development
Recovery and Resilience Plan	plans submitted by Member States to the European Commission, outlining their proposed reforms and investments over the next five years, in order to access funding through the Recovery and Resilience Facility
RERA	Romanian Energy Regulatory Authority
saline aquifers	geological formations characterised by the presence of water-permeable rocks which are saturated with salt water (brine)
serpentinite	a metamorphic rock that is mostly composed of serpentine group minerals

structural funding (EU)	a set of EU funding pots designed to support economic development and reduce inequality between and within countries
t	tonnes
WP	Work Package
y.o.	years old

1. Overview of project and region

The "Building momentum for the long-term CCS deployment in the CEE region" project (CCS4CEE) aims to reignite the discussion on carbon capture and storage (CCS) in Central and Eastern Europe (CEE). 11 countries in the region are covered by the project scope, assessing the current state of CCS and developing roadmaps for implementation in the different states. The project is composed of three main work packages (WPs), running in sequence across a period of three years (2020-2023) (Figure 1). The intended outcomes of the project include improved stakeholder communication at national and regional level, concrete plans for national or regional pilot projects and input into policymaking to accelerate deployment of CCS projects in participant countries.

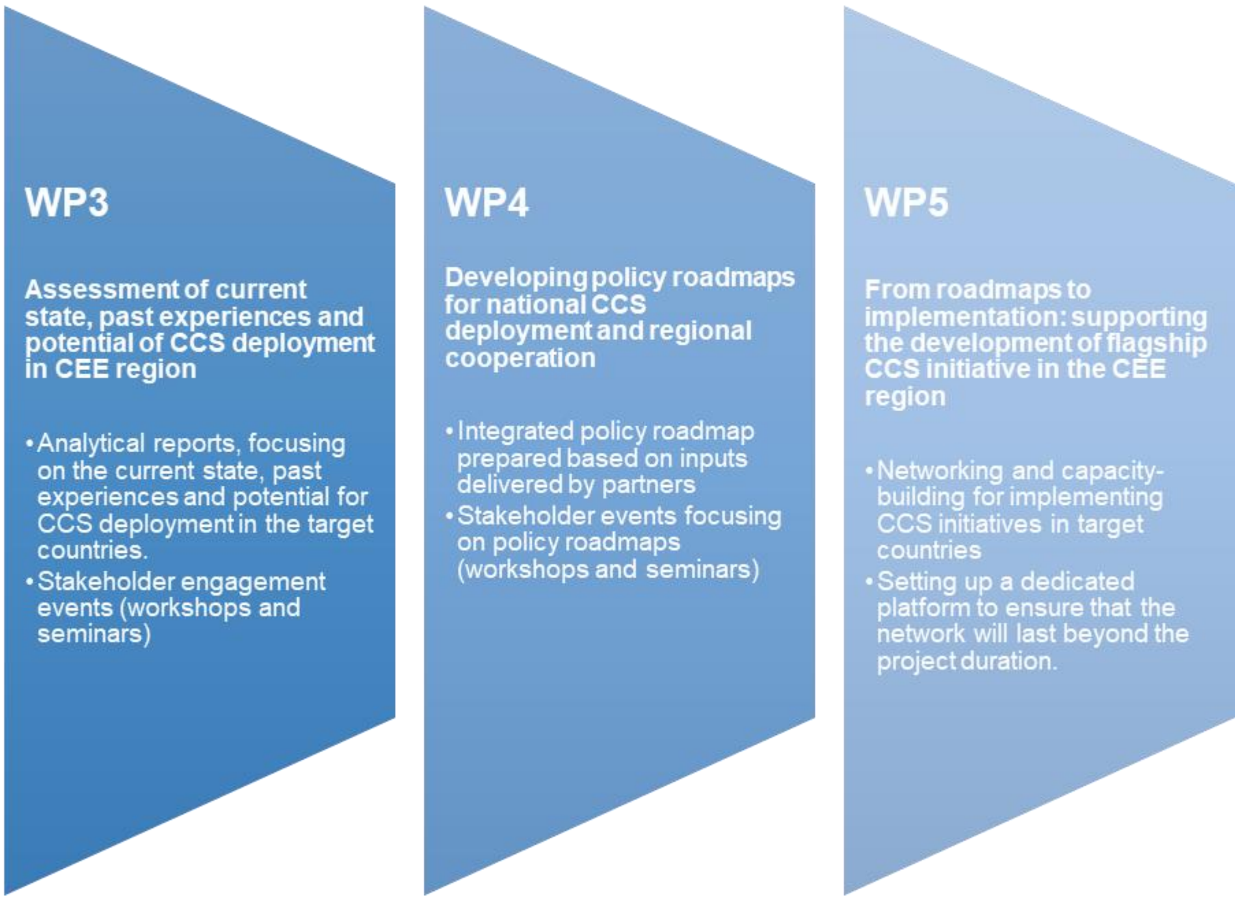

Figure 1. Overview of main work packages (WPs) in the CCS4CEE project. Source: Energy Policy Group.

The CCS4CEE participant countries (referred to as "partner countries" throughout this report) and their associated project partners are:

- Poland (WiseEuropa)
- Czech Republic (Institute for European Integration)
- Slovakia (Institute for European Integration)
- Romania (Energy Policy Group)
- Hungary (Energy Policy Group, subcontracted to Közép-Európai Biztonsági Képzési és Kutatási Központ – Central European Safety Training and Research Center)

- Croatia (WiseEuropa, subcontracted to the Department of Petroleum and Gas Engineering and Energy of the University of Zagreb)
- Slovenia (WiseEuropa, subcontracted to Dr. Marko Maver, Assistant Director at the National Laboratory of Health, Environment and Food of Slovenia)
- Estonia (Civitta)
- Latvia (Civitta)
- Lithuania (Civitta)
- Ukraine (Civitta)

Within the project, Work Package 3 (WP3) sets a baseline for incipient discussions on implementing CCS projects in the CEE region. Its main aim is to assess the current state of CCS in the participant countries. Project partners in each participating country achieved this aim through a combination of desk-based research (evaluating the carbon intensity of national economies, geological potential for CO_2 storage, history of CCS projects, relevant legislative frameworks, and social acceptance of CCS) and stakeholder engagement (interviews and a workshop with relevant stakeholders, and a seminar to disseminate the findings of WP3).

In WP3, partners engaged a total of 176 stakeholders from the 11 partner countries, through the workshops and interviews. Workshops were conducted in all partner countries between April and June 2021. Two seminars were held in summer 2021 (Poland and Slovenia), with the remainder scheduled for September and October 2021. National reports on the current state and outlook for CCS were published for all 11 partner countries and are available on the CCS4CEE website.[1]

The CCS4CEE project is led by WiseEuropa and supported by Bellona Foundation as expert partner to the project. The project is funded by EEA and Norway Grants Fund for Regional Cooperation (project contract number 2018-1-1141).

[1] CCS4CEE website.

2. Economy and carbon emissions in the CEE region

This section gives a brief history of the economic and emissions trajectories of CEE countries, highlighting commonalities and differences in macro-economic indicators and economic sector contributions, focusing on CCS relevant sectors (energy, chemical, steel, cement and other minor industries). It will also highlight commonalities and differences in the carbon intensity of CCS-relevant sectors and draw out the largest carbon emitters in the region.

2.1. Economic aspects of partner countries

The economies of partner countries, and their related emissions trajectories, were fundamentally affected by the end of the communist regimes in 1989 and the early 1990s. Since 1990, the economies of these states (aside from Ukraine) have grown steadily (Figure 2) and shifted to increasingly service-based economies (ranging from 54% of gross domestic product (GDP) in Ukraine[2] to 64% in Latvia); still slightly below the European Union (EU) average of 66%.[3] This shift can be seen in the declining trend of agriculture and industry as a percentage of GDP (Figure 2), coupled with the growing contribution of the service sector in these countries. From a macro-economic point of view, partner countries are still below EU average, with GDP per capita ranging from 30% (Ukraine) to 92% (Czech Republic) of the EU's average.[4]

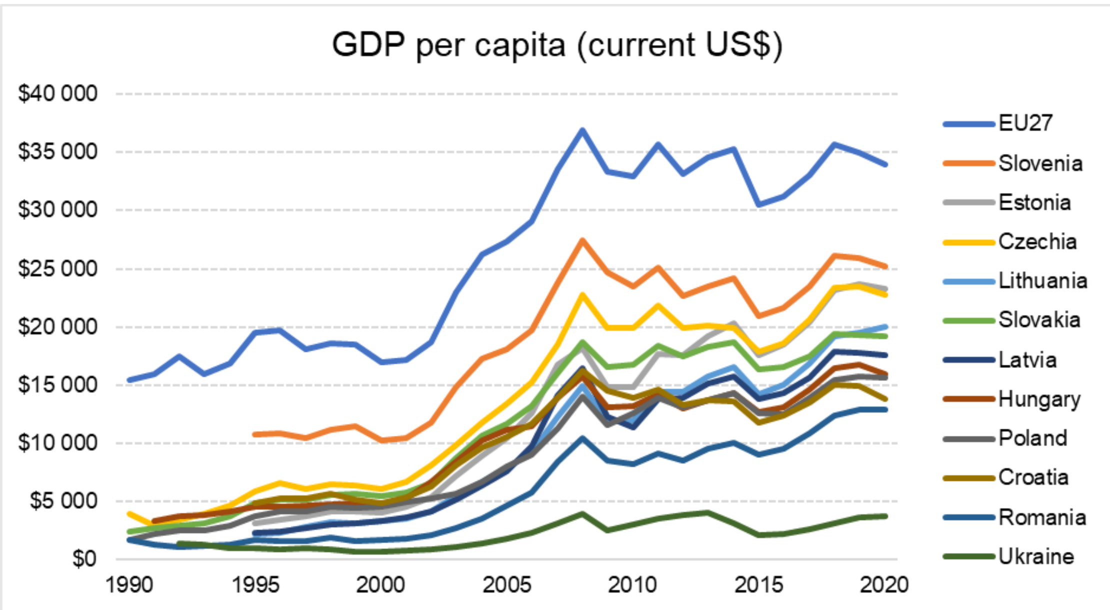

Figure 2. GDP per capita in partner countries between 1990 and 2020. Source: World Bank. Note that only EU-27 data is available from the World Bank.

[2] Credit Agricole Group, 2021. Economic and political overview in Ukraine
[3] Statista, 2021. Share of economic sectors in the gross domestic product (GDP) in 2020, by global regions
[4] Trading Economics, 2021. GDP per capita PPP (Europe).

Despite the ongoing transition to service-based economies, industry continues to play an important role in CEE countries, with all partner countries bar Latvia showing a contribution of industry to Gross Value Added (GVA) higher than the EU value of 19% (2018 data). The industries of the Czech Republic, Slovenia, and Romania in particular contributed between 30% and 50% more than the EU average to the economies of these partner countries; and despite a dramatic decline in its share of industry in GDP (Figure 3), Ukraine is also above EU level in this respect.

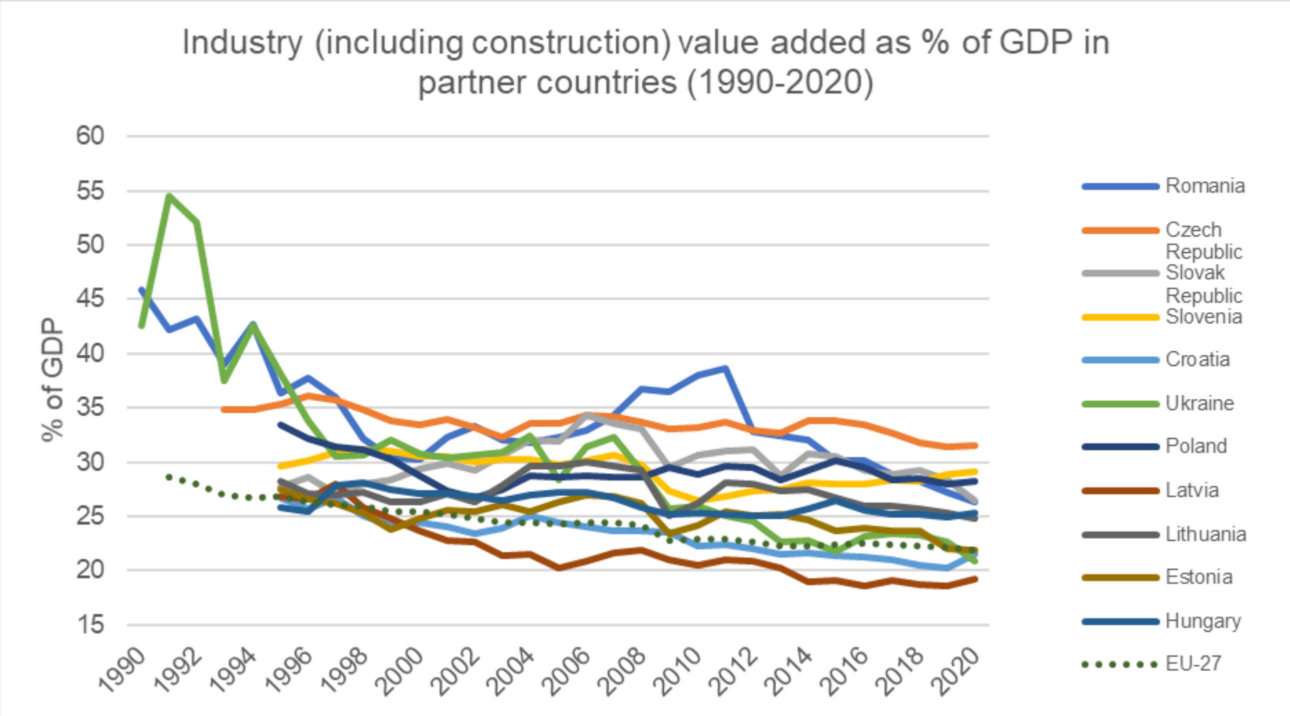

Figure 3. Industry contribution to GDP in partner countries (1990-2020). Source: World Bank.

In the following sections, we analyse the contribution of key economic activities relevant to CCS in partner countries to the economies of these countries. These are primarily activities pertaining to the production of energy (including fossil fuels and waste-to-energy) and manufacturing. We also briefly analyse the contribution of mining and quarrying, including the mining of coal and lignite, to better understand the dependence of partner countries' economies on the exploitation of fossil fuel resources. Overall, this brief analysis serves to sketch potential sectors of opportunity for CCS implementation across the region, and key differences in this potential between partner countries.

All cited data is for GVA in 2018, based on national accounts data (unless otherwise mentioned).

2.1.1. Energy production

In terms of the contribution of energy production (electricity, gas, steam and air-conditioning supply)[5] to national economies, most partner countries[6] are above the EU-28 level (1.8%), ranging from 22% higher (Slovenia) to 73% higher in Ukraine and 81% higher in Estonia.[7] In addition to this higher contribution of energy supply to the economies of CEE countries, energy production is

[5] Code D in the Nomenclature of Economic Activities (NACE), used to categorize types of economic activity.
[6] All countries (including Ukraine), apart from Latvia, Lithuania and Hungary.
[7] Note that EU-28 is used as a comparison basis in all sections of this report, where possible. "EU" refers to "EU-28" unless otherwise indicated.

overwhelmingly more dependent on fossil fuels than the European average (Figure 4). Over 90% of the primary energy supply in Poland, Estonia and Lithuania comes from fossil fuels; coal dominates in Poland,[8] oil shale in Estonia[9] and oil and natural gas in Lithuania.[10]

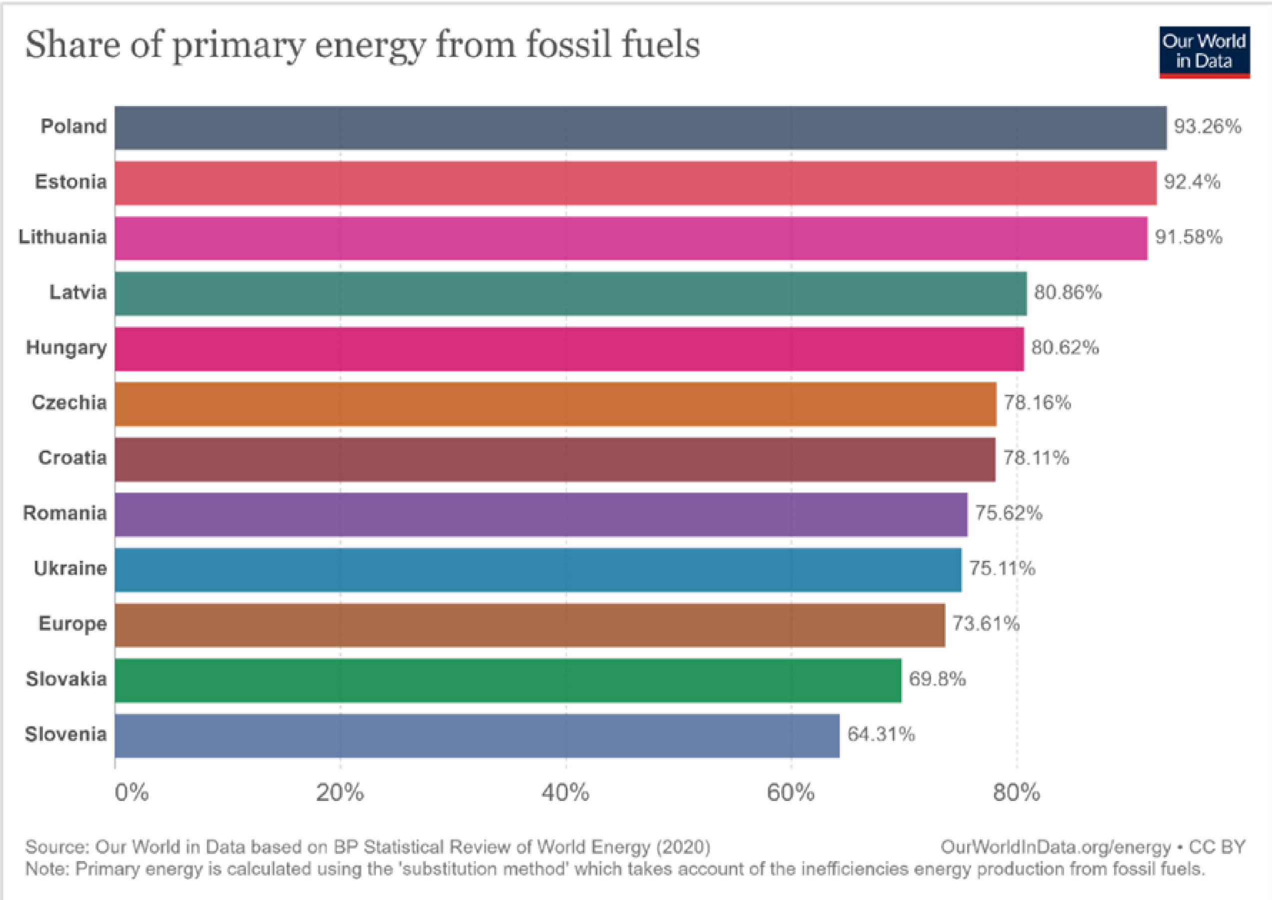

Figure 4. Share of fossil fuels in primary energy supply, 2019. Average data was only available for Europe, rather than the EU. Source: Our World in Data.

Singling out electricity production, fossil fuels again dominate in several partner countries, although the picture is less striking than for primary energy supply (Figure 5). An overwhelming percentage of Poland's electricity has fossil origins (coal), followed by Estonia (oil shale) and the Czech Republic (coal). Lithuania and Latvia are also above European average, with Lithuania relying mainly on imported fossil energy since the closure of its only nuclear power plant in 2009.[11] Only Slovakia and Slovenia are below the European average in terms of their share of fossil fuels in electricity production; Slovakia's GHG intensity of electricity production is half that of the EU.[12] However, both countries are still higher than the European average in terms of fossil fuel consumption per capita.

[8] International Energy Agency (IEA), 2020. Poland.
[9] CCS4CEE country report: Estonia. Available on the CCS4CEE project website.
[10] International Energy Agency (IEA), 2020. Lithuania.
[11] International Energy Agency (IEA), 2020. Lithuania.
[12] European Environmental Agency, 2021. Greenhouse gas emission intensity of electricity generation in Europe.

Despite their heavy use of and reliance on fossil fuels (Figure 6), partner countries will likely slowly move away from them in the immediate next few decades. Coal phase-out dates have been declared in six partner countries: 2025 in Hungary,[13] 2030 in Slovakia,[14] 2032 in Romania,[15] 2033 in Slovenia,[16] 2038 in the Czech Republic[17] and 2049 in Poland.[18] Ukraine set a deadline in 2020 for net zero emissions by 2070, with large utility DTEK committing to carbon neutrality by 2040.[19] Estonia is also planning to phase out its use of oil shale for energy production by 2030 (see Section 2.2.2.). However, in some countries it is yet to be decided what the replacement capacity for phased-out coal power will be – Slovenia is planning to increase its nuclear capacity but is still awaiting a government decision on the matter, and Romania is still debating its decarbonisation plan for the Oltenia Energy Complex, the country's largest lignite-fired power complex. CCS for the energy sectors of some partner countries, particularly Poland and Ukraine, may therefore need to be considered as an option for decarbonisation, at least in the medium term.

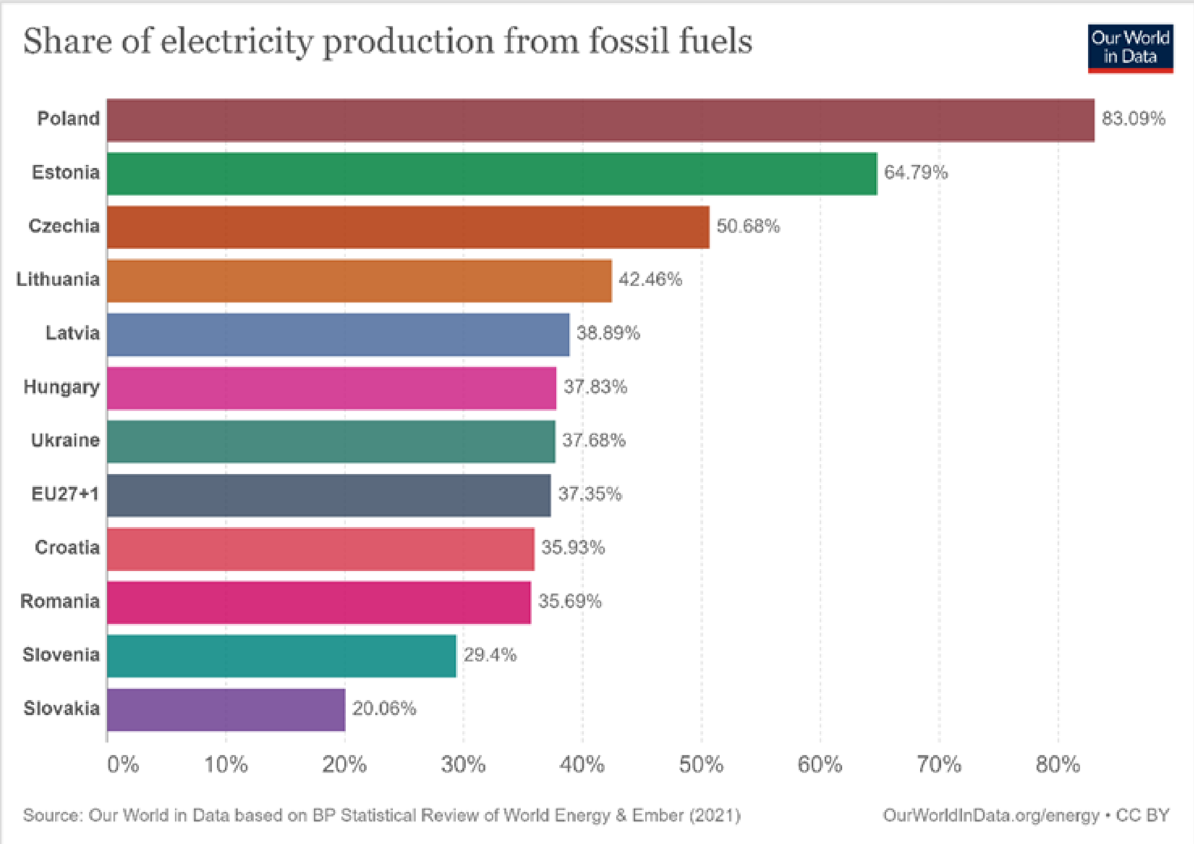

Figure 5. Share of fossil fuels in electricity supply, 2020. EU27+1 refers to the 27 EU countries, and the United Kingdom (EU-28). Source: Our World in Data.

[13] Europe Beyond Coal, 2021. Overview: National coal phase-out announcements in Europe.
[14] Europe Beyond Coal, 2021. Overview: National coal phase-out announcements in Europe.
[15] IEEFA, 2021. Romania announces plans to replace coal plants, end mining by 2032.
[16] Enerdata, 2021. Slovenia proposes to phaseout coal by 2033.
[17] CCS4CEE country report: Czech Republic. Available on the CCS4CEE project website.
[18] CCS4CEE country report: Poland. Available on the CCS4CEE project website.
[19] ICIS, 2021. Subsidies may threaten 16GW coal phase out in Ukraine.

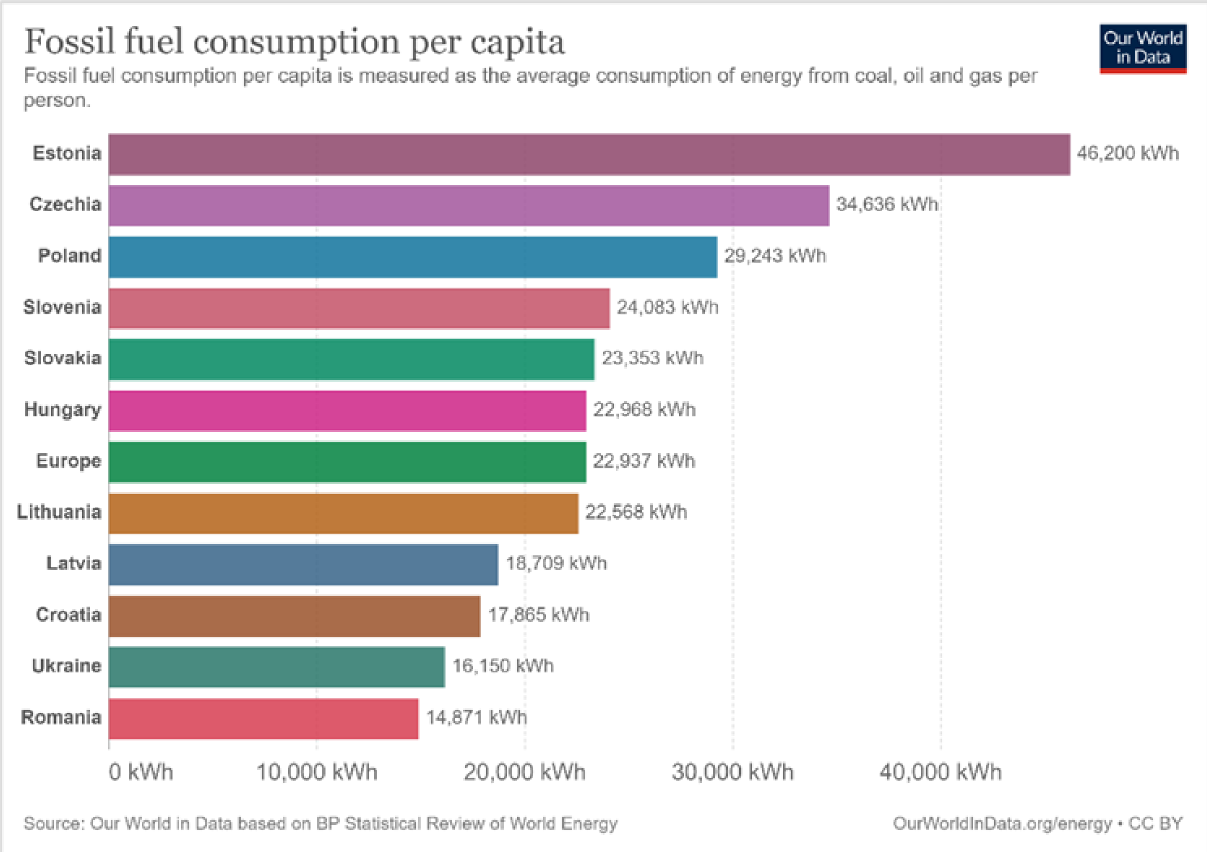

Figure 6. Fossil fuel consumption per capita in partner countries (2019). Average data was only available for Europe, rather than the EU. Source: Our World in Data.

2.1.2. Fossil fuel extraction

Mining and quarrying activities contribute more to GVA than the EU average (0.5%) in several partner countries,[20] with Ukraine topping the list at 6% of total GVA.[21] While GVA data is not available for the mining of fossil fuels, in terms of value added at factor cost (a micro-economic statistic evidencing the performance of enterprises), the mining of fossil fuels (including coal and lignite) contributed significantly more to the economies of Poland and the Czech Republic than the EU average (0.08%) in 2018 (1.7% and 0.64%, respectively;[22,23] however, coal and lignite mining in the Czech Republic has been declining since then, with three coal-fired power plants shutting down in the 2020-2023 period).[24] The coal industry alone in Ukraine contributed 0.78% to GVA, more than the EU average for the entire mining and quarrying industry. For petroleum and natural gas extraction, the contribution in terms of value added at factor cost to Estonia's economy (0.96%) is more than double that of the EU average (0.45%),[25,26] primarily due to the country's ongoing reliance on oil shale for energy production.

[20] Czech Republic, Estonia, Latvia, Poland, Romania and Ukraine.
[21] According to the CCS4CEE country report on Ukraine, the mining industry contributes 6.6% of Ukraine's GDP.
[22] No data was available for Slovakia and Slovenia in 2018.
[23] Eurostat, 2021. Annual enterprise statistics for special aggregates of activities (NACE Rev. 2)
[24] CCS4CEE country report: Czech Republic. Available on the CCS4CEE project website.
[25] No data was available for the Czech Republic, Latvia, Poland, Romania, Slovakia and Slovenia.
[26] Eurostat, 2021. Annual enterprise statistics for special aggregates of activities (NACE Rev. 2)

2.1.3. Manufacturing

Within the industry sector, the contribution of manufacturing activities[27] stands out, contributing more to GVA than the EU average (15.5%) in 7 out of 11 partner countries, ranging from 18% in Lithuania to 25% in the Czech Republic.[28,29] Estonia, Latvia, Croatia and Ukraine are below EU average, compensated in part by specific country differences, including an oversized contribution of agriculture and mining to Ukraine's economy (just over 9% and 6%, compared to the EU average of just under 2%[30] and 0.5%,[31] respectively) and a mix of higher contributions of agriculture, mining, energy supply, construction and wholesale retail in the other countries.

The carbon-intensive manufacturing sub-sectors most relevant for the implementation of carbon capture are the manufacturing of iron and steel, chemicals (particularly ammonia, used in fertilizer production[32]), refined petroleum products and cement. Their relevance comes from their hard-to-abate nature: they have significant process emissions which cannot be avoided by switching fuel sources, as could be done in the energy sector. Glass and paper production also offers potential for carbon capture, albeit less significant than the aforementioned industries; and aluminium smelters can also be equipped with carbon capture installations, however the costs are significantly higher than for other industries.[33] All these sub-sectors show characteristic trends in partner countries (Table 1); sub-sets of partner countries top the list of contribution to GVA of EU countries when it comes to coke and refined petroleum products, chemical products and metallurgy. The most striking trend was the higher-than-average contribution of the non-metallic minerals sector (including cement, lime and glass) to the economies of all partner countries.

Manufacturing sub-sector (NACE category)	**Observations for partner countries**
Coke and refined petroleum products[34]	In six of the partner countries,[35] this sub-sector contributes more than the EU average to GVA. This ranges from 73% higher in Estonia to over four times higher in Romania and five times higher in Croatia.
Chemical products, including ammonia	Although data at EU level for chemical products is scarce, several partner countries top the list of EU countries in terms of contribution of this sub-sector to GVA (Lithuania, Hungary, Slovenia and the Czech Republic).[36] Ukraine's chemical industry has also grown in the last 5 years, primarily due to an uptick in domestic fertilizer consumption and production, and is projected to continue growing in the coming decade.[37]
Basic metals, including basic iron and steel and aluminium	The economies of six partner countries[38] saw a higher contribution than the EU average of this sub-sector to GVA, ranging from just 1.9% higher in Poland to more than double in Slovenia and Slovakia. Relatively rapid growth (3-5% per year) is

[27] Code C in the Nomenclature of Economic Activities (NACE), used to categorize types of economic activity.
[28] World Bank, 2021. Manufacturing, value added (% of GDP) - Ukraine
[29] Eurostat, 2021. Gross value added and income by A*10 industry breakdowns.
[30] World Bank, 2021. Agriculture, forestry, and fishing, value added (% of GDP) - Ukraine, European Union
[31] Eurostat, 2021. National accounts aggregates by industry
[32] It should be noted that the manufacturing of ammonia is reliant on hydrogen as a feedstock, which is produced through steam methane reforming (SMR), a process which could also be supplemented with carbon capture, resulting in so-called "blue hydrogen".
[33] Global CCS Institute, 2021. CCS Technology Readiness and Costs (page 18).
[34] The refining of petroleum products is a prospective sector for carbon capture applications, however it is aggregated with coke production in available data for partner countries' National Accounts.
[35] Croatia, Estonia, Hungary, Poland, Romania and Slovakia.
[36] Summing the GVA of all EU-28 countries results in a total contribution of chemicals to EU GVA of 1%. Lithuania and Hungary have contributions 30% and 50% higher than the EU level.
[37] CCS4CEE country report: Ukraine. Available on the CCS4CEE project website.
[38] Czech Republic, Hungary, Poland, Romania, Slovenia and Slovakia.

	also expected in the coming decade in Ukraine, where steel production is one of the most important components of the national economy.[39]
Other non-metallic mineral products, including cement and glass	This sub-sector contributed more to GVA than EU average in all partner countries, ranging from 26% more in Lithuania to more than double in Poland and the Czech Republic. Ukraine's cement production is expected to grow rapidly (5-8% per year) in the 2020-2030 period. [40]
Paper and paper products	Aside from Estonia, Croatia, Latvia and Romania, all partner countries had more significant paper industries compared to the EU, with GVA shares ranging from just 13% higher in Slovakia to 83% higher in Poland, than the EU average.

Table 1. Characteristics of manufacturing sub-sectors in partner countries. No data on the contribution of individual manufacturing sectors was available for Ukraine. Source: Eurostat and National Accounts (GDP) of Ukraine.

2.1.4. Summary

The economies of partner countries have shifted substantially from heavy industry and agriculture to services since the 1990s. Their GDPs have grown, but are still below EU average in per capita terms, and their economies continue to rely more on industry than the EU average. They also use more fossil fuels in their primary energy supply than the EU average (with a few exceptions), with Poland and the Baltic countries leading. The same can be said for electricity production, although there are more exceptions, and in about half of partner countries, fossil fuel consumption per capita is higher than the European average. Combined with the higher-than-average reliance on energy production of many partner countries' economies, this begins to sketch the importance of fossil fuels to CEE economies. And despite clean energy transition plans in many partner countries, the use of fossil fuels may continue in some states such as Poland and Ukraine, whose coal phase-out and/or net zero targets are still decades away.

Manufacturing is key to the economies of partner countries, with specific sub-sectors having striking contributions in different partner countries, for example coke and refined petroleum products in Romania and Croatia, chemical products in Hungary and Lithuania, metallurgy in Ukraine, Slovakia and Slovenia and non-metallic mineral products (including cement) in Poland and the Czech Republic. Mining and quarrying activities (including coal and lignite), despite having a lower prevalence in partner countries, are significantly important for the economies of states such as Ukraine, and petroleum and natural gas extraction are also key parts of the economies of countries such as Estonia. In all partner countries, the manufacture of non-metallic mineral products (including cement and lime, two potential key industries for CCS application), contributed more to the national economies than the EU average.

The above characteristics highlight that while partner countries are fertile ground for exploring CCU and CCS applications, the applicability of these technologies to various industries will differ between states. Other factors, such as projected phase-out of fossil fuels or the exploration of alternative decarbonisation pathways in industry, should be considered when assessing the suitability of CCU and CCS in specific economic sectors. In the following section, we explore the CO_2 emissions of these industries in partner countries, bringing together economic contribution and emission intensity to further define the most prospective sectors for CCU or CCS application.

2.2. Carbon emissions in partner countries

When it comes to CO_2 emissions, most partner countries witnessed a declining trend between 1990 and 2019 (Figure 7). This was primarily due to the closing or operational improvement of emissions sources from heavy industry, previously highly centralized and inefficient during the communist regime. However, the carbon emission intensity of economies in partner countries are all higher

[39] CCS4CEE country report: Ukraine. Available on the CCS4CEE project website.
[40] CCS4CEE country report: Ukraine. Available on the CCS4CEE project website.

than the EU-27 average (0.18 kg per $ of GDP in 2018)[41,42], with Ukraine, Poland and Estonia standing at nearly eight times, double and double the EU-27 average, respectively (Figure 8). The continued and widespread combustion of fossil fuels for energy production, as well as emissions from partner countries' significant industrial sectors, contribute to these higher-than-average carbon intensities of CEE economies.

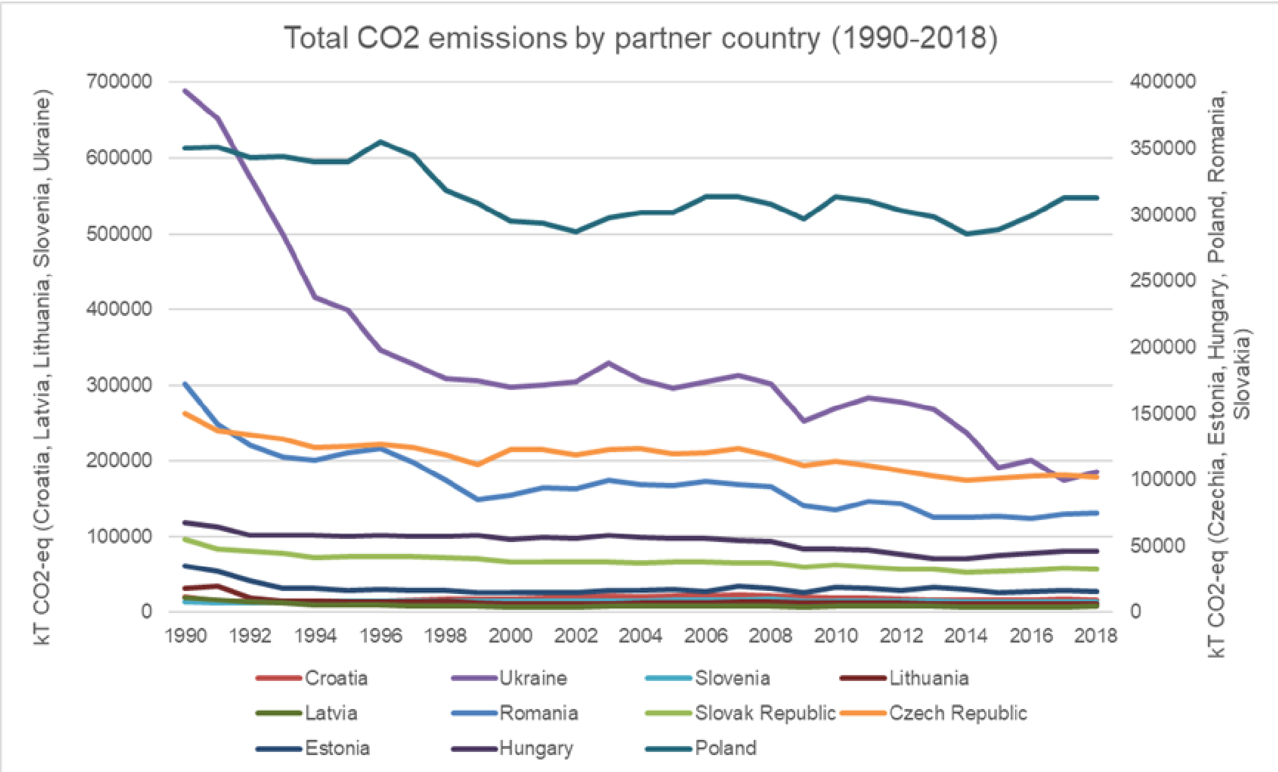

Figure 7. Total CO_2 emissions (kilo-tonnes) of partner countries (1990-2018). Data from World Bank.

[41] Measured in current US$.
[42] Calculated from World Bank GDP data and carbon emissions data (excluding LULUCF) for 2018 (the last year for which carbon emissions data is available from the World Bank). Note that only EU-27 data is available from the World Bank. Also note that at least for Ukraine there are discrepancies between the carbon emissions data (excluding LULUCF) quoted by the World Bank and that quoted in Ukraine's National Inventory Report for 2018. The World Bank data is only used for calculating carbon intensity indicators for comparison between countries and estimating decreases in CO_2 emissions in partner countries over the same time period (Section 2.3.3).

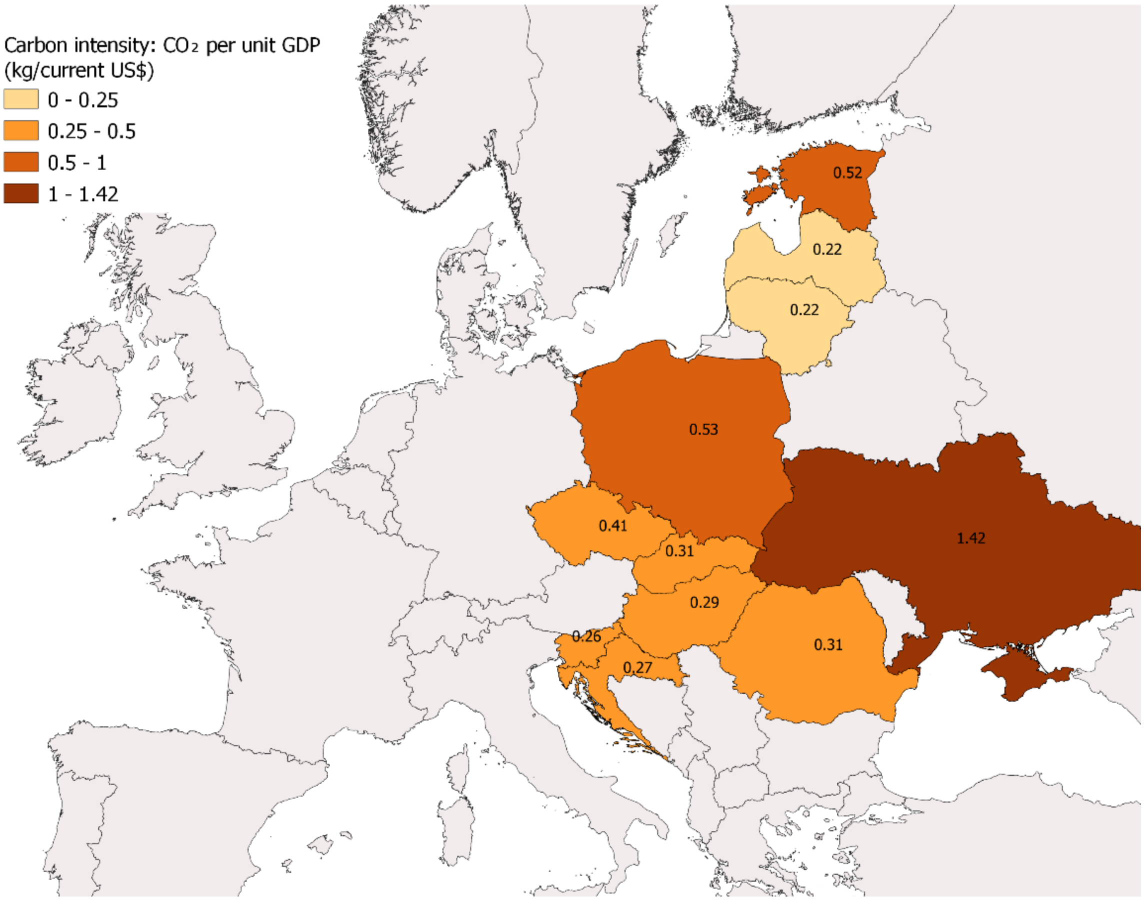

Figure 8. Carbon intensity of economies in partner countries, 2018. Source: EPG from World Bank data (see footnote 42 for source). Note that depending on the data source used, Ukraine's carbon intensity may actually be higher, and there may be discrepancies in the carbon intensity data of other partner countries. Reviewing these discrepancies is outside the scope of this report.

In addition to these similarities in their emissions trajectories and carbon intensities, there are further commonalities, and also slight differences, between partner countries in the contribution of economic sectors to their total emissions. Broadly, the emissions which are relevant to CCS can be classified into those generated by fuel combustion and those generated by industrial processes (for example, the chemical reactions involved in the production of cement, which release CO_2) – so-called "process emissions".

2.2.1. Emissions from fuel combustion

As highlighted in Section 2.1.1, most partner countries showed significantly higher carbon intensities of energy production than the EU average in 2016 (0.18 kg/kWh); only Slovenia and Latvia were lower than average. Standing at 0.28 kg/kWh in 2016, Poland had the most carbon-intensive energy production sector, followed by Estonia at 0.25 kg/kWh, the Czech Republic at 0.23 kg/kWh and Ukraine at 0.22 kg/kWh.[43]

Some partner countries also show significantly higher emissions intensities than the EU average when it comes to electricity production. In 2019, Poland, Estonia, Ukraine, the Czech Republic and Romania had a higher emissions intensity of electricity production than the EU average (253 gCO_2-eq/kWh).[44] Poland's intensity was nearly triple that of the EU average, with Estonia close behind;

[43] Our World in Data, 2021. Carbon intensity of energy production, 2016.
[44] EEA, 2021. Greenhouse gas emission intensity of electricity generation in Europe.

Ukraine's intensity was estimated at 0.58 kg CO_2-eq/kWh in 2018,[45] more than double the EU average. Despite having a higher intensity of electricity production, Romania and Ukraine had a lower and a roughly equal share of fossil fuels in their electricity production than the EU average, respectively (Figure 4), indicating potential inefficiencies in the countries' thermal power plants.[46] The remaining partner countries all had intensities of electricity production below EU average, with Lithuania standing at only 83 gCO_2-eq/kWh.

Potential inefficiencies in thermal energy production may be linked to the average age of thermal power plants, many of which still use coal in CEE countries. Coal-fired power plants with emissions over 1 Mt CO_2-eq ("large power plants") in partner countries are older than the EU average of 35 years,[47] indicating that CEE countries' thermal power plants are large as well as old. The country with the average oldest large coal-fired large power plants is Ukraine (average age of 55 years), followed by Poland (43.8 years), Romania (42.5 years) and the Czech Republic (41.3 years).

The oldest large coal-fired power plant is the Żerań power station in Poland (67 y.o.), which is due for closure.[48,49] According to Carbon Brief and findings from the CCS4CEE project, several old and large power plants in CEE countries are due to be closed or transition to alternative fuels (gas and/or biomass): Nováky in Slovakia (57 years old), Matra (52 y.o.) in Hungary, Šoštanj (44 y.o.) in Slovenia, several power plants in Poland, including Bełchatów (38 y.o.),[50] and a number of power plants in Ukraine, with ages between 49 and 63 y.o.[51]

Similar to the rest of the EU, most of partner countries' national emissions come from the combustion of fuels for energy. Fuel combustion for energy can be divided into two categories of interest to this report: fuel combustion in the energy industries and fuel combustion in manufacturing and construction. Other categories not relevant to CCS are the transport sector and other sectors. Tables 2 and 3 provide an overview of the share of national CO_2 emissions generated by fuel combustion for energy use in sectors relevant to CCS: the energy industries and the manufacturing sector, respectively, in 2019.

Country/region	**Total CO_2 emissions (excluding LULUCF[52]) (Mt)**	**Total fuel combustion for energy (% of total emissions)**	**Fuel combustion for energy industries:**		
			Energy industries total (% of total emissions)	**Public electricity and heat production (% of total emissions)**	**Petroleum refining (% of total emissions)**
EU-28	3289.7	91.9	29.7	24.6	3.5
Croatia	17.8	88.2	21.8	14.9	5.6
Czech Republic	101.5	87 .8	48.2	42.3	0.5
Estonia	12.4	96.7	66.0	53.0	0.0

45 Moro, A. and Lonza, L., 2018. Electricity carbon intensity in European Member States: Impacts on GHG emissions of electric vehicles. Transportation Research Part D: Transport and Environment, volume 64, p. 5-14.

46 Having a lower share of fossil fuels in electricity production despite a high carbon intensity could also be due to these countries using more coal for electricity production. However, both Poland and the Czech Republic have a higher share of coal in their electricity production than Ukraine and Romania (source – Our World in Data), mirrored in their higher-than-average share of fossil fuels in electricity production and carbon intensities. Hence, it is possible that the apparent anomaly in Romania and Ukraine is at least partially driven by inefficiency in electricity production from fossil fuels.

47 Kanellopoulos, K., 2018. Scenario analysis of accelerated coal phase-out by 2030. European Commission JRC Technical Reports, 2018.

48 Carbon Brief, 2021. Mapped: The world's coal power plants in 2020.

49 PGNiG Termika, 2021. PGNiG TERMIKA dodaje gazu – będzie sprawniej i czyściej: pierwsza synchronizacja bloku gazowo-parowego w Elektrociepłowni Żerań (in Polish)

50 Łagisza, Łaziska, Kozienice and Siersza power plants. Source: CCS4CEE Poland experts.

51 Partial closure of Burshtyn, Zmiivska, Dobrotvir, Starobesheve, Pridniprovska, Slaviansk and Kryvi Rih will occur by 2033. Source: CCS4CEE Ukraine experts.

52 Land Use, Land-Use Change and Forestry.

Latvia	7.7	91.1	23.3	22.5	0.0
Lithuania	13.9	80.7	15.9	6.1	9.5
Hungary	49.1	89.0	25.2	21.2	3.2
Poland	319.5	93.4	46.9	44.4	1.4
Romania	76.9	86.0	27.7	23.9	2.3
Slovenia	14.0	93.7	32.5	32.5	0.0
Slovakia	33.8	76.6	20.9	13.2	4.2
Ukraine	222.6	77.0	32.4	30.9	0.1

Table 2. Contribution of fuel combustion in the energy industries and its sub-sectors in 2019.[53] Source: Eurostat (EU countries) and Ukraine's National Inventory Report to UNFCCC.[54]

As can be seen in Tabe 2, most partner countries follow the EU trend, in that most of their emissions originate in fuel combustion for energy use. Two interesting exceptions are Slovakia and Ukraine, where fuel combustion for energy is responsible for only 76% and 77% of CO_2 emissions, respectively, compared to the EU average of 91%; as shown later in Section 2.2.2., this is due a much higher share of process emissions in both countries' CO_2 emissions, as well as significant decarbonization of electricity production between 1990 and 2018, with Slovakia having one of the highest rates in the EU.[55]

Several partner countries[56] have higher-emitting energy industries relative to their total emissions than the EU average. This is primarily due to higher emissions from the production of electricity and heating, which range from 32% higher in Slovenia to more than double in Estonia. In Croatia, Lithuania and Slovakia, fuel combustion for petroleum refining also contributes more to emissions than the EU average. In Croatia, this contribution is 175% higher than the EU average.

When it comes to fuel combustion for the manufacturing industries and construction, several points can be drawn from Table 3. Firstly, this category of fuel combustion contributes more than average to the CO_2 emissions of Romania and Slovakia, driven by the chemicals and non-metallic mineral products sectors in Romania, and by the iron and steel sector (7.22% of total CO2 emissions, nearly triple the EU average) and non-metallic mineral products in Slovakia. Secondly, all partner countries aside from the Czech Republic, Hungary and Ukraine have a higher share of emissions from fuel combustion in the manufacture of non-metallic mineral products, which includes the production of cement, lime and glass, than the EU average. Croatia's share of emissions from this sector is nearly triple the EU average.

Finally, two countries stand out for fuel combustion in specific sectors. Ukraine's share of CO_2 emissions from fuel combustion for iron and steel manufacturing is 40% higher than the EU average – as will be seen in Section 2.2.2, this is dwarfed by the process emissions generated by Ukraine's iron and steel production. Slovenia stands out with a share of fuel combustion emissions from the

[53] The most recent available data was for 2019.
[54] The categories of emissions used in this table are defined by the Intergovernmental Panel on Climate Change (IPCC): "total fuel combustion for energy" represents all CO_2 emissions from stationary and mobile energy activities; "energy industries" means all emissions from fuels combusted for fuel extraction and energy production, and includes public electricity and heat production (emissions from the combustion of fuel by utilities supplying energy to the public), petroleum refining (emissions from the combustion of fuels to refine petroleum) and manufacturing of solid fuels and other energy industries (not included here as it is not deemed relevant for CCS). Source: IPCC.
[55] EEA, 2021. Greenhouse gas emission intensity of electricity generation in Europe.
[56] Czech Republic, Estonia, Poland, Slovenia and Ukraine.

production of paper nearly triple the EU average, and in the production of non-ferrous metals (not shown here)[57], over double the EU average.[58]

Country/region	Fuel combustion in manufacturing industries and construction	Fuel combustion in manufacture of iron and steel	Fuel combustion in manufacture of chemicals	Fuel combustion in manufacture of pulp, paper and printing	Fuel combustion in manufacture of non-metallic mineral products[59]
EU-28	14.6	2.6	2.2	0.8	2.6
Croatia	13.6	0.2	1.6	0.6	7.2
Czech Republic	9.1	1.4	1.8	0.4	2.6
Estonia	6.0	0.0	0.2	0.5	2.7
Latvia	8.2	0.0	0.4	0.1	4.0
Lithuania	9.2	0.0	2.3	0.3	3.5
Hungary	10.4	0.4	0.8	1.0	2.6
Poland	9.7	1.4	2.1	0.5	3.0
Romania	18.8	1.1	2.9	0.3	4.1
Slovenia	12.2	1.5	0.4	2.2	3.3
Slovakia	18.6	7.2	1.4	1.3	4.3
Ukraine	6.5	3.7	0.2	0.0	1.4

Table 3. Contribution of fuel combustion in the manufacturing industries and construction and their sub-sectors in 2019. Figures are in percentages of total CO_2 emissions in 2019. Source: Eurostat (EU countries) and Ukraine's National Inventory Report to UNFCCC.[60]

2.2.2. Process emissions from industry

There are several striking features of process emissions (emissions from "industrial processes and product use" or IPPU) in partner countries. Tables 4 and 5 show the shares of CO_2 emissions contributed by key CCS-relevant industries (mineral, chemical and metallurgy).

Firstly, all partner countries aside from Estonia, Poland and Slovenia have a higher share of emissions from IPPU than the EU average. In most partner countries, this is mirrored by a higher share of process emissions from the mineral industry than the EU average. Of CCS-relevant sectors in the mineral industry, the main drivers of IPPU emissions are cement (aside from Hungary and Czech Republic) and lime (Czech Republic, Romania, Ukraine and Slovakia; Slovakia's lime industry contributes a share over double the EU average).

[57] The non-ferrous metals production sector is not explicitly studied as a relevant sector for CCS in this report, due to its prohibitively high costs of installing carbon capture units (source: GCCSI, 2021. Technology Readiness and Costs of CCS). Furthermore, 51% of emissions associated with non-ferrous metals production are, in fact, indirect emissions – they are produced by the power plants which supply electricity to non-ferrous metal producers, generally through the grid. CCS may only be applicable to non-ferrous metal plants in select cases. Source: IES-VUB. Metals for a Climate-Neutral Europe, page 41.
[58] Not shown here due to overall emissions contribution from this sector being small (0.3% EU average).
[59] This category includes the manufacture of cement, lime and glass.
[60] The categories of emissions used in this table are defined by the IPCC: "fuel combustion in manufacturing and construction" is a sub-category of the "fuel combustion for energy (total)" category and is defined as the emissions from combustion of fuel in industry. It can be further divided into emissions from fuel combustion in specific industries – those of interest to this report are steel, chemicals, paper and non-metallic mineral products (including cement, lime and glass production). (source: IPCC).

Secondly, the chemical industry drives IPPU emissions in several partner countries. Most notably, Lithuania's chemical industry has a share of total CO^2 emissions nine times higher than the EU average; its ammonia production sector, the only chemicals sector to report emissions data in 2019, contributed a share of CO^2 emissions twenty times higher than the EU average. This is particularly relevant for CCS, as ammonia production has among the lowest capture costs and as such is an accessible option for CCS (if transport and storage are ensured). Decarbonising ammonia production could thus be an opportunity for reducing Lithuania's emissions at relatively low cost.

Significantly higher shares of emissions from the chemicals industry are also found in Croatia (more than double the EU average), Hungary (more than triple) and Slovakia (2.6 times higher). Slovakia, Hungary and the Czech Republic also reported a significantly higher share of process emissions from the manufacturing of petrochemicals and carbon black (more than double, nearly seven times and more than double the EU average, respectively).

Country/region	Total process emissions	Mineral industry				Chemical industry		
		Total	Cement production	Lime production	Glass production	Total	Ammonia production	Petrochemicals and carbon black
EU-28	7.6	3.4	2.4	0.6	0.1	1.6	0.7	0.4
Croatia	11.4	7.5	6.7	0.5	0.2	3.3	3.3	N/A
Czech Republic	11.1	3.0	2.0	0.7	0.1	1.8	0.6	1.0
Estonia	3.1	2.9	2.4	0.4	0.1	0.0	0.0	0
Latvia	8.1	7.5	7.3	0.0	0.0	0.0	0.0	0
Lithuania	19.1	4.3	4.2	0.0	0.1	14.3	14.3	0
Hungary	10.5	3.0	2.1	0.3	0.1	4.9	2.2	2.7
Poland	6.1	3.7	2.4	0.4	0.2	1.4	1.1	0.4
Romania	13.8	6.4	5.0	1.0	0.1	1.3	1.2	0
Slovenia	6.0	4.0	3.4	0.4	0.1	0.4	0.0	0.0
Slovakia	23.1	6.8	4.2	1.5	0.1	4.2	2.0	1.0
Ukraine	22.9	3.0	1.8	1.0	0.1	1.6	1.2	0.3

Table 4. Contribution of process emissions from the mineral and chemical industries to total emissions in 2019. Figures are in percentages of total CO_2 emissions in 2019. Note that sub-sectors not relevant to CCS have been excluded, and therefore emission shares do not always add up to the quoted totals. Source: Eurostat (EU countries) and Ukraine's National Inventory Report to UNFCCC.

When it comes to the metal industry, by far the most striking figures emerge in Ukraine (Table 5). In this country, process emissions from the metal industry contribute 18.3% to total CO_2 emissions, a figure over seven times higher than the EU average; or 40.6 Mt, more than half the total emissions in this category in the entire EU-28. This share is overwhelmingly driven by iron and steel production; however the share of ferroalloy production process emissions also stands at 0.83% (1.85 Mt CO_2), over eight times higher than the EU average.

The Czech Republic, Romania and Slovakia also display higher shares of process emissions from metallurgy (over double, over double and five times the EU average, respectively). These emissions are also mostly driven by iron and steel production, as well as ferroalloys and aluminium production in Slovakia (with emissions shares approx. eight and nine times higher, respectively, than the averages in the EU-28) and aluminium in Romania. Slovenia also has a higher share of emissions originating in process emissions from aluminium production (0.8%, relative to the EU average of 0.09%).

Country/region	Total process emissions	Metal industry			
		Total	Production of iron and steel	Ferro-alloys production	Aluminium production
EU-28	7.6	2.4	2.2	0.1	0.1
Croatia	11.4	0.0	0.0	0	0
Czech Republic	11.1	6.1	6.1	0	0
Estonia	3.1	0.0	0.0	0	0
Latvia	8.1	0.0	0.0	0	0
Lithuania	19.1	0.0	0.0	0	0
Hungary	10.5	2.5	2.5	0	0
Poland	6.1	0.7	0.6	0.1	0
Romania	13.8	5.4	5.0	0	0.4
Slovenia	6.0	1.3	0.4	0	0.8
Slovakia	23.1	12.0	10.5	0.7	0.8
Ukraine	22.9	18.3	17.4	0.8	Not available[61]

Table 5. Contribution of process emissions from the metal industry to total emissions in 2019. Figures are in percentages of total CO_2 emissions in 2019. Source: Eurostat (EU countries) and Ukraine's National Inventory Report to UNFCCC.

The remainder of this section briefly reviews emissions in each of the partner countries.

2.2.3. Emission trends and status in partner countries

Croatia

CO_2 emissions in Croatia decreased by 18.4% between 1990 and 2018.[62] Overall, the power sector was the largest contributor to GHG emissions (35%), followed by the cement (28.2%), chemicals (17.2%) and oil and gas sectors (12.6%).[63] The Croatian industry is more carbon-intensive than the EU average.

Czech Republic

The Czech Republic's CO_2 emissions decreased by 31.7% between 1990 and 2018. Fuel combustion, primarily in the energy industries, contributed nearly half of national emissions in 2019, while IPPU emissions stood at 11%. Lignite contributed 40% to power plant gross output as a thermal energy source in 2019, and coal is particularly dominant in the Ústecký (lignite) and Moravskoslezský (bituminous, or black, coal) regions in the northern Czech Republic. Of industry sectors, the production of iron and steel, cement and chemicals contributed most to total IPPU emissions (55.1%, 17.5% and 16%, respectively) (2019).

Estonia

CO_2 emissions in Estonia decreased by over half (54%) between 1990 and 2018. Today, the use of oil shale for energy production is the main source of CO_2 emissions (96% of all emissions are from oil shale mining, combustion of oil shale for energy and manufacturing of shale oil and other chemical products).[64] 65.7% of Estonia's emissions come from its energy industries, while only 3% are due to IPPU. More than 90% of national emissions are generated by three energy groups that use oil shale (Eesti, Auvere and Põhja). Given Estonia's emissions profile and geological conditions (see Section 3), Estonian experts interviewed in the CCS4CEE project

[61] This data is confidential and not reported in Ukraine's National Inventory Report to UNFCCC.
[62] World Bank, 2021.
[63] Source: CCS4CEE country report: Croatia. CCS4CEE country report: Ukraine. Available on the CCS4CEE project website.
[64] Source: CCS4CEE country report: Estonia. Available on the CCS4CEE project website.

estimate that only 1% of CO_2 emissions from oil shale can be captured and used directly.[65] Estonia also plans to completely phase out its use of oil shale for energy production by 2030, and energy producers are gradually shifting towards renewable energy sources and increasing energy efficiency[66]. Enefit Power, Estonia's largest energy producer, is discontinuing the direct use of oil shale for electricity production by 2025.

Hungary

Hungary's CO_2 emissions decreased by 31% between 1990 and 2018, but grew slightly since 2013, plateauing around 2017-2019. The largest emitter is the energy sector (72% of total GHG emissions in 2019), and energy industries contributed 19%. Currently, natural gas accounts for the largest share (44%) of combusted, largely fossil fuels, followed by an increasing share of petroleum products (33%). The proportion of coal used in energy production has fallen from 30% to below 10% in the last 30 years, accompanied an increase in the use of solar energy.

IPPU emissions contributed 12% to total emissions, primarily driven by chemicals production, which made up a third of total process emissions. Notably, this included the production of petrochemicals and carbon black, which had the highest share of national emissions of all partner countries (2.6%, compared to the EU-28 average of 0.44%). Metallurgy emissions have been decreasing due to drop in production of pig iron, however mineral industry emissions have been growing since 2013.

Latvia

Latvia's CO_2 emissions declined by nearly 60% between 1990 and 2018; however, emissions grew by 7% between 2017 and 2018. Most of Latvia's emissions come from the energy sector; however, it is below EU average in terms of its share of fuel combustion for most sectors, aside from the non-metallic mineral industry (including cement), whose share is approx. 50% higher than the EU average. Latvia's IPPU emissions are also slightly higher than the EU average, mainly driven by cement production (91% of IPPU).

Lithuania

Lithuania reduced its overall CO_2 emissions by 64% between 1990 and 2018, the highest rate of reduction in EU partner countries. However, emissions have grown by 6.7% between 2014 and 2018. The bulk of Lithuania's emissions are from energy production, with 38% being generated by heat and power production (10% from just two power plants, Vilnius and Klaipėda)[67]. The share of emissions from fuel combustion in oil refining is over double the EU-28 average (9.5% of total CO_2 emissions). The share of IPPU emissions stands at 19%, over double that of the EU average, and is driven by ammonia production (14.3% of total CO_2 emissions) and cement production (4.15%).

Poland

Poland's GHG emissions were the highest of all partner countries and the fourth highest in the EU in 2018, with CO_2 emissions having declined by only 10.7% since 1990 - the lowest rate of decline of all partner countries, aside from Slovenia. Fuel combustion in the energy industries made up nearly half (47%) of total emissions. Poland's energy production (73.6% of which uses coal) emits by far the most CO_2 of all partner countries (nearly 300 Mt in 2019); this amounts to *9.8% of energy-related CO_2 emissions in the entire EU*. 10% of Poland's total GHG emissions come from fuel combustion in district heating plants. The country has among the largest number of district heat networks in Europe, the majority of which are obsolete and inefficient, and mainly supplied by coal-fired heat (mostly hard coal). Many units are small, as they serve individual cities.

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[65] CCS4CEE country report: Estonia. Available on the CCS4CEE project website.
[66] CCS4CEE country report: Estonia. Available on the CCS4CEE project website.
[67] CCS4CEE country report: Lithuania. Note that for these calculations the volume of CO_2 emissions from the combustion of biomass was also included, leading to a possible inflation of the contribution of these power stations to national emissions. Other power stations in Lithuania rarely use significant amounts of biomass. Available on the CCS4CEE project website.

According to the Energy Policy of Poland until 2040, in a scenario of high EU Emissions Trading System (EU ETS) emissions allowances prices (over €50 – therefore a very likely scenario at the time of writing), Poland would add a total of 14 GW of natural gas (including combined heat and power (CHP) and peaking plants) and over 400 MW of biomass and biogas.

When it comes to the industry sector, industry emissions (both fuel combustion and IPPU) contributed 15% to total CO_2 emissions, both with concentrated point-sources. In 2019, 2.4% of total emissions came from the process emissions in cement production. In partner countries, there are eight cement plants emitting more than 1 Mt CO_2 in the most recent reporting year ("large emitters") - six are in Poland. A further 1.4% of total emissions came from fuel combustion for petroleum refining; Poland only extracted 1 million tons of crude oil in 2019 (3.6% of Polish consumption), and activity in this sector is dominated by Grupa Orlen and Grupa Lotos, who are in the process of merging. For chemicals, emissions have held steady since 2013, and most come from the production of bulk chemicals – in 2019, process emissions from the chemicals sector contributed 1.4%. Finally, the metal industry contributed 0.7% to total emissions, well below the EU average of 2.4%. Most of these emissions come from the production of pig iron or steel: 53% of Polish steel is made with blast furnaces. Poland's two working blast furnaces are in Dąbrowa Górnicza and owned by ArcelorMittal.

Romania

Between 1990 and 2018, Romania's CO_2 emissions declined by 56.6%; in 1991 alone, GHG emissions dropped by 20%. This decline was the result of closure of economically inefficient industrial facilities and decrease in energy demand. Today, energy accounts for 85.9% of CO_2 emissions and IPPU for 13.8%, a split which has remained relatively constant since 1990. The electricity production sector emitted 40% of total CO_2 emissions (including LULUCF) and contributed 0.91% to national turnover.[68]

In terms of fuel combustion, most emissions come from the energy industries (27%), while manufacturing and construction takes up 18.8% - the highest of all partner countries (notably iron and steel – 1.1%, chemicals – 2.8%, and non-metallic mineral products, including cement – 4.1%). The decrease in emissions between 1990 and 2019 is primarily driven by a shrinking of manufacturing and construction emissions (78.6%) and energy industries emissions (70%).

The share of process emissions in Romania's total emissions is nearly double the EU average and is mainly driven by the cement and metallurgy industries. Despite having decreased since 1990, the IPPU emissions of these sectors are still responsible for 6.4% and 5.4% of total CO_2 emissions, respectively. Within the metal industry, although iron and steel production contributes the bulk of emissions, the share of emissions generated by aluminum production is nearly five times the EU average, while within the mineral industry, lime production also contributes a higher share. In the chemicals industry, the share of total emissions generated by ammonia production is also nearly double the EU average. The highest contribution of CCS-relevant sectors to national turnover came from the manufacturing of petroleum products, which contributed 1.29% to national turnover, but only 5% to national CO_2 emissions (including LULUCF) – in contrast to the electricity production sector (see above).

Slovakia

Slovakia's CO_2 emissions decreased by 40% between 1990 and 2018. Although its share of emissions from fuel combustion was lower than the EU average in 2019, its share of IPPU emissions compensated. Similar to other partner countries, Slovakia's economy depends on manufacturing - industry contributes 22% to GDP, of which 86% comes from manufacturing.[69] This significant contribution of manufacturing to Slovakia's GDP translates into the highest share of IPPU emissions of all partner countries – 23% of national emissions. Fuel combustion in manufacturing also accounts for 18.6% of total national emissions, the second-highest of all partner countries after Romania, driven by the steel sector and non-metallic mineral sector.

The largest share of IPPU CO_2 emissions came from the metal industry (12%, *five times the EU-28 average*), followed by mineral products (6.7%, including cement at 4.15%). The production of basic metals is also a high-value sector, contributing 19.1% of GVA in

[68] National turnover is the sum of turnover of Romanian companies operating in a specific sector (i.e. the volume of units sold multiplied by the unit price). Source: CCS4CEE country report: Romania. Available on the CCS4CEE project website.
[69] CCS4CEE country report: Slovakia. Available on the CCS4CEE project website.

2019, only slightly behind the automotive industry.[70] Besides a significantly higher share of emissions from steel production, this includes the production of ferroalloys (0.7% of emissions, relative the EU average of 0.08%) and of aluminum (0.8%, relative the EU average of 0.09%). Chemicals contributed 4.1% to total emissions (over double the EU average).

Slovenia

Slovenia is the only partner country whose emissions have *increased* slightly since 1990 (3.8%).[71] National CO_2 emissions increased between 1992 and 1998, followed by fluctuations around the highest historical emissions in the period in 2008. Most recently, emissions have increased by 6.7% since 2014.

Relative to its size and population, Slovenia has a significant amount of ''heavy'' industry, which in return makes a significant contribution to the country's economy. This heavy industry is responsible for approx. 16% of final energy consumption, and most products are exported. Cement and lime production alone were responsible for 63% of IPPU emissions in 2019. Between 2005 and 2016, Slovenia's industry reduced its direct GHG emissions by 25% and process emissions by 20%. The country's industrial strategy states that heavy industry plants are more efficient than the EU average.[72]

However, Slovenia's biggest CO_2 emitter remains a power generating facility: 25% of Slovenia's emissions come from the combustion of coal in the Šoštanj thermal power plant. Energy accounted for 76% of total CO_2 emissions in 2019; within this, fuel combustion in the energy industries contributed the most (32%), even though its emissions decreased by 28.1% between 1986 and 2017[73].

Ukraine

According to the World Bank, Ukraine's CO_2 emissions decreased the most of all partner countries between 1990 and 2018; in 1990, total CO_2 emissions amounted to 688 Mt, three-quarters of the emissions of all other partner countries combined at the time.[74] Today, total emissions stand at 222.6 Mt,[75] the second-highest of partner countries but significantly lower than Poland's total emissions. This decline has been primarily due to a reduction of coal-related emissions (nearly 70% since 1989). Despite this, and the fact that 29 out of 33 state-controlled mines are not profitable[76] (with an average age of large coal-fired power plants[77] of 55 years, the highest in all partner countries),[78] over half of Ukraine's CO_2 emissions in 2019 came from using coal. GHG emissions from Ukraine's electricity and heat generation increased slightly between 2015 and 2019, but are projected to decrease by 15% by 2030.[79] Mining and quarrying (including the mining of coal and lignite) contributed 6% to national GVA in 2018, *over twelve times* the share of this sector in the EU economy.

Ukraine also has a significant and promising natural gas production industry. Annual natural gas production is about 21 billion cubic meters, and a positive development scenario shows an increase in production to 30 billion cubic meters by 2030. The production potential is approx. 780 billion cubic meters, and almost 80% of natural gas is extracted by Naftogaz, Ukraine's largest oil and gas company (state-owned).[80] According to Ukrainian experts, the natural gas sector is the primary sector interested in CCS in Ukraine,

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[70] CCS4CEE country report: Slovakia. Available on the CCS4CEE project website.
[71] World Bank, 2021. World Development Indicators: total CO_2 emissions.
[72] CCS4CEE country report: Slovenia. Available on the CCS4CEE project website.
[73] CCS4CEE country report: Slovenia. Available on the CCS4CEE project website.
[74] World Bank, 2021. World Development Indicators: total CO_2 emissions. Note that there are discrepancies between the carbon emissions data (excluding LULUCF) quoted by the World Bank and that quoted in Ukraine's National Inventory Report for 2018. The World Bank data is here only used for comparison purposes, for estimating decreases in CO_2 emissions in partner countries over the same time period.
[75] Source: Ministry of Environmental Protection and Natural Resources of Ukraine, 2021. Ukraine's National Inventory Report to UNFCCC.
[76] Heinrich Böll Stiftung, 2019. Ukraine and EU: Towards a decarbonisation partnership.
[77] Large power plants are defined as having emissions higher than 1 Mt CO_2 in 2019.
[78] Carbon Brief, 2021. Mapped: The world's coal power plants in 2020.
[79] CCS4CEE country report: Ukraine. Available on the CCS4CEE project website.
[80] CCS4CEE country report: Ukraine. Available on the CCS4CEE project website.

due to regulatory changes in the purity requirements for natural gas injected into the transmission network – including for CO_2 concentrations to not exceed a certain level (see Section 5.3).[81]

Ukraine's economy is significantly reliant on industry (30% of national GDP), mostly semi-finished products and semi-processed goods – particularly chemicals and metal alloys; Ukraine is 13th largest steel producer in the world. However, their share has declined recently due to a decrease in global demand and increased competition. Indeed, overall industrial production and associated emissions declined after 1990, with steel production at 39% of 1990 production values and cement at 42%.[82] However, growth is expected in both these industries in the coming decade (5-8% per year for cement and 3.5% per year for steel).[83]

As for emissions, those generated by IPPU amounted to 22.9% of total emissions in 2019, nearly triple the EU average. Metal production contributed between 70% and 80% of IPPU emissions,[84,85] with Ukraine being one of the few countries that still uses open-hearth furnaces in steel production (23% of output uses this technology).[86,87] The chemical industry and the production of non-metallic minerals also contribute significantly to IPPU emissions (7% and 13%, respectively).[88] Among the latter, cement accounts for 8% of emissions, and its share will gradually increase. The chemical industry has also grown: fertilizer consumption in Ukraine (including ammonia) has increased by 7% on a compound basis since 2015, and production has followed suit, primarily due to the substitution of Russian imports in the wake of the Russia-Ukraine conflict. Overall, industrial emissions have declined across all Ukrainian industries since 1990, except mineral products (including cement) where emissions grew by 15.6% between 2015 and 2019, and the chemical industry, with an increase in CO_2 emissions of 48% between 2015 and 2019. CO_2 emissions in these sectors, as well as the metal industry, are projected to continue growing.[89]

2.2.4. Summary

Although all partner countries have witnessed a decline in their emissions since the end of their communist regimes, their carbon intensities mostly remain higher than the EU average. Most have a higher carbon intensity of energy production (with Poland and Estonia in the lead), as well as electricity production. Alongside the use of fossil fuels in energy production, the relatively advanced age of coal-fired thermal power plants in partner countries may be contributing to inefficiencies in energy production and a higher carbon intensity of this sector. Ukraine's large coal-fired power plants are, on average, 20 years older than the average EU coal-fired power plant.

As is the case for the EU, most emissions originate in fuel combustion in partner countries; wherever the contribution of fuel combustion emissions is lower than the EU average, it is compensated by process emissions. Aside from fuel combustion for the energy industries, some partner countries emit a higher proportion of their emissions from fuel combustion for the manufacturing industries (for example, iron and steel in Slovakia and Ukraine; paper production in Slovenia; and non-metallic mineral products in most partner countries).

When it comes to the share of process emissions in total CO_2 emissions, most partner countries are above EU average. Cement is a major driver in most partner countries, and lime, chemicals and metal production in several. Despite the contribution of process

[81] CCS4CEE country report: Ukraine. Available on the CCS4CEE project website.
[82] Industrial GHG emissions in Ukraine have declined by 66% since 1990; however, this trend includes several cycles of growth (1995-2007, 2009-2011, 2017-present). Such cycles are firmly tied to the growth rate of industry. Given the projected growth of such rates, GHG will likely also increase. Source: CCS4CEE country report: Ukraine.
[83] CCS4CEE country report: Ukraine. Available on the CCS4CEE project website.
[84] CCS4CEE country report: Ukraine. Available on the CCS4CEE project website.
[85] Source: Ministry of Environmental Protection and Natural Resources of Ukraine, 2021. Ukraine's National Inventory Report to UNFCCC.
[86] Producing steel in open-hearth furnaces is a particularly polluting steelmaking process, and was superseded by basic oxygen steelmaking in most steel production around the world.
[87] bneGreen, 2021. Steel faces paying for its carbon
[88] Source: Ministry of Environmental Protection and Natural Resources of Ukraine, 2021. Ukraine's National Inventory Report to UNFCCC.
[89] CCS4CEE country report: Ukraine. Available on the CCS4CEE project website.

emissions to overall emissions being small overall, the differences in contribution of some industry sectors are downright striking: compared to EU averages, the share of ammonia process emissions in Lithuania is *twenty times higher*, that of petrochemicals and carbon black process emissions in Hungary *nearly seven times higher*, and that of ferrous metal emissions in Slovakia *five times*, respectively. Ukraine is possibly the standout feature in this respect, with process emissions from its metal industry (40.6 Mt in 2019) equivalent to *more than half of total metallurgy process emissions in the entire EU-28*.

Emissions from the manufacturing industries of partner countries represent, therefore, a substantial contribution to national emissions, both through fuel combustion and process emissions. Given the unavoidable nature of process emissions in industries such as cement and steel manufacturing,[90] potential applications for CCU and CCS can be discerned. However, the bulk of emissions still come from an over-reliance on fossil fuels, combusted in older-than-average thermal power plants. As will be shown in later sections, the energy sector has thus remained an opportune ground for the deployment of CCS in partner countries, regardless of phase-out and green transition plans.

2.3. MAJOR CO_2 EMITTERS IN THE REGION

2.3.1. OVERVIEW

To assess the regional potential for CCS, including possible capture clusters and transborder projects, it is useful to highlight the main point sources of CO_2 emissions in the CEE region. The following section pinpoints "large emitters" in partner countries (defined as having emissions of more than 1 Mt CO_2-eq/year in 2020, as reported in the EU Emissions Trading Scheme,[91] or in 2019, as calculated by EPG[92] and in the CCS4CEE country report on Ukraine) and briefly discusses the main emitters in each country.

In 2020, there were a total of 9,989 stationary emission sources[93] subject to the EU ETS, 270 were large emitters.[94] Of these 270 sources, 27.7% (75 sources) were located in partner countries, emitting a total of 204.7 Mt CO_2-eq per year (30.1% of all European ETS emissions from sources larger than 1 Mt/year). Latvia had no ETS installations emitting more than 1 Mt/year; in 2020, the largest volume of emissions came from the Schwenk Latvija cement plant at Broceni, (0.77 Mt).[95]

[90] The nature of unavoidable process emissions is further detailed in the "Current state of CCS technologies and the EU policy framework", written by Bellona Foundation as part of the CCS4CEE project (available on the CCS4CEE website).
[91] The year 2020 was chosen as the most recent year of available data from the EU ETS, a reliable source of verified GHG emissions. The Covid-19 pandemic and associated economic shrinkage, experienced over the course of the year 2020, did not have a major impact on large emitters in partner countries. Large emitters in partner countries emitted 24 Mt less in 2020 than they did in 2019 (a 6.5% reduction), but this decrease was smaller than that observed across the EU; the contribution of large emitters in partner countries to emissions from EU large emitters actually *increased by 13.65%* between 2019 and 2020. Overall, the total number of emitters with over 1 Mt CO2-eq decreased by four between 2019 and 2020; however this was a combination of seven emission sources reducing their emissions to below 1 Mt, and three actually increasing them from below 1 Mt to above 1 Mt between 2019 and 2020. Furthermore, at least three of the seven emitters whose emissions dropped below 1 Mt in 2020 may have been driven by non-pandemic related reasons: in the Czech Republic, the Prunéřov 1 coal-fired power plant stopped operating in 2020,and Mělník 2 and 3 (also coal-fired power plants) will likely be phased out soon (Mělník 3 is planned to stop operating in 2021). Furthermore, it is noted that a total of 20 emitters from partner countries *actually emitted more in 2020 than they did in 2019*. This includes emitters who passed the 1 Mt threshold in 2020 (3) and another 17 who were already classified as large emitters in 2019, and whose emissions increased in 2020. Given the relatively small differences, the lack of a discernible trend in large-source emissions between 2019 and 2020, and as the presence of other confounding factors such as coal phase-out, we opt for the most recent year of available data to provide a snapshot of major emitters in the region.
[92] The CO_2 emissions of coal-fired power stations in Ukraine were calculated based on the IPCC (2006) methodology, using data from Ukraine's Ukraine's National Inventory Report to UNFCCC. The CO_2 emissions of steel plants are those reported in the CCS4CEE country report for Ukraine (available on the CCS4CEE website).
[93] I.e. all emission sources excluding airlines.
[94] This limit has been chosen in order to identify the largest emitters in partner countries, and compare across countries the presence and density of these emitters.
[95] Union Registry, 2021. Verified Emissions for 2020.

When adding large emission sources located in Ukraine (which is not subject to the EU ETS), partner countries host a total of 94 installations with emissions higher than 1 Mt CO_2-eq/year. This is equivalent to 32.5% of all large emitters which are either subject to the EU ETS, or which would be subject to the EU ETS but are in Ukraine (hereafter referred to as the "expanded EU ETS"). It should be noted that due to a lack of data, only coal-fired thermal power stations and five steel plants from Ukraine are included in these 94 installations.

These 94 stationary installations (Figure 9) emitted a total of 267.6 Mt CO_2-eq in 2020 (caveated by the different data availability for emission sources in Ukraine),[96] making up 36% of emissions in the expanded EU ETS.[97] The largest contributor to emissions is Poland, whose 37 sources contributed 124.1 Mt CO_2-eq (16.7%) to the expanded EU ETS. 146.7 Mt CO_2-eq (17.7%) to the expanded EU ETS. Ukraine is the second-largest contributor, with 62.8 Mt CO_2 in 2019 (8.45% of emissions in the expanded EU ETS) - these emissions came from only 14 coal-fired power stations and five steel plants (emissions data was not available for gas-fired power stations or other industrial emitters in Ukraine). Overall, emission sources in Poland and Ukraine made up 25.1% of emissions from the expanded EU ETS, but only 4.88% of the GDP (EU-28 plus Ukraine).[98] The full list of large emitters in the expanded EU ETS is provided in Table A. 1 in Annex A. List of large stationary emitters in partner countries

The single largest emitter in the EU Emissions Trading Scheme (EU ETS) is the Bełchatów power plant in Poland, a lignite-fired power station with verified emissions of 30 Mt in 2020. Polish authorities plan to close Bełchatów by 2036, after PGE, the owner and operator of the plant, scrapped plans for an open-pit coal mine to fuel the plant.[99] The Kozienice and Opole power stations, also in Poland, and the Burshtyn and Starobesheve power plants in Ukraine, follow in the top ten emission sources, with emissions of 10.46, 9.7, 8.75 and 7.54 Mt, respectively. Many of Ukraine's large coal-fired thermal power plants are at least partially due for closure in the next decade.[100]

The Turów and Połaniec coal-fired power plants in Poland (5.81 and 4.56 Mt CO_2-eq, respectively, in 2020), the Kurakhov and Zaporizhia coal-fired power stations in Ukraine (5.71 and 4.9 Mt CO_2, respectively, in 2019) and the Počerady power plant (4.5 Mt) in the Czech Republic, further top the list of large emitters in partner countries. Other notable emissions sources are the U.S. Steel Košice plant (4.4 Mt) in Slovakia, the Mátra power plant in Hungary (4.2 Mt) (due for transition away from coal in 2025),[101] Liberty's steel plant in Galați (3.9 Mt) and the Rovinari power plant (part of the Oltenia Energy Complex) (3.1 Mt) in Romania, and the Šoštanj power plant (3.7 Mt) in Slovenia. Ukraine's ferrous metallurgy plants are also important emitters, with the largest for which data is available (ArcelorMittal Kryvyi Rih) emitting 2.35 Mt CO_2 in 2019 (see Section 2.3.2 for further details).

The remainder of this section briefly reviews key characteristics of ETS emitters in partner countries. Only stationary emission sources are considered.

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[96] Note that the data for Ukrainian emission sources is Mt CO_2, while for other partner countries it is Mt CO_2-eq. This is due to emissions data for Ukrainian sources not being standardized with that in the EU ETS.
[97] If we restrict the expanded EU ETS to include only EU-28 countries and Ukraine (thus excluding Norway, Iceland and Liechtenstein which participate in the ETS but are not in the EU), sources in partner countries make up 31.4% of emission sources and contribute 41.9% to emissions. Given the small nature of the differences, the rest of this report uses the unrestricted expanded EU ETS in any subsequent analysis.
[98] Source: World Bank, 2021. World Development Indicators – GDP.
[99] Reuters, 2021. Poland plans to close Europe's most polluting power plant by end 2036.
[100] According to Ukraine's National Plan on Reducing Emissions from Large Industrial Plants, the following coal-fired thermal power station blocks will be closed. Kryvi Rih: 4 of 10 blocks to be closed by 2033; Zmiivska: 4 of 10 blocks to be closed by 2032; Burshtyn: 5 of 12 blocks to be closed in 2023, and a further 2 in 2032; Starobesheve: 2 of 13 blocks to be closed in 2030; Prydniprovska: 4 of 14 blocks to be closed by 2033; Dobrotvir: 6 of 8 blocks to be closed in 2023; Kurakhov: 3 of 9 blocks to be closed by 2033; Zaporizhzhia: 3 of 3 blocks to be closed in 2033; Vuglegirska: 3 of 7 blocks to be closed in 2033; Trypilska: 2 of 6 blocks to be closed in 2033; Slaviansk: 2 of 2 blocks to be closed in 2033. Source: CCS4CEE Ukrainian experts.
[101] After the expiry of its operating license in 2025, the Mátrai power plant will transition to "low-carbon" technologies but will preserve two of its lignite-fired units as strategic reserves.

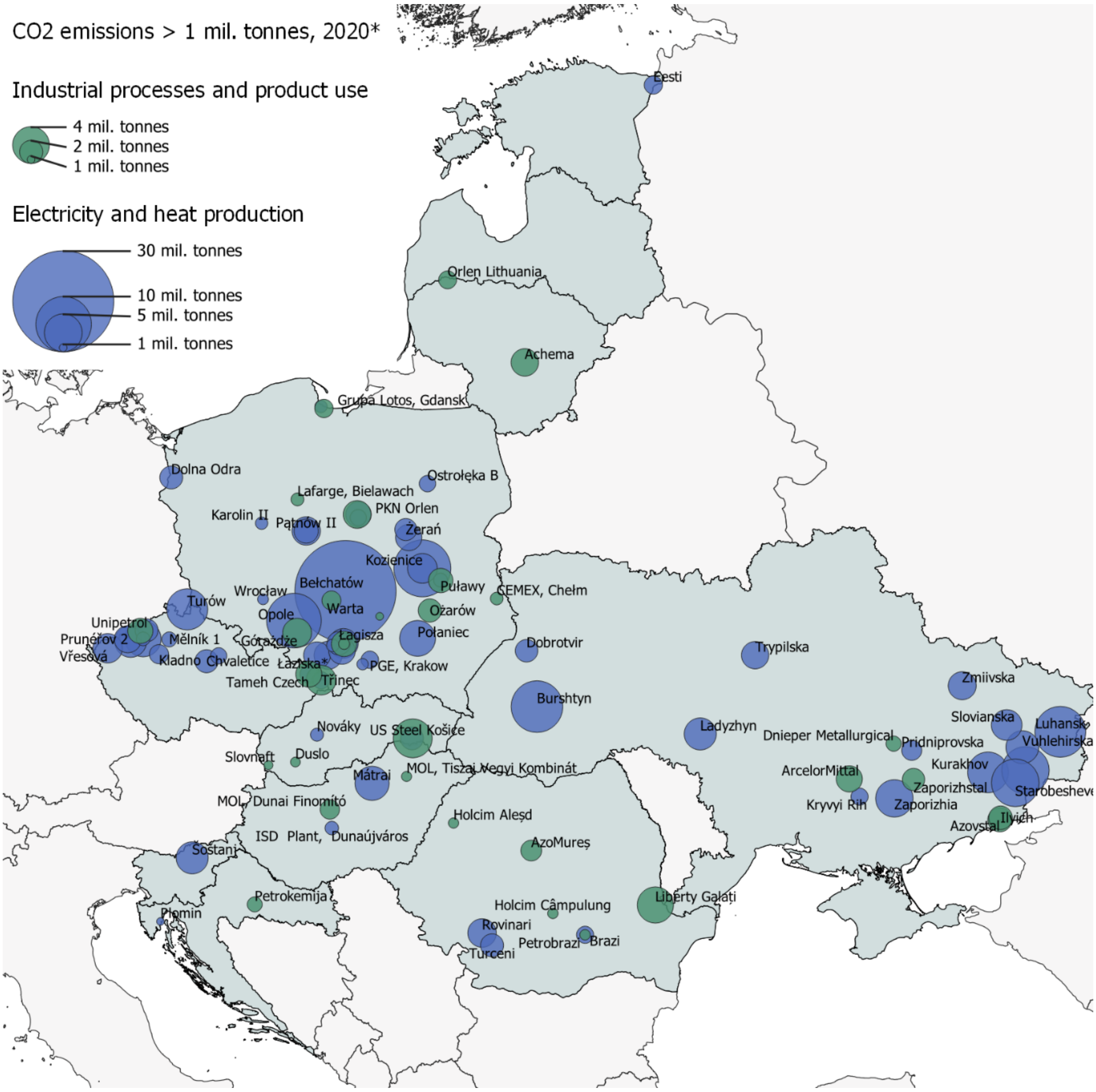

Figure 9. Emission sources in the expanded EU ETS. Note that available data for Ukraine only covered coal-fired power plants and five steel plants. Further research should determine the location and magnitude of other emission sources in Ukraine.

2.3.2. Major emitters in partner countries

Croatia

Croatia only contributed 0.55% of all EU ETS emissions in. It had 2 emitters with emissions larger than 1 Mt CO_2-eq/year in 2020: the Petrokemija fertilizer plant (1.26 Mt CO_2-eq) and block B of the Plomin power station (1.02 Mt CO_2-eq).[102] The power station, which

[102] In 2019, the Plomin power station emitted a total of 1.34 Mt CO_2-eq (all blocks). Source: CCS4CEE Croatia national report.

uses bituminous coal, is nearly 200 km away from the most suitable carbon storage sites (northern Croatia), and CCS4CEE experts consider that offshore storage locations would be required for this emitter. Of the Croatian ETS installations emitting more than 100 kt CO_2-eq in 2019, six were power or CHP plants and five were cement factories.[103] A notable emitter is also the Rijeka oil refinery, whose 2019 emissions were 708 kt CO_2-eq, down from 1 Mt in 2018.

Czech Republic

The Czech Republic's ETS emissions sources contributed 4.11% to total EU ETS emissions in 2020. The four largest emitters in the country are lignite-fired power stations, which will be subject to national plans for coal phase-out (by 2038).[104] The single largest emitter is the lignite-fired Počerady power station (a total of 5.75 Mt CO_2-eq in 2020); although its phase-out was planned in recent years, a change in ownership resulted in longer planned operations (likely until 2038). The lignite-fired Tušimice 2, Vřesová and Prunéřov 2 power stations are also likely to continue operations until 2038; Vřesová already uses natural gas alongside lignite, and may use biomass in the future. Of the remaining power stations with emissions above 1 Mt CO_2-eq, only the lignite-fired Opatovice power plant is undergoing modernization for the use of natural gas and waste-to-energy,[105] and none of them have yet closed or are planned for closure before 2038.

Of installations with emissions over 1 Mt CO_2-eq, three are non-energy sources: the Třinec Iron and Steel Works steel plant (2.8 Mt), the Liberty Ostrava steel plant (2.3 Mt) and the Unipetrol oil refinery (2.2 Mt). The two steel plants alone are responsible for 83% of the Czech Republic's emissions from the metal industry, and 5.1% of the country's total CO_2 emissions. Additionally, although neither the Mokrá or Radotin cement plants emitted more than 1 Mt CO_2-eq in 2020, they are both owned by HeidelbergCement (through its Czech subsidiary Českomoravský cement) and their emissions summed up to 1.16 Mt CO_2-eq in 2020, stressing the importance of this Czech emitter.

Regions with significant power plant emissions are 1) Karlovarsky (where Vřesová is located), and Ústecký (where the Počerady, Tušimice 2, and Prunéřov 2 plants are located, as well as the Unipetrol refinery), at the German border, 2) Moravskoslezský (where the Liberty Ostrava and Třinec steel plants are located) and Pardubický, at the Polish border, and 3) Středočeský in central Czech Republic.

Estonia

ETS installations in Estonia contributed 0.42% of EU ETS emissions in 2020. The country's only emitter with more than 1 Mt-eq CO_2 in 2020 was the Eesti power station (1.65 Mt), primarily using oil shale. It is the world's biggest power plant using oil shale as its primary fuel; however, to cope with environmental aspects, in 2005 some of the energy blocks were updated to use fluidized bed combustion technology, which would allow substituting up to 50% of the fuel with biomass (wood chips/shavings). The owning company, Enefit, will stop using oil shale by 2025, shifting instead to shale gas (a by-product from oil production), and increased their renewable energy production in 2019 and 2020.

Hungary

Hungary's ETS installations contributed 1.4% of emissions in the EU ETS. It has only four stationary installations with emissions higher than 1 Mt CO_2-eq in 2020: the Mátra power station (4.1 Mt), the MOL refinery at Dunai Finomító (1.6 Mt), the gas-fired ISD power plant (1.2 Mt)[106] and the MOL Petrolkémia Zrt/Tiszai Vegyi Kombinát chemical processing plant. Although not a stationary source and thus not included in this report, Wizz Air recorded verified emissions of 1.2 Mt CO_2-eq in 2020.

[103] CCS4CEE country report: Croatia. Available on the CCS4CEE project website.
[104] The 2038 deadline was originally recommended by the Czech Coal Commission to the government. However, they have stated recently that phase-out may happen as early as 2033, due to market forces. Source: CCS4CEE experts: Czech Republic.
[105] CCS4CEE country report: Czech Republic. Available on the CCS4CEE project website.
[106] The ISD gas-fired power plant is likely to cease operations in the 2020s, as it is rarely used. Source: CCS4CEE country report: Hungary. Available on the CCS4CEE project website.

LATVIA

Latvia's ETS installations contributed 0.45% of emissions in the EU ETS in 2020. It had no ETS installations with emissions higher than 1 Mt CO_2-eq in 2020. Latvenergo, an energy company, is largest emitter in economy (with total emissions of 1.2 Mt/year CO_2 in 2019), with installations concentrated around the capital of Riga. The company is planning development of renewable energy and energy efficiency improvements.[107] Out of the 28 largest CO_2 emitters in Latvia (totaling over 80% of national CO_2 emissions), 20 are related to electricity or centralized heating production. In general, Latvia's energy companies are mostly located near settlements to supply district heating and are gradually transitioning to the use of biomass (from 597 to 994 MW installed capacity between 2010 and 2018).

In industry, a single cement producer (Schwenk Latvija) emitted 779 kt CO_2/year in 2020 from its plant in western Latvia. The plant wants to be first CO_2-neutral cement production installation in the Schwenk Group.[108]

LITHUANIA

Lithuania contributed 0.15% of EU ETS emissions in 2020. It has only two installations emitting more than 1 Mt CO_2-eq in 2020: Achema, a fertilizer production plant (2.5 Mt) and Orlen Lietuva, an oil refinery (1.47 Mt). Akmenės Cementas is another important emitter, with emissions of 0.97 Mt in 2019 and 0.87 Mt in 2020. It is close to the Orlen refinery and to the Latvian border. Of Lithuanian installations with emissions higher than 50 kt/year in 2019, 57% (15 installations) are district heating plants.[109]

POLAND

In 2020, Poland's EU ETS installations contributed 12.2% to EU ETS emissions, the largest contribution of all partner countries by far. The Bełchatów power plant was the largest emitter in the EU ETS, with just over 30 Mt CO_2-eq in 2020. Poland's second-largest emitter, the Kozienice power station, emitted 13.7 Mt in 2020. Poland also has the most installations (37)[110] of all partner countries in the expanded EU ETS, contributing 15.5% of emissions from these installations located in partner countries.[111] Of the whole EU, 15% of all power plants emitting more than 1 Mt CO_2-eq in 2020 are in Poland.

Although 70% of Poland's large EU ETS installations are power plants, and the country plans to phase out its use of coal by 2049,[112] only eight power stations are planned for closure or classified as closing: Bełchatów, Jaworzno, Łagisza, Łaziska, Kozienice and Siersza (according to CCS4CEE Polish experts); and Rybnik and Żerań according to Carbon Brief (the Żerań power plant being the oldest coal-fired power plant of Poland's large emitters).[113] The TAMEH industrial CHP plant in Krakow emitted more than 1 Mt CO_2-eq in 2019, however emissions dropped sharply in 2020 are likely to remain low given the planned phase-out of the Krakow blast furnace and steel mill.

As for industrial emitters, Poland's Górażdże cement plant had the highest emissions (2.7 Mt CO_2-eq in 2020), followed by the PKN Orlen refinery (2.5 Mt, fuelled by the natural gas-fired Płock CHP, also a large emitter), the ArcelorMittal blast furnace in Dąbrowa Górnicza (2.2 Mt) and the Puławy fertilizer plant (2.1 Mt). Five further cement plants, a steel mill and an oil refinery had emissions higher than 1 Mt CO_2-eq in 2020. The Głogów copper smelter had emissions just under 1 Mt in 2020 (0.92 Mt).

Poland's large emissions sources are relatively spread out across the country, but a cluster can be contoured in S-SE Poland (including Bełchatów). Polska Grupa Energetyczna (PGE), the largest power producer in Poland, is by far the largest-emitting company in Poland.

[107] CCS4CEE country report: Latvia. Available on the CCS4CEE project website.
[108] CCS4CEE country report: Latvia. Available on the CCS4CEE project website.
[109] CCS4CEE country report: Lithuania. Available on the CCS4CEE project website.
[110] This includes three installations which did not report data for 2020, but had CO_2 emissions higher than 1 Mt in 2019: the Łaziska power plant, the CHP in Dąbrowa Górnicza and the ArcelorMittal blast furnace in Dąbrowa Górnicza.
[111] It should be noted that data for large emitters in Ukraine was incomplete for this report.
[112] CCS4CEE country report: Poland. Available on the CCS4CEE project website.
[113] Carbon Brief, 2021. Mapped: The world's coal power plants in 2020.

Romania

Emission sources in Romania contributed 2.4% to emissions in the EU ETS. The country had eight sources with emissions over 1 Mt CO_2-eq in 2020, most of which are non-energy emitters. The Liberty steel plant in Galați is Romania's largest emitter, with 3.9 Mt CO_2-eq in 2020. Two units of the Oltenia Energy Complex, the lignite-fired Rovinari and Turceni plants, emitted 3.1 Mt and 2.2 Mt CO_2-eq in 2020, respectively; in total, the Oltenia Energy Complex emitted 7.1 Mt CO_2-eq, making it the 15th highest emitter in partner countries (and the fourth in EU partner countries). A decarbonisation plan for the Oltenia Energy Complex is currently underway. The remainder of large emitters come from various industries: the Azomureș fertilizer plant, the gas-fired Brazi co-generation plant, the Petrobrazi oil refinery and two cement plants operated by Holcim Romania.

Slovakia

Slovakia's emitters contributed 1.36% of emissions in the EU ETS in 2020. The country had five sources with emissions over 1 Mt CO_2-eq in 2020, the largest being the US Steel plant in Košice (4.39 Mt). The plant's energy is supplied by Ferroenergy, a recently-operational subsidiary of US Steel and Slovakia's second-largest emitter (2.2 Mt CO_2-eq in 2020), which uses metallurgical gases, coal and natural gas. The remaining emitters are the lignite-fired Nováky power station, the Duslo fertilizer plant and the Slovnaft oil refinery. The Rohožník cement plant also emitted close to 1 Mt CO_2-eq in 2020 (963 kt CO_2-eq).

Notably, the Nováky power plant had its capacity reduced in 2015, with two units shutting down. The plant will stop using lignite in 2023, transitioning to natural gas and biomass at a much smaller capacity than the original plant (71 MWe, relative to 486 Mwe). The reduction in coal-fired power capacity is partly driven by Slovakia's increase in its nuclear power capacity, including two new reactors planned for completion in 2021 and 2022.[114]

Slovenia

Slovenia contributed just 0.46% to EU ETS emissions in 2020. Only one installation had emissions higher than 1 Mt CO_2/year: the lignite-fired Šoštanj power station (TEŠ) (3.7 Mt CO_2-eq). As late as 2015, a new coal-fired Unit 6 was introduced into operation, and by 2030 will gradually replace the production of all other existing units of the TEŠ. A 2012 agreement between the government of Slovenia and TEŠ establishes an annual CO_2 emissions ceiling for the plant, which will be progressively reduced, achieving 52% a reduction by 2040. The National Energy and Climate Plan (NECP) or Slovenia envisages the gradual abandonment of the use of coal for energy production or at the very least a 30% reduction by 2030. The precise timetable for abandoning the use of coal, including shutting down the Velenje Mine and TEŠ Unit 6, is meant to be determined by 2021.[115]

Other notable emitters from Slovenia are Salonit Anhovo, a cement manufacturer (708.5 kt CO_2-eq in 2020) and Energetika Ljubljana, the municipal energy company supplying Slovenia's capital, emitted 530.8 kt. In the iron and steel sector, the main two companies are SIJ Slovenian Steel Group and Štore Steel. According to the World Steel Association, CO_2 emissions in the SIJ Group are 22% lower than in comparable global steelworks; if they continue at the current rate of reduction of CO_2 emissions by 2030, they will need to pay more than €63 million for emission allowances in the EU ETS (based on current prices). Their turnover is currently €570 million.[116]

Ukraine

Even with data available only on 19 large emitters,[117] Ukraine is the second-largest contributor to emissions from large sources of all partner countries (with Poland close behind). Emissions from these emitters totalled 146.8 Mt CO_2 in 2019, equivalent to 17.6% of expanded EU ETS emissions in 2020, and to 11% of all EU ETS emissions. The 14 power plants included in these 19 emitters use various types of coal (anthracite, bituminous and sub-bituminous coal), sometimes accompanied by heavy fuel oil and natural gas. They are significant emissions sources, with four out of the ten largest emitters in partner countries being Ukrainian thermal power

[114] CCS4CEE country report: Slovakia. Available on the CCS4CEE project website.
[115] Government of the Republic of Slovenia, 2020. Slovenia's fourth biennial report to the UNFCCC, page 44.
[116] CCS4CEE country report: Slovenia. Available on the CCS4CEE project website.
[117] Data for the coal-fired power plants and steel plants is available for 2019.

plants, ranging from 4.9 (Zaporizhia) to 8.7 (Burshtyn) Mt CO_2 emissions in 2019. Ten of these stations,[118] with emissions totalling 35.5 Mt CO_2, are located in eastern Ukraine, with Starobesheve and Kurakhov being relatively close to the Sea of Azov. The Kryvorishska, Zaporizhia, Trypilska and Prydniprovska power stations are also situated on the Dnieper River, Ukraine's largest waterway, which flows into the Black Sea just west of Kryvorishska.[119]

CCS4CEE experts on Ukraine have highlighted that, despite the potential applications of CCU or CCS to Ukraine's coal-fired power plants, the timelines for closure of these plants' blocks (see footnote 100) and lack of a clear national decarbonization strategy means that Ukrainian energy producers are not likely to consider these technologies in their decarbonization plans. Eight out of Ukraine's 14 large coal-fired power plants are owned by DTEK, Ukraine's largest utility with total emissions of 31.2 Mt CO_2 in 2019,[120] which plans to achieve carbon neutrality by 2040. However, it is unclear whether the remaining blocks will continue using coal or transition to natural gas, particularly given Ukraine's extremely distant target for net zero emissions (2070). Indeed, Ukraine's coal phase-out plans will bring emissions from heat and electricity generation down from approx. 90 Mt CO_2 today to 75 Mt by 2030.[121]

In addition to its coal-fired thermal power plants, Ukraine's largest industrial polluters include its ferrous metallurgy plants. Key emitters from this sector are also located in eastern Ukraine, and primarily operated by Metinvest, ArcelorMittal, Industrial Donbas Union and NZF. Today, emissions from steel plants operated by Metinvest, ArcelorMittal and Industrial Donbas Union make up 50% of Ukraine's industrial emissions. Emissions from large steel plants (over 1 Mt CO_2 emitted in 2019) have decreased in the last decade; in 2010, three Metinvest steel plants in eastern Ukraine emitted a total of just over 26 Mt CO_2: the Ilychi steel plant nearly 12 Mt, the Azovstal plant 8 Mt and the Zaporizhstal plant just over 6 Mt.[122] In 2019, the largest steel emitters for which data was available were ArcelorMittal Kryvyi Rih (2.35 Mt CO_2 in 2019), Azovstal (2.1 Mt), Ilychi (2.04 Mt), Zaporizhstal (1.89 Mt) and the Dnieper Metallurgical Combine (1.28 Mt).[123] According to Metinvest, emissions amounted to 8.4 Mt of direct CO_2 emissions across all its steel plant assets in 2019, a reduction most recently enabled by improvements to the Azovstal blast furnaces, the shutting down of a blast furnace at Ilyich and modernisation of the Zaporizhstal plant.[124]

Several of these large steel plants are also located in Eastern Ukraine, with Azovstal and Ilychi in particular being situated on the Black Sea coast, in the port city of Mariupol. Zaporizhstal and the Dnieper Metallurgical Combine are situated on the Dnieper River, relatively close to the Zaporizhia and Pridniprovska thermal power plants, respectively. Current data on the CO_2 emissions of other metallurgy plants in Ukraine could not be sourced as part of the CCS4CEE project; however, it is well-established that these are significant emissions sources for Ukraine, and further data collection and research will be crucial to aggregate these emissions data and evaluate the carbon capture potential of industrial producers in Ukraine.

2.3.3. Summary

At least 94 stationary sources[125] in partner countries emitted more than 1 Mt CO_2-eq in 2020 (including CO_2 emissions from 2019 for Ukrainian sources), a total of 267.5 Mt CO_2-eq, or 36% of emissions from European and Ukrainian sources over 1 Mt CO_2-eq/year which would be subject to the EU ETS. Poland had the largest contribution of partner countries to emissions from these sources, and hosted the largest emitter in the whole EU ETS (including Ukraine) - the Bełchatów power plant. Most emitters in partner countries were thermal power plants (72% of installations were classified as having fuel combustion as their primary source of activity).[126] Eight cement plants and four oil refineries were among the emitters, as well as three ammonia producers and nine steel producers. The largest non-energy emitters in the region were two steel plants in Slovakia and Romania. Poland has a notable share of non-energy

[118] These ten power stations are Kryvorishska, Zaporizhia, Prydniprovska, Kurakhov, Starobesheve, Zuevskaya, Vuglegirska, Luganskaya, Slaviansk and Zmiivska.
[119] Mapped: The world's coal power plants in 2020 (carbonbrief.org)
[120] DTEK, 2019. Integrated annual report: financial and non-financial results.
[121] CCS4CEE Ukraine experts.
[122] Source: CEE Bankwatch Network, 2011. ArcelorMittal Kriviy Rih – transition without sustainability).
[123] Source: CCS4CEE country report: Ukraine. Available on the CCS4CEE project website.
[124] Source: Metinvest sustainability report, 2019.
[125] Given the limited data available for Ukraine, it is possible there were more than 94 large emitters in partner countries.
[126] Note that this sometimes included non-energy producers, such as U.S. Steel Košice.

emitters, including six cement plants emitting more than 1 Mt CO_2 in 2020. It should be noted that several industrial emitters – US Steel Košice (Slovakia), the Dąbrowa Górnicza steel mill and blast furnace and the PKN Orlen refinery (Poland), and the Petrobrazi refinery (Romania) – are supplied with energy by nearby power stations or CHPs, all of which emitted more than 1 Mt CO_2-eq in 2020 (2019 in the case of the Dąbrowa Górnicza, which did not report emissions in 2020), and all of which (aside from the Petrobrazi supplier) are at least partially coal-based. Data on the fuel supply of other industrial emitters was not available, however they may also be at least partially supplied by nearby dedicated power stations, especially given the tendency to construct large industrial plants near fuel sources, during the time of the communist regime. This is also noticeable also in the case of Ukraine, with three of the five steel plants listed in this report being adjacent to large coal-fired power plants.[127]

Several partner countries stood out in terms of their hosting of large emission sources. Poland and Ukraine contributed the most to the aggregate emissions of the 94 identified sources, but in the case of Ukraine these came from only 19 emitters, as opposed to 37 in Poland. Ukraine's thermal power plants and steel factories make its decarbonisation one of the most challenging of all partner countries. Another large emitter was the Czech Republic, which may see its emissions decline over the next decades as its use of coal is phased out; however, its steel production and oil refining sectors are still significant emitters. Romania's emissions are also concentrated in the power sector (the lignite-fired Oltenia Energy Complex) and steel (Liberty Steel Galați, Romania's largest emitter). The Baltic States all have relatively low emissions, which may decline further still (especially for Estonia, as it phases out its use of oil shale for energy production; Latvia and Lithuania show a higher proportion of large emitters in industry sectors such as cement and chemicals production). Slovenia's emissions are also low, but significantly contributed to by the lignite-fired Šoštanj power station.

In terms of their locations, several patterns in large emission sources can be noted (Figure 9). Many of Ukraine's coal-fired power plants and steel plants are in Eastern Ukraine, some along the Black Sea and the Dnieper River, indicating a potential for offshore storage or marine transport of CO_2. Several carbon-intensive regions in the Czech Republic are situated close to the German and Polish borders, indicating a potential to form emissions clusters for CO_2 capture – particularly in Poland, with a number of emissions sources in its southern regions, relatively close to the Czech border (the Turów power plant in particular). Emitters in the Baltic States, located relatively close to the borders, may be suitable for potential transborder emissions clusters (for example, Schwenk's cement plant in western Latvia (not shown in Figure 9 as its emissions were below 1 Mt CO_2-eq in 2020), and Lithuania's Akmenės Cementas cement plant and Orlen refinery, close to the Latvian border). Coastal emitters in the region, such as Gdansk in northern Poland, may also be suitable for marine CO_2 transportation, as already planned by Lithuania's Klaipėda consortium (see Section 4.2). Large emission sources are relatively spread out across the territories of Romania, Hungary and Slovakia, and mostly far away from other large emitters across their borders.

The above observations indicate that some of the major CO_2 emitters in partner countries may show potential for CO_2 capture, and some even for transborder CO_2 capture clusters. As indicated in Section 2.2.3., many partner countries will likely be phasing out their use of fossil fuels for energy combustion. These plans are as yet undefined, and in some countries, such as Poland or Ukraine, the deadlines for phase-out are still decades away, indicating that CCS may be necessary to keep emissions reductions on track. Additionally, CCS/CCU may prove a feasible opportunity for decarbonisation of major non-energy emitters in partner countries. However, the fate of the captured CO_2 depends on the storage and/or utilization potential in partner countries. In the following section, we review the potential for geological CO_2 storage, as well as briefly outline possibilities for CO_2 utilization.

[127] ArcelorMittal Kryvyi Rih to the Kryvorishska power station; Zaporizhstal adjacent to the Zaporizhia power station; Dnieper Metallurgical Combine to the Pridniprovska power station.

3. Storage and utilization potential in the CEE region

3.1. Overview

Geological potential for CO_2 storage occurs in three main types of structures: saline aquifers (at a depth of at least 800 m),[128] hydrocarbon fields and unmineable coal seams. In the case of hydrocarbon fields, depleted oil or gas reservoirs may be used for CO_2 storage for enhanced oil or gas recovery (CO_2-EOR or CO_2-EGR, respectively). The presence of these structures in each partner country varies, and the following section reviews the regional geological structures suitable for CO_2 storage, as well as details for each partner country.[129]

There are also possibilities for storing CO_2 through a process called mineral carbonation. This process involves the immobilization of CO_2 in naturally occurring minerals, such as those found in basaltic rocks. This method of CO_2 sequestration has the advantage of enabling storage areas which have previously been assessed as unsuitable.[130]

A 2013 report from the CGS Europe project, "State of play on CO2 geological storage in 28 European countries", [131] highlights suitable formations for CO_2 storage in Europe. All partner countries, aside from Ukraine, are members of the CGS Europe project and were covered by the report. As shown in Figure 10, the extent of sedimentary basins in partner countries is significant and includes major hydrocarbon fields in Romania and Hungary. Coal fields (not shown in Figure 10) occur in southern Poland and Hungary, and to a very small extent in Croatia and the Czech Republic.

When it comes to CO_2 utilization, several major uses emerge. Mature uses for CO_2 are the production of urea; the drinks industry (where CO_2 is used as a coolant and in the production of carbonated drinks); and greenhouses. In these cases, the utilized CO_2 mostly comes from the ammonia industry, a set-up which is relatively widespread across Europe. However, given the niche nature of these destination sectors and the associated difficulty in assessing the significance of their contribution to partner countries' economies, they are not studied further in this report.

In other mature uses, CO_2 is also a versatile solvent and working fluid commonly used in various production processes, such as materials processing and manufacturing, the food, medical and pharmaceutical industries and enhanced hydrocarbon recovery. In particular, enhanced hydrocarbon recovery - enhanced oil recovery (CO_2-EOR) or enhanced gas recovery (CO_2-EGR) - has been extensively applied in the United States and used in some European countries, such as Romania, Croatia and Hungary.

While historically CO_2 has been mostly used in its molecular form (i.e. how it was found), in more novel utilization methods captured CO_2 can be converted to feedstocks, such as polymers (used for the manufacture of chemicals), fuels and building materials, or energy

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[128] The safe storage of CO_2 in saline aquifers occurs at a depth of minimum 800 m (at which point CO_2 exists in a supercritical state suitable for storage). Source: Bruant, R.G., Celia, M.A., Guswa, A.J., Peters, C.A, 2002. Safe storage of CO_2 in Deep Saline Aquifers. Environmental Science and Technology 36 (11), pp 240-245.
[129] Further details on CO_2 storage are provided in the "Current state of CCS technologies and the EU policy framework", written by Bellona Foundation as part of the CCS4CEE project (available on the CCS4CEE website).
[130] Snæbjörnsdóttir, S.Ó., Sigfússon, B., Marieni C., Goldberg, D., Gislason, S. R., Oelkers, E. H. Oelkers, 2020. Carbon dioxide storage through mineral carbonation. Nature Reviews Earth & Environment volume 1, pages 90–102.
[131] "Pan-European coordination action on CO2 Geological Storage", funded under the 7th Framework Programme of the European Community for research, technological development and demonstration activities.

carriers such as synthetic fuels and formic acid. CO_2 can also be used as a working fluid in supercritical CO_2 power cycles and enhanced geothermal systems. [132]

Whether utilizing or storing CO_2, the transportation of CO_2 from the capture site is also an element to be considered when planning the deployment of CCU/CCS. The choice of the transport mode depends primarily on the locations of the capture and storage site, the distance between them, and the expected volume of CO_2 emissions to be transported. In some cases, CCS projects may combine multiple modes of transport.

The primary methods of CO_2 transportation are via pipeline and via road (trucks), rail and marine (ship) transportation. Currently, the largest proportion of CO_2 globally is transported by pipelines, which has the advantage of being able to move larger volumes of CO_2 and potentially reusing existing oil and gas pipelines; however, this comes at the cost of flexibility and with a requirement to secure these large volumes to keep operational costs low. Trucks are the main transportation mode for small-scale transport of commercial CO_2; however, rail transportation is more economical (albeit less flexible) and can transport larger volumes of CO_2 than trucks. Trains can therefore support small-scale CCS projects where the construction of pipelines is unfeasible, provided that the capture and storage units are accessible by rail. Alternatively, rail could be used for one part of the route in projects using multiple modes of transport. Finally, transport by ship is more flexible than offshore pipeline transport, and more economically favourable for small volumes of CO_2.[133]

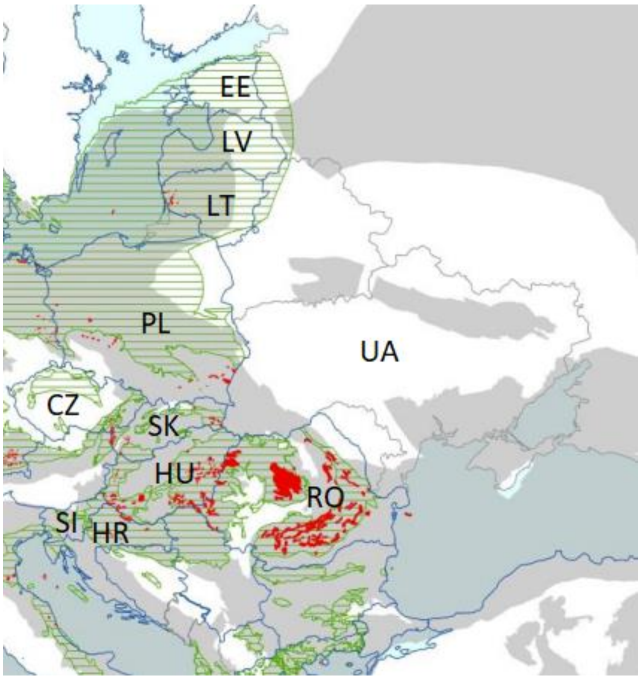

Figure 10. Map of sedimentary basins and hydrocarbon fields in partner countries. Areas shaded in grey are sedimentary basins identified by Fugro Tellus (2008),[134] and in green by EU GeoCapacity (GC) (2009); potential hydrocarbon fields are shown in red (EU GeoCapacity, 2009). CGS Europe countries are marked by blue borderlines. Adapted from CGS Europe, 2013: State of play on CO2 geological storage in 28 European countries.

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[132] CO_2 utilization methods are further detailed in the "Current state of CCS technologies and the EU policy framework", written by Bellona Foundation as part of the CCS4CEE project (available on the CCS4CEE website).
[133] CO_2 transportation mediums are further detailed in the "Current state of CCS technologies and the EU policy framework", written by Bellona Foundation as part of the CCS4CEE project (available on the CCS4CEE website).
[134] Fugro Tellus Sedimentary Basins of the World Map, Fugro Robertson Limited; retrieved via CGS Europe, 2013.

3.2. STORAGE AND UTILIZATION POTENTIAL IN PARTNER COUNTRIES

CROATIA

Most of Croatia's CO_2 storage potential (90%) is in six regional deep saline aquifers, with a total capacity of 3.18 Gt CO2 (mostly sandstone formations). However, these formations have been relatively poorly characterised and explored, compared to Croatia's hydrocarbon fields where more data and even injection facilities are currently available, but where storage potential is much lower (175 Mt CO_2).

Of its saline aquifers, the bulk of Croatia's CO_2 storage potential lies in onshore formations (80%) – the largest is the Drava formation in north-eastern Croatia, on the Hungarian border (1.9 Gt). Only one offshore aquifer (Dugi Otok) has been characterised so far, with a relatively significant capacity of 601 Mt. A significant share of inland saline aquifer capacity occurs in north-eastern Croatia, at the border with Hungary) – and with 50% of Croatia's emissions occurring on the coast (including the Plomin power plant, Croatia's second-largest emitter), the importance of extensive CO_2 transportation systems for CCS is clear. In some cases, logistics may be simpler: the Petrokemija fertilizer plant, Croatia's largest emitter, is adjacent to the Iva, Okoli and Poljana saline aquifers in northern Croatia (505 Mt storage capacity).

When it comes to hydrocarbon fields, most storage potential (141 Mt CO_2) lies in a total of ten gas fields, three of which are offshore (still productive, but likely only for a few years longer).[135] An assessment of storage potential of oil fields via CO_2-EOR (Enhanced Oil Recovery), conducted as part of the Strategy CCUS international project, revealed that its economic feasibility is questionable, particularly given that emissions of CO_2 from Croatia's largest emitters located close to oil fields are well below the volumes needed for CO_2-EOR in Croatia.[136] Storing CO_2 through EOR would thus require an extensive transportation system, possible including cross-border transport connections. However, given the contribution of Croatia's oil refining sector to the national economy (1.25% of GVA in 2018), it is worth highlighting the Ivanić and Žutica oil fields (central Croatia) and the Beničanci oil field (eastern Croatia). These fields could benefit from proximity to CO_2 emitters, as well as already-ongoing CO_2 EOR projects in the Ivanić and Žutica fields. Ultimately, in the view of CCS4CEE Croatian experts, CCS or CCU clustering between the oil, cement and fertilizer industries in northern Croatia is likely, given transport and storage logistics considerations.

CCS for Croatia's coastal emitters may face high transportation and storage costs. As indicated above, the Plomin power plant is nearly 200 km away from the most prospective CO_2 storage sites in northern Croatia and may require offshore storage. Croatia's three offshore gas fields would be the first candidates, but the high volume of Plomin's CO_2 emissions means that either all three locations would need to be used, or additional capacity would have to be found in structurally defined carbonate aquifers that are both deeper and further away from all littoral sources. Similarly, cement production facilities near Split would either require onshore transportation for more than 300 km, or offshore transportation and storage (in the Dugi Otok saline aquifer, a structurally defined aquifer in the Central Adriatic Sea; or connecting with the Ravenna Hub in Italy. In all these solutions, ship transport should also be considered).

As for CO_2 storage capacity in coal seams, no estimates are available, and Croatian coal mines have been shut since 1990. The seams in these coal basins are either shallow or highly fractured due to tectonic activity.[137]

CZECH REPUBLIC

Like the rest of continental Europe, the bulk of the Czech Republic's CO_2 storage capacity lies in saline aquifers. According to the most recent geological surveys, the Czech Republic has a total CO_2 storage capacity of 766 Mt in saline aquifers (Central Bohemian Upper Palaeozoic basins, in the north of the country), 33 Mt in hydrocarbon fields (the Hrušky oil field in the south-eastern Czech Republic) and 54 Mt in coal fields (the Upper Silesian Basin in the eastern Czech Republic, close to the border with Poland). There are significant

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[135] CCS4CEE country report: Croatia. Available on the CCS4CEE project website.
[136] CCS4CEE country report: Croatia. Available on the CCS4CEE project website.
[137] CGS Europe, 2013. State of play on CO_2 storage in 28 European countries.

differences between these (conservative) estimates and theoretical estimates of CO_2 storage capacity; for example, the estimate of storage potential in saline aquifers is as high as 2.8 Gt.[138]

The Czech Republic's potential storage sites are located relatively close to the highly industrial regions of the country, particularly the Karlovarský and Ústecký regions in the north-western region. Similarly to Croatia, although the bulk of storage capacity in saline aquifers is much higher than in hydrocarbon fields, more research and data is available for the latter, with the geological survey responsible for the above capacity estimates being done in cooperation with oil and gas companies in the eastern part of the country. Although the potential of saline aquifers is higher, no investments or planned projects exist for storing CO_2 in these geological formations.

CO_2 transportation in the Czech Republic could occur through pipelines, with the country having a dense and robust pipeline system, including border transfers to Slovakia and Germany and an interconnector to Poland. According to the national gas transmission operator, a national development plan until 2030 mentions "blue" hydrogen with connection to CCS/CCU; however, no mention is given regarding the possibility of CO_2 transport itself.[139] During the CCS4CEE workshop in the Czech Republic, stakeholders mentioned that the southern transit pipeline (Waidhaus–Břeclav) is currently inoperative and could be used for future testing and experiments with CO_2 transport.

Another possibility of CO_2 transport is through rail transportation. Although it may be more costly than pipeline transportation, it could be a short-term solution until CO_2 pipeline networks are built. The Trans-European Transport Networks cross the Czech Republic both east to west and north to south, and cargo-specific transport networks span the east of the country (including the Rhine-Danube and Baltic-Adriatic corridors). Future cargo-specific railway corridors are also planned for the north-western part of the Czech Republic, through the Ústecký region. Czech railway networks, as well as the gas pipeline system, were built to meet the needs of a developing heavy industry, and as such the highly industrialized regions of the Czech Republic have good access to both these transportation modes.

The Baltic States

Overall, the Baltic countries are situated in the Baltic sedimentary basin, which contains a number of regional-scale aquifers. However, only two of these, the Lower-Middle Devonian (marked D1 and D2 in Figure 11) and Middle Cambrian reservoirs (marked Cm), meet the basic requirements for CO_2 storage.

Estonia

The northernmost of the Baltic states, Estonia is located on the eastern edge of the Baltic sedimentation basin, which extends across the three Baltic countries and varies in thickness. In Estonia, this depth is generally less than 800 m, and as such the geological potential for carbon storage is limited. In addition to the shallow sedimentary basin, any potential aquifers in the region are used for Estonia's water supply, and thus could not be contaminated with any amount of CO_2, especially in large amounts. Estonia also has no hydrocarbon fields or coal fields, and as such its overall CO_2 storage capacity is estimated to be negligible.[140,141] The closest suitable areas for CO_2 storage are in Latvia and Lithuania; however, this would require a pipeline extending over 800 km across the two countries' biggest cities, an extremely expensive investment unlikely to receive public support, according to stakeholders engaged in the CCS4CEE project. There are some possibilities for CO_2 immobilization through mineral carbonation in oil shale ash and wastewater,[142] however these have not been highlighted in the CCS4CEE project findings for Estonia.

[138] CCS4CEE country report: Czech Republic. Available on the CCS4CEE project website.
[139] Net4gas, 2020. Desetiletý plán rozvoje přepravní soustavy v České republice 2021 – 2030 (in Czech).
[140] CCS4CEE country report: Estonia. Available on the CCS4CEE project website.
[141] EU GeoCapacity: Assessing European Capacity for Geological Storage of Carbon Dioxide. D16, WP2 Report (storage capacity).
[142] CGS Europe, 2013. State of play on CO2 geological storage in 28 European countries. Mineral carbonation involves the immobilization of CO_2 in naturally occurring minerals.

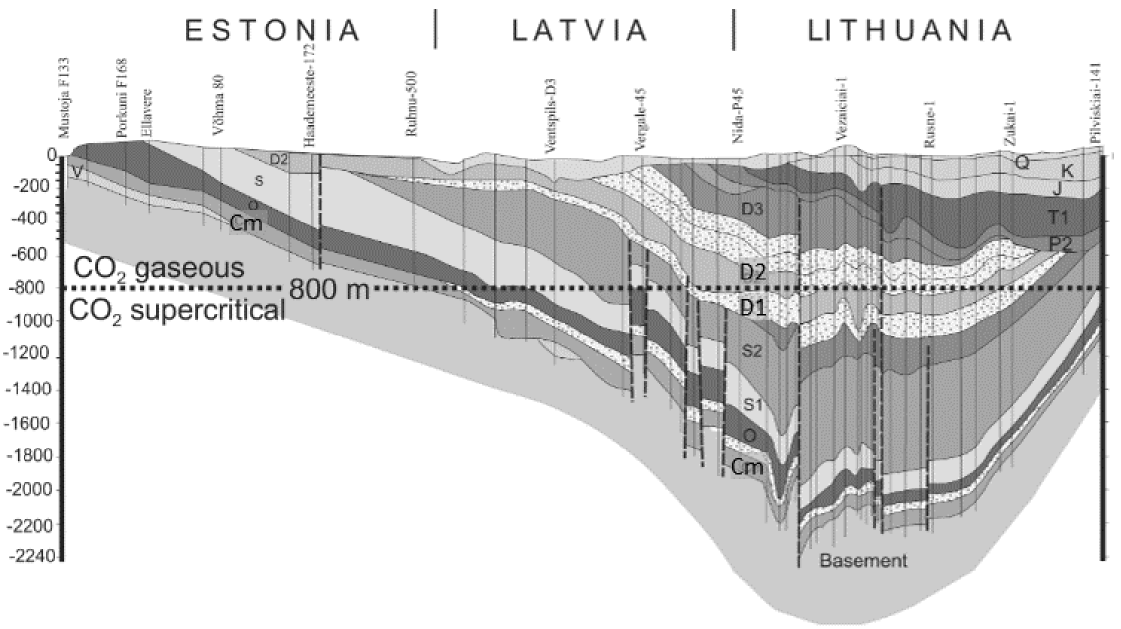

Figure 11. Geological cross-section across Estonia, Latvia and Lithuania. Major aquifers are indicated by dots. V - Vendian (Ediacaran), Cm - Cambrian, O - Ordovician, S - Silurian, D1, D2 and D3 - Lower, Middle and Upper Devonian, P2 - Middle Permian, T1 - Lower Triassic, J - Jurassic, K - Cretaceous, Q - Quarternary. Source: CCS4CEE country report: Estonia.

Latvia

The most favourable geological conditions for CO_2 and natural gas storage in Latvia are found in the Middle Cambrian reservoir. Suitable structures (deep saline aquifers) in these geological formations have been identified in western Latvia, and the capacities of 16 potential storage sites have been estimated by the Latvian Environment, Geology and Meteorology Centre, totalling 404 Mt (conservative estimate) - 790 Mt (optimistic estimate) of potential CO_2 storage.

In the same Middle Cambrian reservoir, the Inčukalns structure has been used for underground natural gas storage since 1968 (2.3 billion m^3 storage potential). Recently, it was proposed to use the Dobele underground structure for natural gas storage; however plans have since stalled, given that the Inčukalns natural gas storage facility offers more than enough capacity to meet Latvia's needs. These structures still need to be studied in detail to confirm their geological suitability for CO_2 storage; existing data dates back to geological research conducted during Soviet times, and exploration ceased in the 1980s. More up-to-date geological research is required to obtain more accurate information, including the data on the structure, dimensions, and fracture characteristics of potential storage sites. Another issue may be the potential competition between natural gas storage and CO_2 storage; a 2011 study reviewed the potential to store CO_2 produced in Estonia in Latvian geological structures, finding that the most promising structures in Latvia have already been planned for natural gas storage (and the storage of Latvian CO_2 emissions).

Offshore, potential geological structures for CO_2 storage are also available. Although offshore oil exploration was stopped in 1993, the BASTOR project (2011-2014) estimated CO_2 storage potential in the Cambrian sandstones of the southern Baltic Sea at 16 Gt, with 2 Gt localized in the Dalders Monocline, an offshore geological structure spanning the coastal waters of the Baltic states. Šliaupa et al. (2012) estimate CO_2 storage capacity in Latvian marine territories at about 400 Mt, which combined with estimated onshore capacity would be sufficient for Latvia's CO_2 storage needs for about 350 years. To clarify total potential storage capacity and suitability of these structures for CO_2 storage, more detailed geological surveys are required.

Latvia has no CO_2 storage potential in hydrocarbon fields or coal seams.

Lithuania

Lithuania's sedimentary cover varies in thickness from 200 m (in the south-east of the country) to 2.3 km on the Baltic Sea. Two possibilities exist for CO_2 storage in Lithuania: in anticline-type structures, including oil fields, and monoclinal-type saline aquifers. Anticline-type structures are the safest, but their potential is limited compared to monoclinal aquifers. Two promising saline aquifers are identified in Lithuania – the Cambrian aquifer, covering the western half of Lithuania, and Pernu-Kemeriai (Lower Devonian and Lower Middle Devonian), covering a smaller portion of western Lithuania. The Cambrian aquifer has the most favourable conditions for CO_2 storage; no promising structures have been found within the Devonian strata, so prospects for storage in this aquifer are negligible.

Within the Cambrian aquifer, the Syderiai storage site in central Lithuania (100 km from the port of Klaipėda) and Vaškai in northern Lithuania (100 km from Riga), have been identified and characterized. The Syderiai elevation can hold 21.5 Mt CO_2 and is close to the gas network, as well as being relatively close to the Orlen oil refinery, Lithuania's second-largest emitter. However, this structure is one of the most promising for the development of an underground gas storage facility in Lithuania, therefore a conflict of interest is possible here.[143] No significant geological studies have been carried out for the Vaškai structure, with estimates for the chamber temperature indicating that it may be a bit too low to maintain the CO_2 in a supercritical state, leading to a possible downwards migration and leakage from the structure. The Vaškai structure could store 8.7 Mt CO_2 and is close to gas pipelines. However, it may be subject to the same conflict of interests as outlined for the Syderiai elevation, as well having an unclear fracture closure and lacking temperature measurement data to substantiate the potential of storing CO_2 in a supercritical state.

Both the Cambrian and Pernu-Kemeriai aquifers extend into the Baltic Sea, where geological and geophysical surveys have been carried out, mainly related to oil exploration. The highest elevation identified in this area, D11, is located five km from the shore, in the Cambrian aquifer, and has an estimated potential of 11 Mt. Other structures range from 100,000 tons to 7.8 Mt.

In addition to geological structures, which are the main CO_2 storage options in Lithuania, mineral carbonation in serpentinite rocks is a promising option. A large serpentinite deposit was mapped in the crystalline basement of southern Lithuania, associated with high-quality iron ore. The largest deposit, the Varena iron ore deposit, is estimated to have CO_2 sequestration potential of 0.5-1 Gt, equivalent to storing 200-500 years of CO_2 production by the major south-eastern Lithuanian CO_2 emissions cluster. However, CO_2 immobilization in these deposits is challenged by the volume of resources used and waste created, as well as logistical issues of transporting CO_2 to the location of serpentinite deposits. As a result, mineral carbonation technologies require considerable developments.

Lithuania has no storage capacity in hydrocarbon fields or coal seams.

Hungary

Hungary's CO_2 storage capacity is significant, amounting to approx. 847 Mt (97 Mt in depleted hydrocarbon reservoirs and 750 million in deep saline aquifers). Most suitable depleted hydrocarbon fields are located in south-eastern Hungary, close to the border with Romania; explorations by MOL are also underway in western Hungary, including the southern Babócsa field at the border with Croatia. These fields tend to not be near the largest emission sources, however two clusters of emitters are noticeable in south-eastern Hungary (combustion units and glass or ceramics production) and south-western Hungary (including combustion units, glass or ceramics production and the Duna-Dráva cement plant).

Hungary's south-eastern depleted hydrocarbon fields are nested in a much larger sedimentary basin containing expanses of saline aquifers, composed of seven sub-regions and potentially suitable for CO_2 storage. The easternmost regions of Szegedi, Békési and Bihari – the eastern part of the Pannonian Depression - stretch all the way to the Romanian border and beyond – occupying most of the underground of the western plains of Romania. The second saline aquifer region potentially suitable for CO_2 storage is situated in the west of Hungary, spanning the Croatian, Slovenian and Austrian borders (as well as part of the Slovak border).

[143] CCS4CEE country report: Lithuania. Available on the CCS4CEE project website.

In 2006, the EU GeoCapacity study reported 87 Mt of CO_2 storage potential in three large coal fields in Hungary, mostly in eastern Hungary. However, a subsequent review by the CGS Europe project (2013) reported no storage potential in Hungary's coal fields. In the CCS4CEE project, no potential of CO_2 storage in Hungarian coal fields was identified.

Hungarian stakeholders engaged in the CCS4CEE project highlighted potential competition between the uses of reservoirs for CO_2 storage, hydrocarbon production, natural gas storage and geothermal energy. The characteristics of the reservoirs to be exploited for these purposes are similar, and business and strategic considerations will determine which use will be prioritised. In light of this, an appropriate national CCS strategy should be developed.

POLAND

Poland has the third-largest CO_2 storage potential of all partner countries, estimated at between 10.1 and 15.5 Gt theoretical capacity (with the more conservative figure excluding aquifers with questionable safety status or without defined structures). With the bulk of its storage options in deep saline aquifers (Poland covers a large part of the biggest Permian-Mezozoic basin in Europe) and minor contributions from depleted hydrocarbon fields, Poland is also the only partner country with CO_2 storage potential in unmined coal seams. However, these coal seam storage sites are generally poorly identified and have low potential, as well as potential conflicts of interest regarding their use.

The EU GeoCapacity and CASTOR projects (2004-2008) identified a total storage potential of 77.9 Gt in Poland's saline aquifers (1.7 - 3.5 Gt effective potential in 18 anticlinal structures), as well as 764 Mt in hydrocarbon fields and 415 Mt in coal fields. At the time of the studies, these 18 aquifer structures alone could have stored Poland's 2004 emissions for 11 years; since then, Poland's emissions have dropped by 21%.[144]

Between 2008 and 2012, a national assessment programme of CO_2 storage commissioned by Poland's Ministry of Environment estimated static storage capacities in eight regions, selected on the basis of storage potential as well as proximity to large emitters (a narrower and more practical definition of storage potential).[145] These regions include aquifer structures close to Bełchatów and Warsaw, structures in the Upper Silesian coal basin (one aquifer and coal seams) and depleted and uneconomical hydrocarbon deposits, mainly in western and SE Poland. The assessment found 14.5 Gt CO_2 storage potential in deep saline aquifers (with the highest share, 3.5 Gt, in Kujawy in north-western Poland), including the offshore Łeba-Baltic structure off the coast of north-eastern Poland. Although they offer the greatest potential, saline aquifers in Poland may be subject to conflicts of interest with geothermal energy.

The same assessment found storage potential in depleted hydrocarbon deposits, amounting to 845 Mt. Of depleted hydrocarbon deposits (located in the south-east and west of Poland), four gas fields were found to have storage capacities larger than 50 Mt; an offshore oil and gas field in the Baltic Sea was found to have a storage capacity of 7 Mt. Other offshore assessments by oil company Lotos Petrobaltic found storage and eventual EOR potential for two oil fields and storage potential for two gas fields in the Baltic Sea.

Finally, estimates of storage potential in unmined coal deposits in Poland's Upper Silesian Coal Basin found 100 Mt theoretical static CO_2 storage capacity. The selection of sites for assessment was done based on the potential for Enhanced Coal Bed Methane Recovery (ECBMR); suitable sites seem to only be present in the Upper Silesian Coal Basin. Overall, the total storage capacity found by Poland's national CO_2 storage assessment programme placed the country at approx. 15.5 Gt.

ROMANIA

Romania has the second-largest CO_2 storage potential of all partner countries, the bulk of which is found in deep saline aquifers, with depleted hydrocarbon reservoirs (primarily onshore) contributing a smaller share. The most detailed estimate of Romania's storage capacity found a total theoretical capacity of 22.6 Gt, 18.6 Gt in deep saline aquifers and 4.0 Gt in depleted hydrocarbon fields (mainly

[144] World Bank, 2021. CO2 emissions (kt) - Romania, Croatia, Slovak Republic, Ukraine, Slovenia, Czech Republic, Estonia, Lithuania, Latvia, Hungary, Poland.
[145] CGS Europe, 2013. State of play on CO2 geological storage in 28 European countries.

depleted gas reservoirs, with 3.41 Gt total storage capacity).[146] By far the largest storage potential is in the Transylvanian Depression in north-western Romania (8.8 Gt in aquifers and 2.27 Gt in depleted gas fields), followed by the Moesian Platform and Southern Carpathian Foredeep in south-western Romania (5.2 Gt in aquifers and 0.82 Gt in depleted oil and gas fields) (Figure 12).

Romania's onshore geological storage options are generally bound to the sedimentary basins covering the major geological platforms. The Moesian Platform in southern Romania contains a prolific accumulation subzone, with numerous hydrocarbon deposits in geological formations situated along alignments parallel with the southern Carpathian Mountain chain. A feasibility study for the Getica CCS Demonstration Project (see Section 4) found a storage capacity of approx. 100 Mt each in two suitable sites identified in the Getica Depression, the sedimentary foreland basin between the South Carpathian Foredeep and the Moesian Platform.[147] This area of potential storage is well-placed in proximity to the Oltenia Energy Complex, which houses some of Romania's most significant emissions sources (lignite-fired power plant units). Another potential storage area of hydrocarbon fields for CO_2 storage was identified by the Strategy CCUS project in the Galați region (where Liberty Steel, Romania's largest emissions source, is located); in particular, the Bobocu depleted hydrocarbon field, located just 85 km from the city of Galați in an area with very low population density.

Offshore saline aquifers do not present any significant CO_2 storage capacity, due to their low capacity and low level of knowledge associated with them. In a 2020 study, three deep saline aquifer structures were identified offshore, with a combined storage capacity of 17 Mt. Offshore hydrocarbon fields in the western Black Sea, however, present good opportunities for CO_2 storage and EOR. Five oilfields located on a NW-SE alignment have been discovered so far.

With its 150-year oil and gas exploration history, Romania also has a history of experimental CO_2 injection in oil fields, and short-term CO2 injection has been applied to a number of wells, mostly with positive results. The best results were obtained by underground combustion (thermal EOR), which has been applied in 26 Romanian oil fields. However, the most efficient method of enhanced recovery suitable for Romanian oil fields is CO_2-EOR. A 2017 study identified 130 potential EOR sites, of which ten oil field regions, consisting of 19 individual fields, were coupled with 15 nearby emission sources including three power stations in Bucharest and 4 units of the Oltenia Energy Complex in south-western Romania. Another project, the ECO-BASE project, proposed a business case for the Brâdești oilfield in the western Oltenia region. Strategy CCUS also identified 15 depleted hydrocarbon fields in the southern Carpathian basin and North Dobrogea Promontory (south-eastern Romania), with a total storage capacity of 0.2 Gt – including the Roșioru field, located in the same region as Bobocu. The difficulties of applying CO_2-EOR in Romanian oil fields include a lack of practical fieldwork and management of injection in the past 20 years, as well as a lack of adequate infrastructure in many commercial oil fields.

Non-mineable coal seams are not suitable for CO_2 storage in Romania.[148]

[146] EU GeoCapacity: Assessing European Capacity for Geological Storage of Carbon Dioxide. D16, WP2 Report (storage capacity).
[147] Anastasiu, N., 2019. Major tectonic units within the Carpathian-Danubian area.
[148] EU GeoCapacity: Assessing European Capacity for Geological Storage of Carbon Dioxide. D16, WP2 Report (storage capacity).

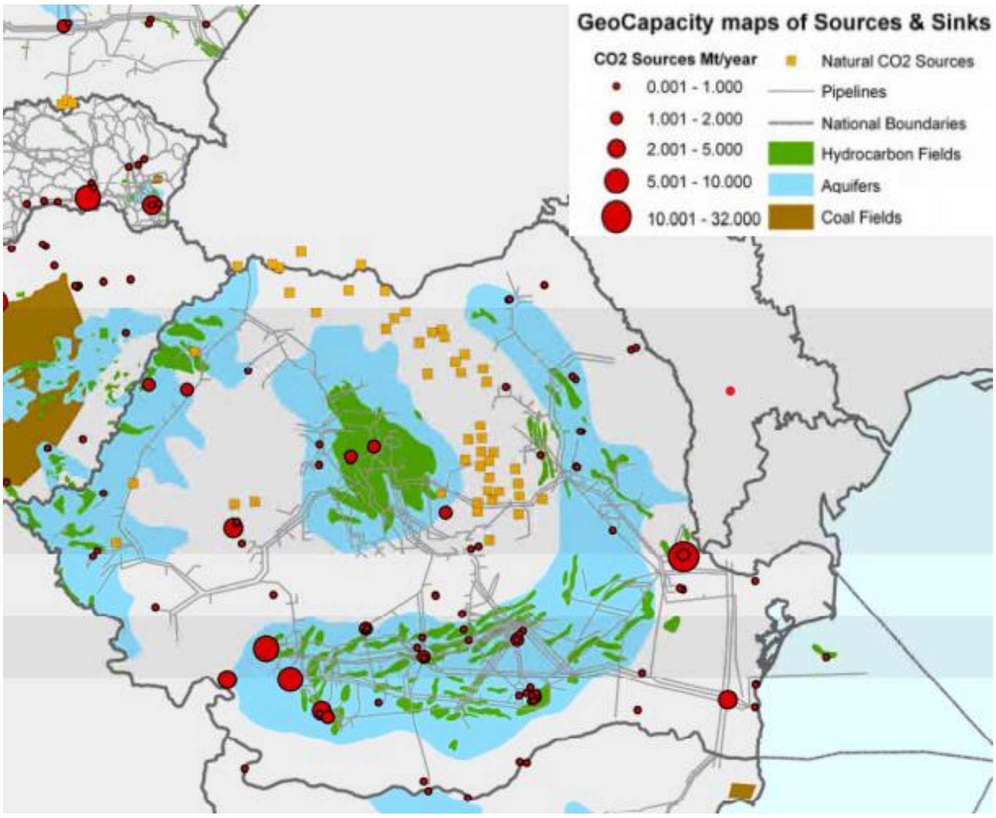

Figure 12. Map of potential CO2 storage sinks and sources in Romania. Note that emissions data used to define the sources is from 2006 or earlier. Source: EU GeoCapacity, 2006.[149]

Research on CO_2 transportation potential in Romania is relatively scarce. However, the transport part of the CCS chain has been fully analysed only for the Oltenia region, in the context of the feasibility study for the Getica project. In this study, a 40 km onshore pipeline was designed from the Turceni power plant (CO_2 source) to two proposed storage sites, with two corresponding CO_2 transport pipeline routes.[150] Both potential pipeline routes would traverse areas with a population density of 50-250 persons/km^2 and would require underground installation as well as a minimum clearance of 500 m from the existing villages and buildings. Possible surface subsidence risks generated by coal mining activities in the area also make it vital to avoid mining areas when selecting the pipeline route, regardless of whether the mines are operational or decommissioned. Other challenges for CO_2 transport construction may relate to the poor public evidence of ownership – Romania is still in the process of conducting cadastral surveys at the national level, which may introduce complications in the centralization of land ownership information in view of developing multimodal transport masterplans.[151] Indeed, multi-modal transportation of CO_2 could offer a significant opportunity in Romania, given the ample presence of the Danube River and the existence of both riverine and marine ports (on the western Black Sea, close to potential sites for CO_2-EOR or EGR).

[149] EU GeoCapacity: Assessing European Capacity for Geological Storage of Carbon Dioxide. D16, WP2 Report (storage capacity).
[150] GCCSI, 2013. GETICA CCS Demo Project Romania: feasibility study overview report to the Global CCS Institute.
[151] GCCSI, 2011. Permitting Report to the Global CCS Institute, Getica CCS Demo Project Romania.

Slovakia

Estimates of Slovakia's CO_2 storage potential total between 1.71 Gt (conservative approach, 100% in aquifers) and 13.8 Gt (theoretical estimate, including 134 Mt storage in hydrocarbon fields). Saline aquifers are located mainly in the Danube Basin in south-eastern Slovakia, and they represent the largest possible CO_2 storage capacity in the country. The largest aquifer is in south-western Slovakia, spanning part of the border with Hungary and relatively close to the Duslo fertilizer plant and Slovnaft refinery (both large emitters in Slovakia in 2020). Another, smaller aquifer is in south-eastern Slovakia, near the Košice steel plant and its power plant subsidiary, Ferroenergy.

An interesting and challenging feature of Slovakia when it comes to CO_2 storage is the prevalence of protected water and landscape areas (14.15% and 23.3% of the country's surface, respectively). These areas tend to overlay promising aquifer structures, with the potential to store Slovakia's CO_2 emissions over 50 years.[152] For example, the so-called "Žitný ostrov", a river island in south-western Slovakia, lies on top of the biggest aquifer structures in the country, while at the same time being the biggest protected water zone in Slovakia.

Hydrocarbon fields are located mainly in the Vienna Basin (where the borders of Austria, the Czech Republic and Slovakia meet), and could be an option for EOR as outlined in the ENOS project (see Section 4). Another prospective location is the Transcarpathian Basin in south-eastern Slovakia on the border with Ukraine, where one of the largest natural gas storage hubs (Veľké Kapušany) is located. However, these prospective locations are prohibited from exploration by the Ministry of Environment, as they are either protected or other uses take precedence (e.g. exploration, extraction and storage of hydrocarbons, geothermal use, storage of radioactive waste, and others).

Although Slovakia has several small coal fields in its central, southern and eastern areas, no storage capacity is found in unmined coal seams.

When it comes to CO_2 transportation, Slovakia has a good existing pipeline network, which transfers gas from Russia to Central Europe. Natural gas storage hubs are present both in eastern and western Slovakia (close to Bratislava and the Austrian border). A transit gas pipeline between Veľké Kapušany and Strachocina in Poland is currently being built, as part of a larger North-South Gas Corridor, and should be finished at the end of 2021.[153] Slovakia also has a dense transport network of railways; however this transport option could be up to four times more expensive than pipeline transport.[154]

Slovenia

Slovenia has a complex geological structure, both from a structural and tectonic point of view. Research into potential for underground CO_2 storage in Slovenia started in the early 2000s and has to date yielded results which show that although Slovenia is a small country, it does have some storage potential within its territory.

First estimates from the 2006 CASTOR study identified 35 potential storage sites in aquifers, based, however, on established assumptions. CO_2 storage capacities were estimated at 147 Mt CO_2 for aquifers, and 2.2 Mt CO_2 for hydrocarbon fields. The EU GeoCapacity project found 92 Mt of CO_2 storage capacity in deep saline aquifers[155] and 2 Mt in depleted oil and gas fields. Theoretical capacities were also calculated to be up to 200 Mt.[156] The most significant aquifers are on Slovenia's coast (relatively close to Salonit Anhovo,

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[152] CCS4CEE country report: Slovakia. Available on the CCS4CEE project website.
[153] European Commission, 2020. Dobré fondy EÚ: Plynovodné prepojenie Poľsko – Slovensko, Veľké Kapušany (in Slovak).
[154] CCS4CEE country report: Slovakia. Available on the CCS4CEE project website.
[155] The Milan Vidmar Institute (2010) study on CO2 capture readiness of Unit 6 in Thermal powerplant Sostanj noted that optimistic storage capacities in Slovenia exceed 500 Mt CO_2.
[156] CCS4CEE country report: Slovenia. Available on the CCS4CEE project website.

a large cement producer), in central Slovenia (relatively close to the Šoštanj power plant, Energetika Ljubljana and the IGM Zagorja lime factory) and on the southern Slovenian border with Croatia (relatively close to the Vipap Videm Krško paper producer).[157]

It should be noted that the 92 Mt CO_2 capacity estimates were based on few reliable data for each aquifer, and were done primarily on a theoretical level for three of the individual aquifer structures (Pečarovci, Dankovci and Besnica) with a total storage capacity of 63 Mt. More reliable data is available for assessment of hydrocarbon fields, with the two most notable ones being the Dolina and Petišovci oil and gas fields in north-eastern Slovenia (on the Croatian and Hungarian borders), with a total capacity of 1.8 - 5.3 Mt and relatively close to the Talum aluminum production plant (118 kt CO_2 emitted in 2020).

While the project did not find options for storage within unmineable coal seams, a study by the Milan Vidmar Institute (2010) suggested that coal seams storage potential should not be discounted and recommended assessment, in particular for the Velenje coalmine (adjacent to the Šoštanj thermal power plant). The coalmine was also part of the 2008 MOVECBM[158] which found that Slovenia's capacity for CO_2 storage in unmineable coal seams appears limited because of low permeability and swelling.[159]

To this end, it is important to note that further practical research is required to confirm effective storage capacity. There has been no research on CO_2 storage capacities in Slovenia since 2010 and no current plans to do so. However, if effective capacity estimates prove accurate, the identified sites could store Slovenia's stationary emissions for more than 20 years.[160]

When it comes to CO_2 transportation, Slovenia's pipeline infrastructure may be relatively favourable.[161] Their potential use or re-use of gas pipelines, however, has not yet been assessed for CO_2 transport purposes. Given the current legislative barriers (see Section 5.1), and as suggested by stakeholders engaged in the CCS4CEE project, it is likely that additional CO_2 pipeline infrastructure would be needed to connect Slovenia's largest stationary emitters to storage sites in neighboring countries (Croatia – 3.36 Gt, Hungary – 847 Mt, and Italy - 6.5 – 13 Gt CO_2 storage capacity). Italy could prove to be a destination point for captured CO_2, as some of its storage capacities are situated near the Slovenian border. Nevertheless, stakeholders participating in the CCS4CEE stakeholder workshop highlighted that it is unlikely for onshore storage to occur in neighboring countries and suggested that Italy and/or Croatia could be destination countries for Slovenia's captured CO_2 if off-shore storage sites are developed and/or terminals for further transport are constructed.

UKRAINE

The Donbass region in north-eastern Ukraine (bordering Russia) may have by far the largest potential in Europe for CO_2 storage.[162] Two reports have identified this storage potential and find a wide range of estimates, from 45.7 to 428 Gt.[163] No detailed capacity estimations were calculated, however Nedopekin et. al. (2019) identified eight suitable structures in the Donbass region, which have low population density and do not contain operating coal mines or areas of tectonic disturbance. These structures are of a variety of types, including salt- and coal-bearing sediments and saline aquifers. These potential storage sites are also close to major emissions sources in Eastern Ukraine, including several coal-fired power plants and metallurgy factories with significant emissions (see Section

[157] 2020 emissions of the listed sources are: Šoštanj power station 3.7 Mt CO_2-eq/year, Salonit Anhovo 700 kt, Energetika Ljubljana 475 kt and IGM Zagorje 59 kt.
[158] Monitoring and certification on CO_2 storage and ECBM in Poland.
[159] W.F.C van Wageningen et al., 2009. Report and modeling of the MOVECBM field tests in Poland and Slovenia. Energy Procedia 1 (2009), 2071-2078.
[160] Geoinzeniring (2016), Tehnologija zajema in skladiščenja CO2 (CCS), 7. Možnosti za CCS v Sloveniji. Predstavitev v okviru predmeta Okoljska geologija, Univerza v Ljubljani, 13. december 2016 (in Slovenian).
[161] CCS4CEE country report: Slovenia. Available on the CCS4CEE project website.
[162] Nedopekin, F., Shestavin, N., Yurchenko, V., 2019. Environmental safety in the implementation of carbon dioxide geological storage technologies in the Donbass. E3S Web of Conferences 126, 00074 (2019)
[163] UNECE, 2021. Geologic CO_2 storage in Eastern Europe, Caucasus and Central Asia: An initial analysis of potential and policy.

2.3.2). The Donbass region is also rich with oil and gas fields, some still under exploitation, while others are conserved or abandoned – thus indicating potential for EOR or EGR.[164]

Aside from the Donbass region, the State Service of Geology and Subsoil of Ukraine estimates that the most suitable geological formations for CO_2 storage are depleted oil and gas reservoirs in western (the Carpathian Foreland, bordering Poland) and southern Ukraine (bordering the Black Sea and the Sea of Azov, where offshore oil and gas fields are present) (Figure 13). The best locations for burial may be depleted gas fields in Hlinsko-Rozbyshevskoe (or Hlinkso-Rozbyshivsk, central-eastern Ukraine), Novogrigorivske oil and gas condensate field (or Novo Hrihorsky, eastern Ukraine), Sagaydatskoe (or Sagaidatsky, north-eastern Ukraine) and Malosoro-chynske (Poltava region, eastern Ukraine).[165] Ukraine's significant and potentially growing gas extraction industry may serve to pin-point depleted gas fields as a good option for CO_2 storage.

In addition, CO_2-EOR in depleted oil fields (for example, the Myhyryn field in eastern Ukraine) may have potential in Ukraine. The UCube database, compiled by Rystad Energy, estimated approx. 450 Mt storage potential through advanced EOR in Ukraine (onshore storage only). When coupling this figure with the supply of CO_2 from currently available sources, Ukraine's CO_2 storage capacity via EOR is 364 Mt.[166]

Several coal-bearing regions in the Donbass region could also be suitable for CO_2 storage, as they are currently not under exploitation; however, their potential is yet to be estimated.[167]

According to a study by the Donetsk National University,[168] the Donbass region may also show potential for CO_2 immobilization via carbonation in naturally occurring minerals, such as bischofite. The Dnieper-Donetsk region in eastern Ukraine has significant deposits of bischofite, and as such could offer a promising direction for CO_2 storage via mineral carbonation.

When it comes to possible transportation, Ukraine benefits from an extensive network of gas transmission lines, carrying natural gas from Russia to Europe. A 2017 report from the Bellona Foundation also found that Ukraine may be well-positioned to supply key components for CO_2 transport infrastructure. Many large metal producers are already producing the type of piping which would be required for CCS infrastructure, as well as auxiliary equipment such as valves and compressors.[169]

Ukraine's marine transportation is also strongly developed, with 18 seaports and 11 river ports which ship over 170 million tons of products annually. Its fluvial transport being twice as cheap as rail transport and four times cheaper than road transport, but has declined from 60 to 18 million tons annually, primarily due to the regulation of government-owned river ports which deterred infra-structure investments (although the situation has improved recently).[170]

[164] Nedopekin, F., Shestavin, N., Yurchenko, V., 2019. Environmental safety in the implementation of carbon dioxide geological storage technologies in the Donbass. E3S Web of Conferences 126, 00074 (2019).
[165] CCS4CEE country report: Ukraine. Available on the CCS4CEE project website.
[166] United Nations Economic Commission for Europe, 2021. Geologic CO2 storage in Eastern Europe, Caucasus and Central Asia: an initial analysis of potential and policy.
[167] Donetsk National University, 2013. Guidelines for the Implementation of CCT and CCS technologies in the Eastern Regions of Ukraine.
[168] Donetsk National University, 2013. Guidelines for the Implementation of CCT and CCS technologies in the Eastern Regions of Ukraine.
[169] Bellona Foundation, 2017. The Opportunities for Ukraine in a Low-Carbon Future.
[170] CCS4CEE country report: Ukraine. Available on the CCS4CEE project website.

Figure 13. Oil and gas fields in Ukraine. Source: CCS4CEE country report: Ukraine.

3.3. CO_2 UTILIZATION POTENTIAL IN PARTNER COUNTRIES

When it comes to CO_2 utilization potential, the first mention should be for CO_2-EOR and CO_2- EGR. Although there is still controversy around considering EOR as CO_2 utilization or storage, several partner countries have already made significant strides in CO_2-EOR, indicating potential fertile ground for further applying CO_2 injection in depleted oil and gas fields. Romania and Hungary, with their significant history of oil and gas extraction, have already conducted a number of EOR projects, as has Croatia. Ukraine's oil and gas extraction industry may also prove promising for the applicability of CO_2-EOR and EGR.

Using CO_2 as a feedstock for the chemicals industry may also show promise in partner countries. In countries with significant chemical production industries, such as Lithuania and Hungary, CO_2 utilization may be appealing. Indeed, chemical producers in Romania, including large emitter and fertilizer producer Azomureș, have already been using CO_2 as a feedstock for a number of years. The production of chemicals using captured CO_2 can also contribute to the formation of clusters around major chemicals producers (for example, ChimComplex in the Oltenia industrial region of Romania, where the Oltenia Energy Complex is also located).

One final mention should be made for the use of CO_2 as a working fluid in enhanced geothermal systems. Countries with interest and potential in geothermal energy may benefit from the use of CO_2 – such as Croatia and Slovakia. However, it should be noted that in some countries geothermal energy can compete with CO_2 storage for the use of subterranean space. In Slovakia, the use of the subsurface for geothermal energy production is prioritized over the use for CO_2 storage.

3.4. Summary

There is variation between partner countries in terms of geological storage potential (Figure 14). The observed storage potentials mostly align with the storage sub-indicator of the CCS Readiness Index, an index developed by the Global CCS Institute to score different countries in terms of their potential for CCS deployment. The results on storage potential of the CCS4CEE project, shown in Figure 14, are mirrored by the findings of the CCS Readiness Index storage sub-indicator, with a few exceptions: relative to other partner countries, Hungary and Poland score higher, and Romania and Slovakia lower in the storage sub-indicator, compared to the findings of the CCS4CEE project. This is because the storage sub-indicator is comprised not only of the geological storage potential, but also of the maturity of storage assessments and progress of deployment of CO_2 injection.[171] It is therefore likely that the history of CCS projects in Poland and of CO_2-EOR in Hungary, coupled with the lack of detailed geological assessments in Romania and barriers to exploration in Slovakia (see Section 5.3), is the root cause of this discrepancy.

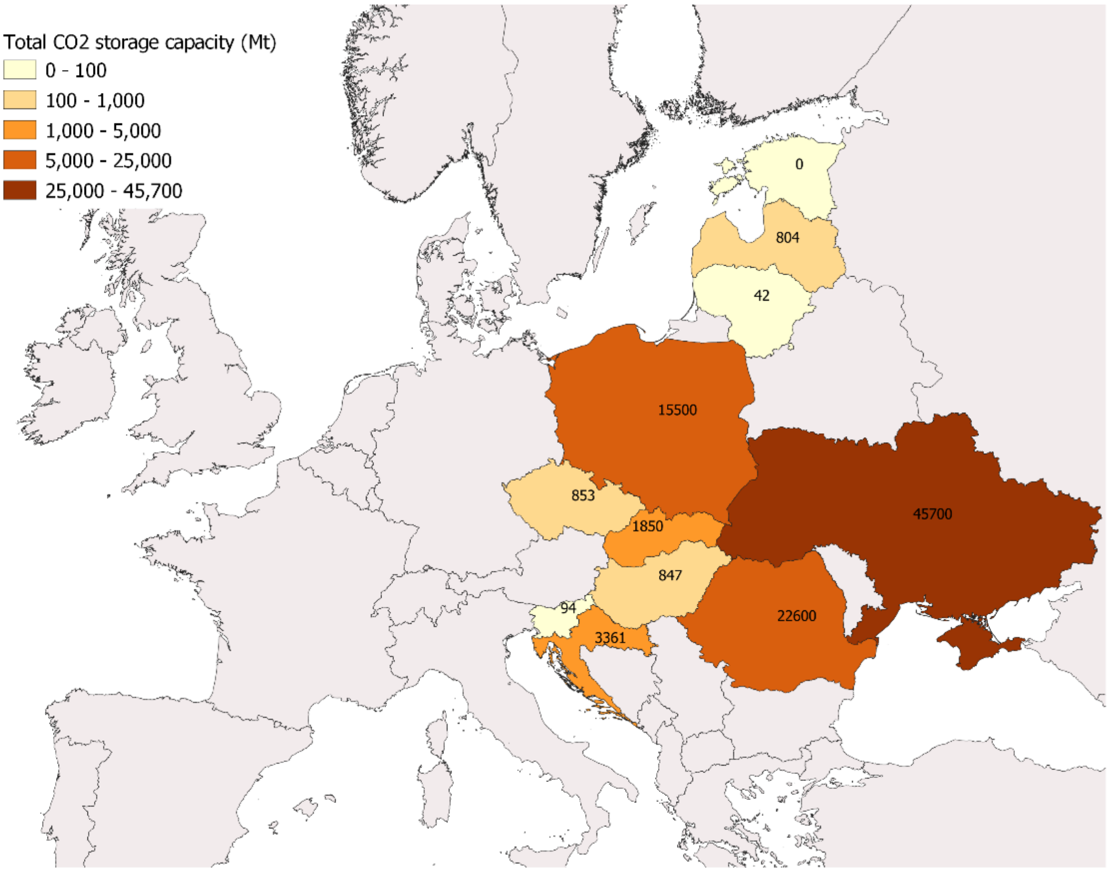

Figure 14. Geological CO_2 storage potential (Mt) in partner countries. Source: CCS4CEE country reports and Nedopekin et al, 2019 (for Ukraine).

Returning to the findings of the CCS4CEE project, the Donbass region in eastern Ukraine provides a vast sedimentary basin for potential CO_2 storage. Estimates of storage potential are as high as 450 Gt CO_2, including potential for mineral carbonation and storage in coal seams. Less dense and less-studied, the hydrocarbon fields in western Ukraine and in the northern Black Sea may also offer potential for CO_2-EOR and EGR. Romania and Poland also show significant storage potential, with the bulk residing in saline aquifers, and less so in depleted hydrocarbon fields. This ratio of aquifer storage potential to hydrocarbon field potential is common across

[171] GCCSI, 2020. CCS Readiness Index – Storage.

partner countries; however, given the history of oil exploration in most, hydrocarbon fields have been better characterised in terms of their geology, thus having richer data on their CO_2 storage potential. Much lower storage potential is seen in the Baltic States, with Estonia's being fundamentally negligible due to its geological conditions. In general, coal seams offer very low potential for CO_2 storage in partner countries.

In some cases, the storage sites of partner countries are situated in challenging locations for onshore storage within their territories. In particular, emitters located in coastal areas may require offshore storage, for example the Plomin power plant in Croatia. On the other hand, some large combustion plants are located close to hydrocarbon deposits potentially suitable for CO_2 storage – for example, in Romania, where during the communist regime large industrial energy consumers were constructed close to fossil fuel extraction sites, such as the Oltenia industrial region in south-western Romania.

Many geological features of partner countries are superimposed onto formations which span huge areas and traverse borders. Transborder storage projects are a thus possibility for some clusters of partner countries. Some of these projects has already been explored – the ENOS project studied the potential of a storage site situated in the Vienna Basin, at the intersection of the Czech, Austrian and Slovak borders (see Section 4). The coal fields in Poland's Upper Silesian Basin at the Poland-Czech Republic border may also show potential for storing CO_2 emissions from industrial plants in the Moravskoslezský region of the Czech Republic, such as Třinec Iron and Steel Works (which produces approx. half of all steel in the Czech Republic).[172] Initial studies have been conducted as part of the CO_2-EuroPipe project, on a potential transborder pipeline connecting Czech industrial emitters with the Lutomiersk, Budziszewice and Kutno saline aquifers in central Poland.[173]

Further opportune areas in transborder storage projects could occur in northern Croatia/northern Slovenia/south-western Hungary (saline aquifer and hydrocarbon deposits), eastern Hungary/western Romania (saline aquifer and hydrocarbon deposits), northern Slovakia and southern Poland (depleted hydrocarbon fields and coal seams), and the Baltic Sea (depleted hydrocarbon fields in Poland's territory and saline aquifers off the coasts of Poland and the Baltic States). Other transborder projects may emerge from planned regional gas infrastructure projects – for example, Slovenia's Plinovodi is planning to work with Hungary's gas transmission operator Foldgazszallito Zrt (FGSZ) to construct a new gas interconnector to link Hungary and Slovenia, with funding from the Connecting Europe Facility.[174] With partner countries all well-linked on gas transmission networks, pipeline CO_2 transportation across borders may be feasible. However, it is likely that this would only occur for specific transborder clusters in the near- or medium-term future.

CO_2 utilization potential will also vary between countries but has been explored relatively extensively through CO_2-EOR projects and the chemical industries of some partner countries. Given the contribution of both the oil extraction and chemical industries to certain partner countries (for example, Croatia, Ukraine and Romania for oil extraction, and Lithuania and Hungary for chemicals), CO_2 utilization may be promising – and indeed, was identified by many stakeholders in partner countries as being more favourable than CCS (Section 6). However, the overall contribution to emissions reduction of CCU is still being assessed and depends on the life-cycle carbon footprint of the process, including its output products. Further study is likely required to quantify the life-cycle footprint of CCU and opportunities for regional clusters based on CO_2 utilization, with or without adjacent CO_2 storage.[175]

[172] Ocelářská unie, 2020. Výroba Oceli V Česku Loni Klesla O 8%, Výhled Pro Eu Je Letos Ještě Horší (report on steel production in the Czech Republic
[173] CO2-Europipe, 2011. Towards a transport infrastructure for large-scale CCS in Europe. CEZ CO_2 transport test case.
[174] International Trade Administration, 2020. Slovenia: Commercial Country Guide – Energy.
[175] Further information is available in the "Current state of CCS technologies and the EU policy framework" report, written by the Bellona Foundation as part of the CCS4CEE project (available on the CCS4CEE website).

4. History of CCS in the CEE region

4.1. Overview

This section will discuss previous CCS projects in partner countries, as well as their participation in CCS research, with a special focus on international research projects and consortia. It will also briefly highlight any major carbon utilization projects.

In 2013, the CGS Europe project mapped CCS research activities in 28 European Countries.[176] It calculated an indicator of CO_2 storage research, based on the number of minor and major research institutions in each country (weighted at 0.25 and 1, respectively). Of partner countries, only Poland and Slovenia scored above 2, with the remaining countries scoring between 0.2 and 1 (Slovakia, Croatia, and the Baltic States) or between 1.2 and 1.8 (Romania, Hungary and Czech Republic). Ukraine is not included in the study.

In general, partner countries' research activity is lower than that observed in CCS research "hotspots" in Northern and Western Europe (particularly Norway) (Figure 15). However, Germany and Italy both also received scores of 7-8 in the CGS Europe study, and as they border the Czech Republic and Slovenia, respectively, potential transborder cooperation and knowledge exchange activities may emerge on CO_2 storage. The CGS Europe report states that most partner countries are engaged in storage capacity assessment research, however less so in the development of new methods or technologies. As outlined below, we find that several partner countries have since 2013 conducted relatively significant research in capture technologies as well as geological storage assessment.

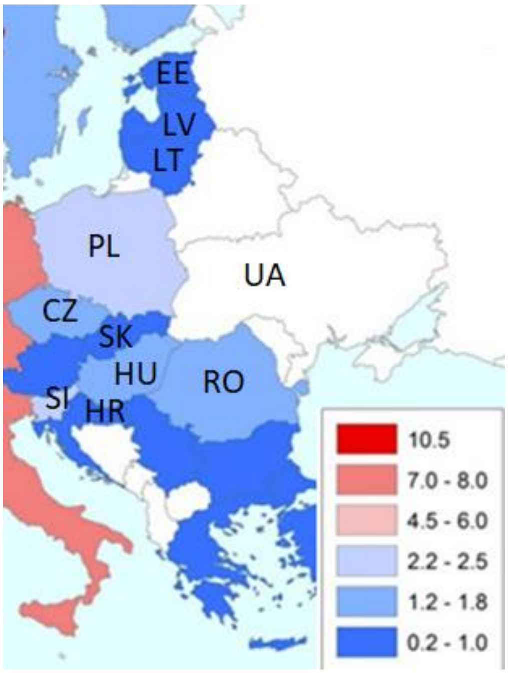

Figure 15. Research hotspots in partner countries, based on CGS Europe, 2013.[177] Colour-coding reflects the weighted number of major and minor research institutions performing research related to CO_2 storage in each country (as of July 31st 2012).

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[176] CGS Europe, 2013. State of play on CO2 geological storage in 28 European countries.
[177] CGS Europe, 2013. State of play on CO2 geological storage in 28 European countries.

4.2. CCU AND CCS ACTIVITY IN PARTNER COUNTRIES

CROATIA

Croatia has several CCS/CCU current or planned projects, financed by industry or structural funds. Two privately funded projects are ongoing. Firstly, the CO_2-EOR project in the at Ivanić and Žutica oil fields - operated by INA, a leading oil company, and operational since 2014, it injects 0.56 Mt CO_2/year captured from the Molve natural gas processing plant (also operated by INA) and piped for 88 km to the oil fields.

Secondly, the geothermal power plant with CO_2 reinjection at Velika Ciglena - operated by MB Holding and operational since 2018, it captures approx. 0.15 Mt CO_2/year, but no details are publicly available on the transportation and storage processes or locations. Another geothermal power plant project at Draškovec is planned and officially outlined in Croatia's list of strategic investment projects (OG 72/2019). It is projected to capture and inject approx. 0.05 Mt CO_2/year. The project is currently at conceptual stage.

A biorefinery plant planned at Sisak, 60 km from Zagreb, is projected to capture approx. 0.06 – 0.46 Mt CO_2/year, with operations expected to start in 2024. Operationalization of the biorefinery is planned as part of the closure of the existing Sisak oil refinery, as part of the transition of INA, its operator, away from fossil fuels.

Finally, the iCORD project (industrial capture followed by CO_2-EOR) is planned to start by 2025, capturing approx. 1 Mt/year from several locations (fertilizer plant, natural gas processing station and/or fractioning facility) in central Croatia. The captured CO_2 would be injected into oil fields in the Croatian territory of the Pannonia Basin. The project operator is INA, and the feasibility study should have been prepared by the end of 2020.

Croatia is also taking part in international research and development projects on CCUS, such as Strategy-CCUS, which is conducting economic evaluations for CCS deployment in southern and eastern European countries.

CZECH REPUBLIC

A broad range of geological surveys, laboratory experiments and research have been conducted in the last 15 years in the Czech Republic. The research covers a range of aspects of CCS, including capture, storage, and the full CCS chain. No CCS pilot projects have been undertaken so far. Only very recently, however, Českomoravský cement (the Czech subsidiary of HeidelbergCement) disclosed a planned full-chain CCS project in cooperation with the Czech Geological Survey, aiming for CO_2 storage in a depleted hydrocarbon reservoir in Moravia (southeast of the Czech Republic). No CCU projects are mentioned in the CCS4CEE country report.

Of partner countries, the Czech Republic is a leader in participating in international CCS projects.[178] Early such projects include CASTOR (assessing capture technologies and geological storage options), EU GeoCapacity (assessing CO_2 storage capacity in Europe), CO_2-EuroPipe (focusing on CO_2 transportation) and CO_2NET EAST (extending CCS-related networking activities to new EU Member States and candidate countries). The international TOGEOS (Towards geological storage of CO_2 in the Czech Republic) specifically assessed the CO_2 storage potential of saline aquifers in the Czech Republic. In most international projects, the Czech Geological Survey was the institution responsible for the Czech Republic's participation. More recently, a project under the Czech-Norwegian Research Programme focused on capture technologies and CCS chain deployment.[179] Cooperation with Norway also took place under the REPP-CO_2 project (2015-2017), which specifically studied the LBr-1 hydrocarbon field in the Vienna Basin as a potential CO_2 storage site. Its successor, the ENOS project, produced a roadmap for CO_2-EOR development in the Czech Republic, Slovakia and Austria, as a cluster-based assessment for the LBr-1 storage site. Further cooperation took place for dissemination of CCS/CCU knowledge in the Czech Republic, as part of CCS-ShaKE (CCS – Sharing Knowledge and Experience, 2015-2017). ČEZ, a large energy provider in the Czech Republic, has participated in several research projects, including leading the Czech Republic's participation in the CO_2-EuroPipe

[178] Source: "Regional cooperation for CCS/CCU deployment", a report written by WiseEuropa as part of WP3 in the CCS4CEE project.
[179] Pilot Studies and Surveys on CCS Technology.

project. They also carried out an assessment on the Prunéřov 2 power plant (2011) and were planning two CCS demonstration projects (2007), which were since abandoned due to high costs.

Within the Czech Republic, the first study on CCS was commissioned by the Ministry of Environment in 2005. Subsequently, between 2009 and 2012 the Ministry of Industry and Trade conducted its first research project on post-combustion CCS. Since then, two technical projects on CCS pilot technologies have been coordinated by the University of Chemistry and Technology in Prague (2015-2017), as well as technical projects by other stakeholders. Current projects include a research centre for bio-CCS/CCU (2018-2022) within the Czech Technical University in Prague (one of the largest and best-equipped capture centres in the country); the recent CCUS CZ-NO cooperation project, including stakeholder presentations and METAMORPH (2021-2024), another technology collaboration with Norway led by the Czech Geological Survey and a Czech gas company. Finally, CO_2-SPICER (2020-2024) is considered one of the most important steps towards CCS/CCU full-chain deployment in the Czech Republic, preparing a Czech site for a geological storage project through mapping, modelling and risk assessment.

Estonia

Due to its ban on storage (see Section 5), Estonia has no ongoing CCS research. The country did take part in the BASTOR project (2004), which aimed to increase awareness of the potential for geological storage of CO_2 in the Baltic Sea and to identify barriers to CCS implementation. However, the topic of CCU, mainly related to oil shale, has been explored in several research and development (R&D) projects. Experience with CCU is not new to Estonia – Nitrofert (a fertilizer producer) used CCU before discontinuing its production of ammonia.

An Estonian company, R-S OSA Service OÜ, is conducting research on reusing waste oil shale ash, including CO_2 capture from the combustion process and utilization in the production of precipitated calcium carbonate. Another research and development project, funded by the RITA program (an R&D support program) and implemented by Tallinn University of Technology, assessed the applicability of CO_2 capture technologies for use in the Estonian oil shale industry and their potential environmental impact. The study, completed in 2016, found that although suitable CO_2 capture technologies could reduce the footprint of electricity production significantly, they are not feasible under current market conditions. Finally, the Auvere Agropark, a project in the Ida-Viru County, is planned to construct a plant to capture CO_2 emissions from the Auvere power plant and sell or use it in local greenhouses. Preliminary estimates suggest a capture and utilization capacity of 110 kt CO_2/year in the first phase, increasing to 500 kt CO_2 in ulterior development phases of the Agropark.

Researchers at the Tallinn University of Technology have also written several papers on the topics of CCS/CCU.

Hungary

Hungary's NECP highlights that in 2018 it submitted 0.5 patents[180] in GHG emissions capture and disposal, 0.7% of the number of patents in this category submitted across the EU-28 in the same year.[181] Indeed, experts in the CCS4CEE project found that Hungary has been leading CCS development in many respects, particularly CO_2-EOR (which was pioneered in Hungary in the 1960s) and CO_2-EGR (tested and applied from 1986). However, no CCS project has been implemented to date.

Hungary's MOL Group plans to use privately funded CCS technologies for emissions reduction and possibly to implement CO_2 storage starting from 2026. Siemens is also conducting CCU innovation to reuse captured CO_2 as a heat transfer medium in a future geothermal electric power plant. Although not currently conducting a CCU or CCS project, Pétfürdői Nitrogénművek, the only Hungarian nitrogen fertilizer producer with ammonia production capacities today, is interested in using CCU/CCS technologies and is monitoring

[180] The number of patents in a category may be less than 1, given that a specific invention may simultaneously belong to several categories. Source: National Energy and Climate Plan (NECP) of Hungary.
[181] Hungarian Ministry of Innovation and Technology. National Energy and Climate Plan (NECP) of Hungary.

their potential. For the time being, they are waiting for regulation and clarity at European level and for promising technologies and concepts that will pay off.[182]

On research projects, Hungary was covered by the CASTOR, CGS Europe and EU GeoCapacity projects, and Hungarian institutions involved in CCS research are the Budapest University of Technology and Economics and the Geological Survey of Hungary, among others. Some research projects of Hungarian universities have included activities related to CCS, however no Hungarian research organisations have won national or EU funds for specific CCS research activities.[183] The Hungarian Geological Survey reports on CCS potential in Hungary to the European Commission, however their reports are confidential.

Latvia

Latvia has no practically implemented CCS or CCU projects, however various studies have been conducted. Schwenk Latvija, Latvia's largest cement producer, is an industrial partner in the EU project GENESIS, which aims to develop, demonstrate and scale up membrane systems for CO_2 capture. It plans to achieve at least 90% of CO_2 recovery at a cost of €15/MWh in cement and steel industries.[184]

From 2021 to 2023, researchers from the Institute of Energy Systems and Environment of Riga Technical University are implementing the project "Integrated Decarbonisation Solutions for Effective CO_2 Valorisation in Regions (CO_2 Deal)". The overall objective of this project is to develop a guide for decision makers on efficient CO_2 valorisation in Latvian regions.

Several studies and international projects on the geological storage, economic feasibility and CCS system operation have been undertaken in Latvia. Researchers at the Institute of Energy Systems and Environment of Riga Technical University have written several papers on these topics. The Institute of Applied Chemistry of Riga Technical University and Schwenk Group are researching fuel production from CO_2. Latvia also took part in the BASTOR project (2004).

Lithuania

Given regulatory restrictions (see Section 5), many stakeholders are holding back on planning CCS-related projects. Currently, several companies have shown interest or taken part in steps for pre-feasibility study evaluations of CCS/CCU. This allows for inexpensive, small-scale calculations and experiments. However, very recently, a consortium formed of Klaipėdos Nafta, an oil and LNG terminals operator, Larvik Shipping, a Norwegian ship management company, and Mitsui O.S.K. Lines, a Japanese transport company, will carry out a feasibility study for a liquefied CO_2 and hydrogen project in Lithuania's Klaipėda port. The partners have agreed to develop liquefied CO_2 loading facilities at existing terminal infrastructure in Klaipėda, with the aim to develop a liquefied CO_2 logistics and value chain from Lithuania, and potentially the Baltic region. The feasibility study will identify an optimal configuration to export CO_2 to one or more sequestration facilities within Europe, as well as assess the potential of blue hydrogen production.[185,186]

Lithuania also participated in the BASTOR project (2004).

Poland

Poland has a significant number of past and current CCS projects. Two major past CCS demonstration projects have been abandoned: the Bełchatów CCS demonstration plant (PGE, 2009-2013) and the Zero-Emission Power & Chemical Plant in Kędzierzyn-Koźle (Grupa Azoty, a fertilizer producer, and Tauron, an energy company, 2007-2011). The Bełchatów project was the most advanced Polish full-scale CCS project, including a capture plant, pipeline transport and underground injection into a deep saline aquifer. The Kędzierzyn-

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[182] Source: CCS4CEE country report: Hungary. Available on the CCS4CEE project website.
[183] Source: CCS4CEE country report: Hungary. Available on the CCS4CEE project website.
[184] CORDIS, 2018. High performance MOF and IPOSS enhanced membrane systems as next generation CO2 capture technologies | GENESIS Project | Fact Sheet.
[185] "Blue hydrogen" is hydrogen produced from methane using steam methane reforming (SMR) and capturing the CO_2 from the process
[186] Larvik Shipping, 2021. Klaipedos nafta, Larvik Shipping, and Mitsui O.S.K. Lines will carry out a feasibility study for liquefied CO2 and hydrogen project in Klaipeda, Lithuania

Koźle plant would have stored the CO_2 as well as utilized it to produce chemicals. Both projects were abandoned, in the case of Bełchatów due to rejection from EU funding (driven by the lack of a pre-financing guarantee from the Polish government, as well as social and legal risks), low public acceptance for transport and storage and resulting high transportation costs, and in the case of Kędzierzyn-Koźle due to financial difficulties, including unsuccessful applications for EU financing.[187]

Two carbon capture projects have been realized so far in Poland, both developed by energy company Tauron Wytwarzanie at the Łaziska and Łagisza coal-fired power plants (both large emitters in Poland). Both installations are mobile, providing the opportunity to test the capture process at various locations. However, Tauron has not published the results of their tests, and it is not known what was done with the CO_2 captured in the process.

Very recently, HeidelbergCement announced a pilot CO_2 capture unit at their Górażdże cement plant, Poland's largest emitter from the cement production sector. The pilot is part of Project ACCSESS, an EU-funded project (2021-2025) involving 18 industrial and research partners and aiming to connect CO_2 emitters from continental Europe to storage sites in Northern Europe. HeidelbergCement's participation will involve testing the enzyme-based capture unit at Górażdże, assessing the integration of carbon capture in their Hanover plant (Germany), and developing CO_2 transportation systems from the Górażdże and Hanover plants to the Northern Lights storage facility in Norway.[188]

As for carbon storage projects, an industrial installation for capturing and storing CO_2 in a gas field in Borzęcin was started in 1996, with the aim of purifying extracted natural gas and conducting EGR. It is not clear whether the project is still ongoing, and data is not available after 2012. Poland's Oil and Gas Institute and PGNiG (Polish Oil Mining and Gas Extraction) are the project coordinators. Another project, now closed, injected CO_2 into coal seams in Kaniów (Upper Silesia) within the RE-COPOL research project and demonstrated technical feasibility of this type of CO_2 storage.

Poland has also conducted CCU projects. Between 2015 and 2018, Tauron constructed and operated a CO_2 methanation plant, converting captured CO_2 from the Łaziska Power Station to synthetic natural gas (SNG). Between 2017 and 2021, Poland's Institute for Chemical Processing of Coal, alongside chemicals producer CIECH, implemented CO_2 reuse in producing sodium carbonate in CIECH's Inowrocław production plant. This resulted in a reduction of CO_2 emissions by at least 5 kt CO_2/year.[189]

Poland also has four major planned or potential CCS projects. The gas-fired CHP in Przemyśl, currently due to be completed at the end of 2021, is being considered for implementation of a CCS plant. The operator is PGNiG, who also applied the technology in the Borzęcin power plant. The economic feasibility of the project is still being studied.

Poland has also submitted a cross-border CO_2 transport project as a candidate for the fifth EU list of Projects of Common Interest, due to be adopted in October 2021. The project objective is to connect the main industrial CO_2 emitters in Gdańsk (in northern Poland) and the hinterland to geological carbon storage sites in the North Sea basin, via shipping routes. The project would transport 2.7 Mt CO_2/year between 2025 and 2030 and 8.7 Mt/year between 2030 and 2035.

The social agreement between the government of Poland and the mining unions, as part of the phase-out of hard coal mining by 2049, proposes several CCU/CCS projects, including CO_2 capture from coal gasification units and transportation to a storage site.

Finally, it should be noted that a total of five units of coal-fired power plants at Kozienice, Opole (2) and Jaworzno have been identified as CCS-ready. The 858 MT unit of Bełchatów still remains ready for CCS installation.[190]

Aside from its pilot, demonstration and even commercial projects, Poland has also conducted extensive research and development into CCS. Past projects mostly focus on storage, including in coal seams (Central Mining Institute, Silesian University of Technology, University of Gdansk and others), but also on economic and social acceptance assessments (Silesian University of Technology and

[187] CCS4CEE country report: Poland. Available on the CCS4CEE project website.
[188] HeidelbergCement Group, 2021. Project ACCSESS: HeidelbergCement to pilot carbon capture project in Eastern Europe.
[189] CCS4CEE country report: Poland. Available on the CCS4CEE project website.
[190] CCS4CEE country report: Poland. Available on the CCS4CEE project website.

Częstochowa University of Technology). Current projects are exploring biological routes for CO_2 conversion, technologies for CO_2 capture and storage in aquifers, amongst other topics. Poland was and is also part of international CCS projects, such as Strategy-CCUS and BASTOR, and is a leader among partner countries in participating in international CCS projects. One international project, MOVECBM, specifically focused on the potential for CO_2 storage in coal seams in Poland.[191]

Romania

Romania has had a single attempt at a CCS demonstrator project, the Getica CCS Demonstration Project (2011). It was the first integrated CCS project of Romania and was planned to begin operations between 2016 and 2030. Getica originally involved a consortium of state-owned utilities, planning to implement the project in the Oltenia region, with capture on the lignite-fired Turceni power plant (Romania's largest electric power plant at the time). The demonstrator would have captured 1.5 Mt CO_2 from unit 6 of the power plant and transported it for storage in onshore saline aquifers approx. 50 km away, under a total cost of €1 billion. As part of the project, social acceptance studies were also conducted, and a regulatory toolkit was designed for authorities. Furthermore, to create a favourable climate for the project to be deployed, the EU directive on the geological storage of CO_2 (referred to in this report as the EU CCS Directive) was rapidly transposed into Romanian legislation and operationalized (see Section 5). However, the project never materialized, being put on hold due to lack of funding in 2013, primarily traced back to a lack of continued government support. Despite this, it remains Romania's flagship CCS project, having opened the door for establishing Romania's regulatory framework on CCS.

In the years following the Getica proposal, research on CCS in Romania emerged and proliferated. Researchers at the Babeș-Bolyai University in Cluj-Napoca and the Polytechnic Universities of Timișoara and Bucharest are developing and testing capture technologies, and Romania is part of two ongoing CCS research projects (Strategy-CCUS and Rex-CO_2, with the latter focusing on the re-use of existing wells for large-scale CO_2 storage, in particular the depleted gas field at Salonta, in the Oltenia region). Romania has also taken part in past international CCS projects, including EU GeoCapacity, ECO-BASE (focusing on business models for CO_2-EOR in South-Eastern Europe) and Align-CCUS, focusing on optimising capture costs and developing a guideline for emissions control, including in Romania's Oltenia region. The most active institution in CCS projects in Romania is GeoEcoMar, Romania's institute for geology, ecology and marine research. Romania's participation in many past and current CCS projects has focused on the Oltenia region, a highly industrialized region and the site of both the proposed Getica demonstrator and the Oltenia Energy Complex.

As far as planned projects go, Romania's Recovery and Resilience Plan (2021) originally proposed two CCU demonstrator projects, integrated with hydrogen combustion. Further detail is provided in Section 5.2.

Finally, Romania has also been in the focus of several international reports and case studies on CCUS, including the CGS Europe report on CCS in 28 European countries (2013), the Bellona Foundation's CCS roadmap for Romania (2012), and a case study on the implementation of Romania's national transposition of the EU CCS Directive, which drew out several opportunities and challenges for the regulatory environment of CCS in this country.[192]

Slovakia

Slovakia has participated in several international CCS projects, most of which the Czech Republic also took part in (CASTOR, EU GeoCapacity, CO2NET-EAST and ENOS). However, CCS research within Slovakia is less developed than in the Czech Republic. The main institution involved in CO_2 research is the State Geological Institute of Dionýz Štúr. The 2021 Low Carbon Economy Pathways study by GLOBSEC (a Slovakian think tank) stressed that CCS is the only solution for Slovakia, given the dependence of its economy on hard-to-abate industry sectors. The study also advised that Slovakia prepares for future deployment of CCS in the development of hydrogen.[193]

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[191] Source: "Regional cooperation for CCS/CCU deployment", a report written by WiseEuropa as part of WP3 in the CCS4CEE project.
[192] CCS4CEE country report: Romania. Available on the CCS4CEE project website.
[193] GLOBSEC, 2020. Slovakia Low Carbon Economy Pathways: Achieving more by 2030.

Slovenia

Slovenia's CCS projects and research are somewhat disjointed and mostly focus on capture or storage. No projects have advanced past conceptual stages so far, and most of Slovenia's work has involved participation in European CCS project consortia for a relatively large number of projects.

On carbon capture, cement manufacturer and significant emitter Salonit Anhovo plans to have a pilot CO_2 capture project between 2025 and 2030. Currently, the company is considering CCU, but may explore storage in the future. Energetika Maribor, an energy producer, is also considering CCS possibilities at their proposed waste-to-energy plant in Maribor. The goal would be to capture up to 16,000 tonnes CO_2/year. Slovenia's National Institute of Chemistry is involved in international pilot and demonstration carbon capture and utilization projects.

On CO_2 storage, Geoinženiring, a Slovenian provider of various geotechnical and geological research and consulting services, has participated in several European consortia, including CASTOR, EU GeoCapacity, CGS Europe and ENOS. The company remains part of ENERG (the European Network for Research in Geo-Energy) and the CO_2 Geonet network.

Premogovnik Velenje, Slovenia's largest coal mine and Erico (now Eurofins Erico), an environmental research company, were also involved in the MOVECBM project, whose objective was to improve the understanding of CO_2 injected in coal seams. A small-scale injection was performed at the Velenje coal mine to investigate adsorption, desorption and migration processes for local coal conditions.

Ukraine

There are currently no implemented or planned CCS projects in Ukraine. However, a number of industries (ferrous metallurgy, gas production) envision implementing CCS projects in the long run. According to the Association of Gas Companies and the European Business Association, some Ukrainian companies are launching projects to study the profitability and affordability of CCS technologies. And while these studies show significant costs, carbon capture technologies could become cost-effective in the next ten to fifteen years.[194]

Ukraine has sparse geological research on CO_2 storage. Two studies (one in 2013[195] and the other in 2019[196]) have analysed the geological potential and environmental safety of CO_2 storage in Ukraine, respectively. Ukraine was also covered in a recent UNECE assessment on CO_2 storage potential in Eastern European, Caucasus and Central Asian countries.[197]

4.3. Summary

Research and demonstration projects for CCU and CCS are less prevalent in partner countries than in western and northern Europe, and this is the case for most of Eastern Europe (including CEE countries outside of the CCS4CEE project). Only two countries, Poland and Romania, had serious attempts at CCS demonstrator projects, and only Poland has one ongoing pilot CO_2 utilization project at the time of writing this report. Abandonment of demonstrator projects generally occurred because of lack of financing, however as we will see in Section 7, social acceptance also played a role in the failure of some CCS projects. Overall, Poland appears to have had the most practical CCS and CCU projects of all partner countries. As noted above, major cement producer HeidelbergCement has recently committed to the establishment of CO_2 capture plants in the Czech Republic and Poland.

Implementation of CO_2 utilization and CO_2-EOR/-EGR is more common than "classical" CCS projects. Chemical producers have implemented CCU, some for a long time, and CO_2-EOR/-EGR is nothing new to countries like Croatia, Hungary and Romania. Carbon

[194] CCS4CEE country report: Ukraine. Available on the CCS4CEE project website.
[195] Donetsk National University, 2013. Guidelines for the Implementation of CCT and CCS technologies in the Eastern Regions of Ukraine.
[196] Nedopekin, F., Shestavin, N., Yurchenko, V., 2019. Environmental safety in the implementation of carbon dioxide geological storage technologies in the Donbass. E3S Web of Conferences 126, 00074 (2019)
[197] UNECE, 2021. Geologic CO_2 storage in Eastern Europe, Caucasus and Central Asia: An initial analysis of potential and policy.

utilization research, and potentially planned projects, are taking place in Baltic countries, where storage potential is limited or non-existent. However, aside from these projects, no large-scale demonstrator or commercial projects have been undertaken in any partner countries. As we will see in Section 5, in some cases this is due to restrictive national regulatory frameworks.

Despite the low prevalence of implemented projects, partner countries have been active in research on CCS, being regularly involved in international projects consortia on CCS, such as the EU GeoCapacity project. Most research has been on geological storage of CO_2, however experimental research on capture methods is taking place in countries such as Romania, Estonia, and Latvia. Partner countries have also been subject to international assessments of geological potential for CCS. However, in most partner countries more detailed geological research, including practical research, is required to further define and characterise CO_2 storage potential. In some cases, such as the Baltic States, much of the original research took place during the heyday of oil exploration during Soviet times and requires updating. This can be challenging – in Romania, geological research often requires liaising with oil and gas companies and must overcome difficulties in accessing comprehensive and digitized geological data.

Overall, most partner countries do have a history of research into CCS, with identifiable institutions leading this research (mostly geology or chemistry institutes and universities). In some cases, this research history is complemented by the experience of private operators with CO_2-EOR, CO_2-EGR and CCU. It is apparent that eventual CCS projects would be well-grounded in national know-how as well as willingness to cooperate internationally on research and experimentation. However, barriers to regional cooperation between partner countries may be imposed by the differences in experience and know-how between them, as well as the acceptance of the technology by decision-makers, stakeholders and the public.

5. Legislation and policy support

5.1. Overview

Legislative and regulatory frameworks are key for the deployment of CCU and CCS. As novel technologies with significant investment requirements and no well-defined incentives for deployment, it is crucial that national legislations firmly address CCU and CCS in comprehensive frameworks. Furthermore, the nature of CO_2 storage requires robust frameworks for the assessment of geological characteristics as well as monitoring, meaning that the operationalization of storage sites is reliant on clear and well-coordinated procedures. Given the multiple aspects of CCU and CCS (including environmental, climate, economic and social) it is also important that authorities are well-coordinated and that legislations on these different topics create positive, rather than negative synergies. Other key aspects of CCS which must be addressed by regulations are property rights and liability.[198]

At EU level, the most important regulation for CCS is Directive 2009/31/EC, the EU directive on the geological storage of CO_2 (referred to in this report as the EU CCS Directive). It contains provisions to regulate the safe storage of CO_2 in geological formations in the EU, over the lifetime of the storage sites. The Directive also contains provisions on capture and transport of CO_2, however these are more comprehensively addressed by other EU environmental legislation, such as Environmental Impact Assessment (EIA) regulations or the Industrial Emissions Directive (IED).[199] The IED also requires that all new power plants with a rated output of 300 MW or more submit an assessment of CCS readiness before being granted an operating licence. In addition to these directives, the EU ETS should theoretically also encourage investments in CO_2 abatement technologies, as a way of avoiding the costs of EU emissions allowances (EUAs) (which have been steadily rising since mid-2020).[200]

All partner countries in the EU have transposed the EU CCS Directive, aside from Ukraine which does not have an obligation to do so. Some countries have additional regulations for CCS (see Section 5.3.), however in most cases these are centred on the transposition of the EU CCS Directive.

Aside from major legislative acts defining the terms for CCS deployment, other regulations and laws in partner countries may affect the future of CCS projects. These are generally related to energy, mining and environmental legislation, more specifically governing other forms of underground storage (which could apply to CO_2 storage), procedures for exploration and exploitation of the subsoil, and interference with the environment, respectively. Three partner countries (Poland, Slovenia and Ukraine) also have carbon taxes, which although not directly related to CCS may incentivise carbon capture in industries not covered by the EU ETS (or in Ukraine's case, a national ETS) – for example, municipal waste incineration.

Most partner countries have long-term strategies on energy and climate, with goals for achieving net zero emissions. EU countries have submitted their National Energy and Climate Plans (NECPs), integrated energy and climate plans covering the period from 2021 to 2030. The inclusion of CCU and CCS in national long-term strategies, as well as the NECPs and post-Covid Recovery and Resilience Plans, is a good indicator of the future direction of these technologies in partner countries – not just for implementation but also for funding research and innovation in this space.

This chapter will review the application of the EU CCS Directive in the partner countries, and highlight any relevant adjacent legislation, such as petroleum or mining laws. It will draw out legislative gaps and barriers and highlight the relative favourability of each partner country's regulatory and policy environments for CCS. We begin by reviewing the legislative and policy readiness in partner countries (Section 5.2), detail the regulatory frameworks concerning CCS in these countries (Sections 5.3 and 5.4) and review the support offered by national policies to CCS, including the presence of CCS in major national policies and strategies (Section 5.5).

[198] International Energy Agency, 2011. Incentives for CCS and Regulatory Requirements
[199] European Commission. A legal framework for the safe geological storage of carbon dioxide
[200] Intercontinental Exchange, 2021. EUA Futures.

5.2. CCS REGULATORY AND POLICY READINESS

The “CCS Readiness Index” is a measure developed by the Global CCS Institute (GCCSI) to quantify policy, legal, storage and stakeholder interest factors regarding CCS in various countries.[201] The policy and legal factors are pertinent to this chapter of the CCS4CEE report, and in this section we briefly review differences in these index components between countries, before analysing in more detail the legal and regulatory contexts in each partner country. Note that data on the CCS readiness index is not available for Ukraine.

The legal and regulatory indicator of the CCS readiness index defines the suitability of a country’s national legal and regulatory frameworks relevant for the regulation of CCS, including but not limited to environmental assessments and public consultation.[202] For this indicator, the scores assigned to partner countries vary, ranging from 35 out of 100 in Estonia to 69 in Croatia. The Czech Republic, Slovakia, Lithuania and Hungary all score relatively high (54-56 out of 100), while Latvia and Slovenia bring up the rear, and Poland and Romania show middling values (Figure 16). This indicates that although EU partner countries have transposed (and in some cases operationalized) the EU CCS Directive, they have suboptimal CCS-specific legislation and, as shown later in this chapter, some have even banned geological storage of CO_2. In the wider European context, Bulgaria, the Netherlands, Italy, Germany and the United Kingdom all show higher scores on this indicator.[203]

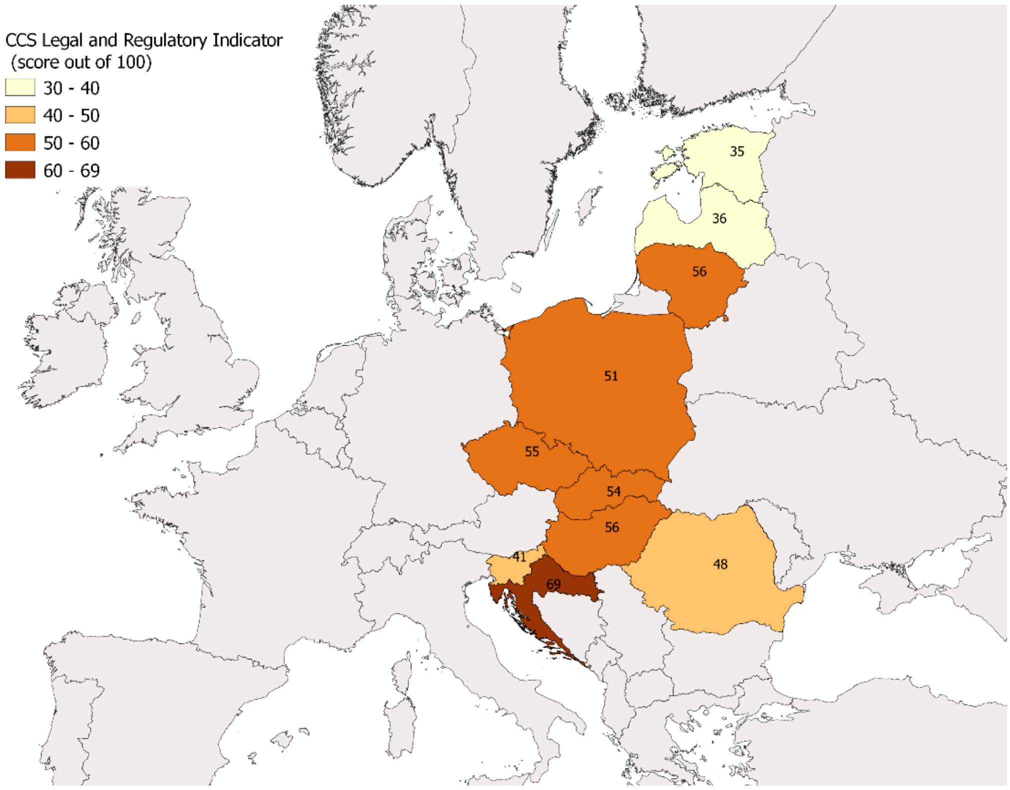

Figure 16. Legal and regulatory sub-indicator of CCS Readiness Index in partner countries. Source: GCCSI, 2021.[204]

[201] Global CCS Institute, 2016. Global CCS Institute CCS readiness Index.
[202] GCCSI, 2016. Carbon Capture And Storage Readiness Index: A global comparative analysis of CCS indicators for the wide-scale deployment of carbon capture and storage projects.
[203] GCCSI, 2016. Carbon Capture And Storage Readiness Index: A global comparative analysis of CCS indicators for the wide-scale deployment of carbon capture and storage projects.
[204] GCCSI, 2021. CCS Readiness Index.

The policy sub-indicator represents a measure of the support offered by policy measures of national and provincial governments to CCS. It includes direct support as well as implicit support, for example through the allocation of research funding.[205] As shown in Figure 17, all partner countries have very low scores on this indicator, with the lowest (7 out of 100) in Romania and Poland, and 9 out of 100 in the remainder of partner countries. For comparison, in the same policy indicator database the Netherlands received a score of 26 out of 100, and Norway a score of 56. This shows that all partner countries lack clear policies on CCS as a climate mitigation technology, with some preferring to explore EOR projects and others restricting the possibilities for industrial-scale CO_2 storage, as we will see later in this chapter.

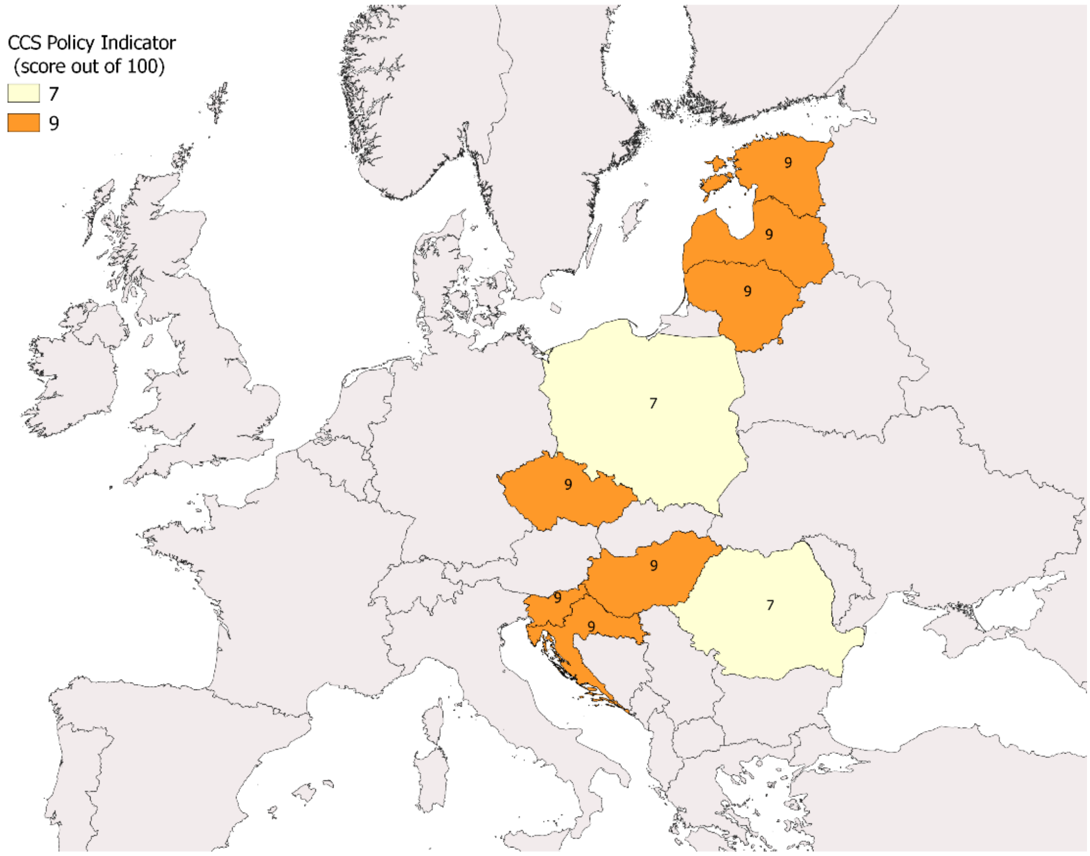

Figure 17. Policy sub-indicators of CCS Readiness Index in partner countries. Source: GCCSI, 2021.[206]

In the following section, we break down the country-specific regulatory and policy contexts further, based on the findings of the CCS4CEE country reports and further research. For each country, we look at the status of transposition of the EU CCS Directive, other relevant legislation, and regulatory hurdles in partner countries. In Chapter 6, we complement these findings with the opinions expressed by stakeholders in each partner country.

[205] GCCSI, 2016. Carbon Capture And Storage Readiness Index: A global comparative analysis of CCS indicators for the wide-scale deployment of carbon capture and storage projects.
[206] GCCSI, 2021. CCS Readiness Index.

5.3. CCS LEGISLATION IN CEE COUNTRIES

CROATIA

Croatia transposed the EU CCS Directive into national legislation in 2013. This legislation provided guidelines for choosing storage sites, conditions for obtaining exploration permits, storage permits and concessions. The framework was relatively vague in defining requirements for CO_2 purity, as well as poorly defining access rights to the storage sites.

In 2018, the legislation was updated through the Ordinance on Permanent Carbon Dioxide Storage in Geological Formations (OG 95/2018). Although it defined purity of CO_2, this legislation still lacks precision, with requirements for storage site characterisation being open to interpretation. It also fails to address the significant differences in geological data availability between depleted hydrocarbon fields (well-studied and recorded) and saline aquifers (highly uncertain). Finally, it does not adequately define the potential interactions between CO_2 storage and alternative uses of storage sites.

The procedures for obtaining concessions and exploration and storage permits are subject to the Hydrocarbon Exploration and Exploitation Law (most recently amended this year, OG 30/2021). It prescribes every part of the exploration and exploitation process and harmonizes Croatian legislation with EU directives. Together with OG 95/2018, it represents the transposition of the EU CCS Directive.

Permits for CO_2 storage are issued by the Ministry of Economics and Sustainable Development and allow the operator to manage the storage site for a minimum of 20 years. The maximum length of a permit is 40 years, after which responsibility is transferred to the state Hydrocarbon Agency. There are some discrepancies between these procedures and OG 95/2018, regarding the responsibility of the operator and the timing of responsibility transfer. Croatia's Hydrocarbon Agency was mandated in 2018 to engage public and private investors, as well as maintain a database of geological potential for CO_2 storage; however, to date, the Agency has been inactive in this respect.[207]

In its 2021 amendment, the Hydrocarbon Exploration and Exploitation Law defined a "development society" as a company registered for the purpose of exploring and exploiting geothermal waters and permanent CO_2 storage and established by the Croatian Government. Croatian experts believe that this system would be unfavourable for the development of a competitive market for CCS.

Croatia's other legislation relevant for CCS is shown in Table 6.

Legislation	Description
Regulation on limit values for air pollutants from stationary sources (OG 42/2021)	Large combustion plants and gas turbines with output of min. 300 MW, or which started operating after 13 May 2009, are required to submit a CCS-readiness assessment. No such plants exist in Croatia currently.
Regulation on concession fees for the exploitation of mineral resources (OG 31/2014, OG 57/2020)	Stipulates that the number of concession fees are derived from the land plot considered for exploitation. If CO_2 storage is to be included, different calculation models must be used (especially for aquifers).
Ordinance on the exploration and exploitation of mineral resources (OG 142/2013)	Defines final reporting requirements for natural gas storage. Requires harmonization with OG 95/2018 on the permanent storage of CO_2.
Mining Law (OG 56/2013, OG 14/2014, OG 98/2019)	Defines exploration and exploitation of CO_2 storage as the exploration of mineral resources, defines a concession for CO_2 storage and outlines reporting requirements.
Regulation on the fee for the exploration and exploitation of hydrocarbons (OG 25/2020)	Defines exploration and exploitation fees for CO_2 storage; these are very high compared to fees for other geological activities.

[207] CCS4CEE country report: Croatia. Available on the CCS4CEE project website.

Law on climate change and ozone layer protection (OG 127/2019)	Among other things, states that CCS installations cannot be granted free emissions allowances.
Other regulations	Other relevant regulations cover requirements for professional qualifications of operators, publication of geological data for suitable storage sites by the relevant Ministry, reservoir engineering projects and the use of environmental and EUA funding for CCS projects. The Law on Energy Efficiency is also important as it directly affects the strategic decisions of oil companies, who are currently the only industrial actors with technical know-how for CCS.

Table 6. Overview of national legislation relevant for CCS/CCU in Croatia.

Based on the above information, there are no legal obstacles for CO_2 storage in Croatia. However, there is an absence of regulations on CO_2 transport, the purity of transported and stored CO_2 or CO_2 monitoring during transport from the capture plant to the storage site.[208]

Czech Republic

In 2012, the Czech Republic transposed the EU CCS Directive into national legislation, through the Act on the Storage of Carbon Dioxide into Natural Rock Structures (Act 85/2012). After an intervention by the Senate, the original Act banned commercial CCS projects and non-commercial projects over 100 kt storage capacity until 1st of January 2020,[209] from which time commercial CO_2 storage is allowed, but limited to 1 Mt per site and per year. The Act on the Protection and Use of Mineral Resources (44/1988), which complements the CCS Act, also restricts CO_2 injection to deposits which do not contain natural gas or oil (see Table 7).

The transposition of the EU CCS Directive also does not address transboundary issues of CO_2 storage. Currently, it is prohibited to store CO_2 in areas where transboundary leakage could occur, potentially introducing challenges for storage in border-adjacent areas, such as the Ústecký and Moravskoslezský regions (see Section 2). The legislation is also missing an implementing decree, with work on this due to commence in 2021.[210] The competent authority for geological exploration is the Ministry of Environment.[211]

Other legislation relevant for CCS is shown in Table 7.

Act on the Protection and Use of Mineral Resources (44/1988)	Complements the Czech CCS act and stipulates that CO_2 injected for EOR or EGR does not count as stored CO_2. It also restricts CO_2 injection to deposits which do not contain natural gas or oil.
Act on geological works and on the Czech Geological Survey (62/1988)	Describes the procedure for geological assessment of storage structures.
Act on Environmental Impact Assessment (100/2001)	Determines when an EIA must be done and what CCS projects must be communicated directly to the Ministry of Environment.

Table 7. Overview of national legislation relevant for CCS/CCU in the Czech Republic.

The limitation of commercial projects to 1 Mt CO_2/year may prove to be a barrier to CCS deployment. This may be a hurdle for large emitters[212] to deploy CCS clusters (whereby multiple emitters store their captured CO_2 in the same site). The largest barrier is the absence of an implementing decree (see Section 5.4).

[208] CCS4CEE country report: Croatia. Available on the CCS4CEE project website.
[209] CGS Europe, 2013. State of play on CO2 geological storage in 28 European countries.
[210] CCS4CEE country report: Czech Republic. Available on the CCS4CEE project website.
[211] Zakony pro Lidi, 2021. 62/1988 Coll. Act on Geological Works and the Czech Geological Survey (in Czech)
[212] Particularly non-energy emitters; given the Czech Republic's plans for coal phase-out by 2038, coal-fired power plants may not be able to support investment in CCS.

ESTONIA

The EU CCS Directive was transposed into Estonian law in December 2011. The law requires an assessment of capture and storage readiness from operators of power plants rated above 300 MW or built after June 2009 (essentially the transposition of Article 9a of the EU Directive). The Ministry of Environment is the competent authority in deciding whether storage is feasible, [213] and is responsible for publishing all information about CO_2 capture and transportation.

The legal landscape of CCS deployment in Estonia currently has inconsistencies that leave room for misinterpretation. In August 2011, the Estonian Ministry of Environment introduced a draft act amending the Atmospheric Air Protection Act, the Earth's Crust Act and the Water Act, all of which provide information related to CO_2 storage, alongside other environmental and pollution acts. These regulations, however, lack coherence: the Atmospheric Air Protection Act seemingly allows storage of CO_2 while the other two documents prohibit it partially or fully.

The Atmospheric Air Protection Act establishes the rights, duties, and responsibilities of any party which stores CO_2, including reporting standards and the assessment of geological locations. However, the Earth's Crust Act prohibits the geological storage of CO_2 (onshore and offshore) "in accordance with the Atmosphere Air Protection Act." The ban does not apply to storage for research, development and testing purposes, where the total stored volume is less than 100 kt CO_2.[214] In addition, the Water Act prohibits any storage of CO_2 in marine areas, including the storage of CO_2 in geological formations under the seabed.

No other legislation relevant for CCS has been identified in Estonia as part of the CCS4CEE project.[215] The single largest barrier to the deployment of CCS is the ban of CO_2 storage in Estonia and the apparent conflict between legislative acts in terms of this prohibition. The country does, however, have provisions in place for establishing CO_2 transportation.

HUNGARY

Hungary transposed the EU CCS Directive into national legislation in May 2012, through the Government Decree 145/2012 (VII.3), which entered into force in the same year. Since then, the Mining and Geological Survey of Hungary (MBFSZ) has been carrying out research on Hungary's CO_2 storage potential, and in 2013 presented its first report to the European Commission, including the geographical location of potential storage sites.[216]

Decree 145/2012 outlines several provisions, notably the responsibility of the Hungarian Mining Supervisory Authority to publish a list of potential CO_2 storage sites every five years. The Authority is also competent in granting exploration permits for CO_2 storage, and the applicant must hold an environmental permit or access permit for use of the area. The operator of the storage site is expected to cover monitoring costs for at least 30 years.[217] The Decree also outlines obligations for regular inspection by the storage site operator and the Mining Inspectorate of Hungary.[218]

Another piece of legislation relevant for CCS in Hungary is the national Mining Act and its implementing decree, which stipulates that a concession tendering procedure must take place before permitting for CCS projects. This is different from the procedure for aggregates and industrial minerals, where a simple vertical permitting scheme exists.[219]

LATVIA

Currently, Latvia's Law on Pollution prohibits the storage of CO_2 in onshore and offshore geological structures. This prohibition has been in force since 2013, following an intervention by the Ministry of Environmental Protection and Regional Development which

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[213] It is not clear from Estonian legislation whether this refers to geological storage or temporary storage at the capture site.
[214] It is not clarified in the legislation whether this limit refers to 100 kt CO_2 per year, per company or per project.
[215] CCS4CEE country report: Estonia. Available on the CCS4CEE project website.
[216] CCS4CEE country report: Hungary. Available on the CCS4CEE project website.
[217] Wolters Kluwer, 2021. 145/2012. (VII. 3.) Korm. rendelet a szén-dioxid geológiai tárolásáról - Hatályos Jogszabályok Gyűjteménye (in Hungarian)
[218] CCS4CEE country report: Hungary. Available on the CCS4CEE project website.
[219] European Commission, 2017. MINLEX Country Report – Hungary.

highlighted a number of risks associated with CO_2 storage, including risk of leakage and harm to human health. Despite this prohibition, the Latvian Cabinet of Ministers is defined as the competent authority on regulating procedures for CO_2 pipeline transportation and disputes regarding storage sites, among others. This is formalized in the act on "Carbon dioxide stream transportation procedures", which is effectively Latvia's national transposition of the EU CCS Directive, and which assigns responsibility for CO_2 transportation to countries where storage is currently permitted.[220]

Other relevant legislation for CCS in Latvia has been identified by the CCS4CEE country report and is shown in Table 8.

Law on Subterranean Depths	Stipulates that subterranean depths and the mineral resources present in them are owned by the landowner. These ownership rights may be transferred to the state for reasons of national security or use of nationally significant sections or deposits (which could, in theory, also apply to CO_2 storage, but were written mostly in connection with natural gas storage). Responsibility for determination of nationally significant sections and expropriation falls to the Cabinet of Ministers.
Energy Law	Stipulates several regulatory aspects for underground natural gas storage, which could in theory apply to CO_2 storage.
Environmental Impact Assessment	Stipulates that research and development CO_2 storage projects storing less than 100 kt CO_2 are exempt from EIAs. However, this is at odds with the fact that all CO_2 storage is banned in Latvia. Also sets the requirement for assessment of CCS-readiness for combustion units with capacities above 300 MW or constructed/expanded after 25th June 2009.

Table 8. Overview of national legislation relevant for CCS/CCU in Latvia.

Similar to Estonia, the deployment of CCS is significantly hampered by the ban of CO_2 storage in Latvia and the apparent conflict between legislative acts in terms of this prohibition. Latvia does have provisions in place for establishing CO_2 transportation.

Lithuania

The EU CCS Directive was fully implemented in 2011. However, the legal landscape of CCS in Lithuania currently has significant discrepancies. Firstly, The Law on Geological Storage of Carbon establishes the rights, duties and responsibilities relevant to CCS in Lithuania, both onshore and offshore; the competent authority is the Lithuanian Geological Survey, with the Ministry of Environment having approval rights for the installation and closure of storage facilities.[221] Secondly, Chapter 4 of the Law on the Depths of the Earth provides guidelines for the use of the Lithuania's subterranean resources. However, amendments to this Chapter introduced in 2019 stipulate that injection and/or storage of CO_2 in natural and/or artificial subsoil cavities and/or aquifers is outright prohibited. Lithuania's Energy Ministry, which at the time of the amendment had just signed a memorandum to build a gas power plant testing and using CCS technology in western Lithuania, criticized the bill. However, fears of leakage drove the amendment to be signed into law, effectively renouncing CO_2 storage in Lithuania.[222]

No other legislation relevant for CCS was identified in Lithuania in the CCS4CEE project.[223]

Like Estonia and Latvia, the largest barrier to the deployment of CCS is the ban of CO_2 storage in Lithuania and the apparent conflict between legislative acts in terms of this prohibition.

Poland

[220] CCS4CEE country report: Latvia. Available on the CCS4CEE project website.
[221] Parliament of the Republic of Lithuania. XI-1550 Law on Geological Storage of Carbon Dioxide of the Republic of Lithuania.
[222] LRT, 2019. Lithuanian parliament moves to ban CO2 storage underground.
[223] CCS4CEE country report: Lithuania. Available on the CCS4CEE project website.

Poland implemented the EU CCS Directive in 2013, through the Act of 27 September 2013, which also brought necessary amendments to the Geological and Mining Law Act, the Energy Law Act and the Act on access to information on the environment, public participation in environmental protection and environmental impact assessments. The most important aspect of the Act of 27 September is that it defers to the Regulation of the Ministry of Environment on permissible CO_2 storage locations – limited by the Regulation to locations in the Baltic Sea (one depleted hydrocarbon field in the Polish Exclusive Economic Zone) until 2024.[224]

The Geological and Mining Law Act governs the procedures for prospecting and implementing CO_2 storage in Poland, including the rules for granting concessions and defining where storage sites can be located. It also outlines operator obligations, CO_2 transport requirements and storage site operation requirements, based on relevant Polish energy and environmental acts. The Act only allows demonstration projects, conducted for the purpose of assessing the effectiveness and usefulness of CCS, and with a minimum threshold of 500 kt CO_2/year/250 MW capacity (power plant demonstrators). These latter thresholds potentially make this Law appropriate for commercial CCS projects; however, given the limitation to demonstration projects, the geological potential for commercial projects cannot even be properly assessed (exploration for the purposes of commercial storage assessment is prohibited).

The Geological and Mining Law Act assigned as a competent authority for CO_2 storage the Polish Geological Institute, who are responsible for site inspection and take over responsibility for the site if the operator's concession ceases. Interestingly, the authority is also responsible for maintaining the site's readiness to restart storage under a new concession, if it proves technically and economically viable. This may highlight an appetite for doing justice to the storage potential of viable identified sites on the part of Polish regulators. Since 2008, the Polish Geological Institute has also been managing the identification of formations and structures for safe geological storage of CO_2.

Poland's Energy Law Act governs CO_2 pipeline transport, including an obligation on operators to obtain a concession for constructing a CO_2 transport network, and exemption of CO_2 transport network operators from rules on avoiding cross-subsidization,[225] from tariffs for CO_2 transport and from rules on unbundling (as such, full-chain CCS can be performed by the same operator).

It is important to note that Poland's Ministry of Climate and Environment is planning amendments to the Geological and Mining Law Act, hoping to facilitate the development of CCS. These include removing the limit on CO_2 storage, discontinuing the need for concessions to prospect underground CO_2 and granting joint concessions for exploration and storage over a minimum period of 30 years. Changes are also being considered to Poland's environmental regulations, specifically removal of the ban on onshore CO_2 storage. Some early-stage changes to the Energy Law Act, concerning CO_2 transport, are also under consideration, including the establishment of a CO_2 transport network.

Other Polish legislation relevant for CCS is shown in Table 9.

Act of 3 October 2008 on access to information on the environment and environmental protection, public participation in environmental protection and environmental impact assessments	CCS operators are required to obtain an environmental permit to be granted a concession for prospecting and implementing CO_2 storage.[226] This regulation was amended by the Act of 27 September 2013 to require an assessment of CCS-readiness for fossil fuel combustion units with capacity above 300 MW. Poland's Energy Policy until 2040 states that all Polish power plants are CCS-ready.
Polish carbon tax (1990)	Poland has a carbon tax which covers approx. 4% of its GHG emissions. It is the lowest in Europe, at €0.07/tCO_2.[227]

Table 9. Overview of national legislation relevant for CCS/CCU in Poland.

[224] Shogenova, A. Carbon-neutral Baltic states: Do we have CCUS among accepted options? Presented at the 2020 BASRECCS Forum.
[225] I.e. CO_2 transport activities can be financed with profit of the operator achieved in other activities; this is not admissible for heat, natural gas and electricity.
[226] CCS country report: Poland.
[227] Tax Foundation, 2021. European Countries with a Carbon Tax, 2021.

Given its significant onshore storage potential, Poland's ban on onshore CO_2 storage is currently the largest regulatory barrier to CCS deployment until 2024 (at least). Restriction of CO_2 storage to non-commercial projects is also a major hurdle, as is the requirement for concessions to perform underground CO_2 storage and transportation. However, as outlined above, many of these hurdles may be removed in upcoming amendments to the Geological and Mining Law and Energy Law. There is also a lack of clarity on the classification of so-called negative CO_2 emissions.[228] Similar to Romania (see below), the exclusion of CO_2 transport from the category of strategic national investments may increase the bureaucratic burden of building pipeline networks. Stakeholders engaged in the CCS4CEE project also highlighted that because of the current regulations, investors are forced to monitor their underground storage sites for 50 years, increasing costs and reducing appeal for private operators.[229]

Romania

Romania transposed the EU CCS Directive into national legislation through a Government Emergency Ordinance in 2011 (GEO 64/2011).[230] In preparation of transposing the Directive, the Ministry of Environment and Forests, as a coordinator, set up a working group involving four ministries and several relevant authorities, including the Romanian Energy Regulatory Authority (RERA)[231] and the National Agency for Mineral Resources (NAMR).[232] GEO 64/2011 was finally in approved in 2013 in a rapid parliamentary procedure, with little debate (Law 114/2013). Following transposition of the Directive, competence in the matters of CCS was assigned to the NAMR, which established a dedicated service for CO_2 geological storage and a procedure for operators to solicit the right to explore CO_2 storage opportunities in a selected perimeter. Any issued exploration permits are open to public consultation for 30 days. Competence for issuing CO_2 transportation licenses rests with RERA.

GEO 64/2011 aimed to facilitate the implementation of the Getica CCS Demonstration Project (see Section 4); however, it was not accompanied by the necessary regulatory framework for the actual operation of demonstration plants.[233] In effect, it only provides a minimal institutional set-up and is lacking in procedures such as authorization, monitoring, and control. Notably, there is no mention in the GEO about CO_2-EOR or -EGR. Although it was declared that a government decision on dedicated support schemes for CCS would be issued within 12 months of adoption of the GEO, no such support scheme has ever been introduced. To this date, NAMR's CO_2 storage service is underdeveloped, with at most two persons employed.

Relevant institutions in Romania's CCS regulatory environment are the NAMR, RERA, the National Environmental Protection Agency (approves operators' monitoring plants) and National Environmental Guard (monitoring and inspection), and the Ministries of Energy (strategic energy sector programmes), of Economy (undetermined role) and of Environment (supervisory role with no substantial attributions). It is worth noting that in 2011 the Ministry of Economy, Trade and Business Environment was the main responsible authority for the Getica CCS pilot project; since then, several ministerial restructures have taken place. Local authorities, such as city halls and county councils, are responsible for issuing building permits for CO_2 transport or storage infrastructure.

Other legislation relevant for CCS deployment in Romania is shown in Table 10.

Procedure for granting the exploration permit for CO_2 geological storage (Procedure 5 of April 30 2015)	Stipulates that operators may solicit an opportunity analysis for CO_2 storage in a selected perimeter. NAMR may also open a tender for favourable sites.
Procedure for granting the exploration permit for CO_2 geological storage (NAMR Decision 16/2017)	Stipulates that the owner of a valid exploration license or a petroleum agreement can directly obtain a storage permit, subject to the provision of technical documentation. On the other hand, NAMR can grant storage permits competitively (however to date no bid has taken place or been announced).

[228] Further information on negative carbon emissions is available in the "Current state of CCS technologies and the EU policy framework" report, written by the Bellona Foundation as part of the CCS4CEE project (available on the CCS4CEE website).
[229] CCS4CEE country report: Poland. Available on the CCS4CEE project website.
[230] CGS Europe, 2013. State of play on CO2 geological storage in 28 European countries.
[231] In Romanian, ANRE (Autoritatea Națională de Reglementare în Energie).
[232] In Romanian, ANRM (Agenția Națională pentru Resurse Minerale).
[233] Jozon, Monika, 2011. Case studies on the implementation of Directive 2009/31/EC on the geological storage of carbon dioxide: Romania. University College London

	NAMR is obliged to notify European Commission within 30 days after the tender completion.
Guideline for preparing the documentation by operators/owners: Notification regarding the abandonment of offshore wells and disaffecting the facilities	The Regulatory Authority for Offshore Petroleum Operation in the Black Sea (ACROPO), which regulates and monitors offshore petroleum operators, issued these guidelines in 2018. They mandate operators, owners and subcontractors active in the Black Sea to document changes or abandonment of offshore wells, which could bring an opportunity for well reuse, including CO_2-EOR.
Law on expropriation of land for public utility purposes (255/2010)	This Law would currently place a bureaucratic burden on CO_2 transport operators, for obtaining required approvals. Until CCS projects are declared as projects of national significance, expropriation of land for constructing CO_2 transport infrastructure will be challenging and time-consuming.[234]

Table 10. Overview of national legislation relevant for CCS/CCU in Romania.

Romania's regulatory environment for CCS hampers deployment due to the fragmented nature of legislation and governance structure[235] and the bureaucratic burden of approvals for CO_2 transportation. The division of responsibilities for environmental protection between NAMR and the National Environmental Guard may also affect the effectiveness of intervention in the case of environmental or health impacts of CO_2 storage.[236] Regional and local authorities have no role in drafting CCS legislation, and the lack of budget allocated to responsible authorities for the fulfilment of their competencies as stipulated by GEO 64/2011 may prove problematic.

One important hurdle is also the absence of a regulatory framework for wells reuse for CO_2-EOR. Romanian regulatory acts only establish the conditions for abandonment of wells. Technical documentation for well abandonment is not required to provide data on the geological resources of the well.[237] In addition, transfer of ownership for well operations is currently permitted for hydrocarbon operations only. Neither GEO 64/2011 nor Law no. 114/2013 (which approved the GEO) contain any provisions about offshore projects.

Planning permissions for CO_2 pipeline transportation will also prove challenging. Aside from obvious issues such as building permits, Romania is still in the process of conducting cadastral surveys at the national level. Thus, it may be time consuming to identify landowners and obtain their approval for pipelines.[238]

Finally, the opportunities for public participation in decision making concerning CCS are limited. There is no dedicated public body in Romania responsible for dealing with public engagement in CCS projects,[239] and the opportunities for participation of local communities and non-governmental organisations are negligible.

Slovakia

Slovakia transposed the EU CCS Directive in 2011, through its Act on the Permanent Storage of Carbon Dioxide in the Geological Environment. However, the Act does not apply to storage projects with capacity lower than 100 kt, which were permitted for research, development and technology experiments. These small research storage projects are still subject to Slovakia's environmental impact assessment legislation.

The transposed Directive lacks an implementing decree and does not fully address transboundary issues of CO_2 storage, potentially creating obstacles for the use of storage sites near Slovakia's borders (as shown in Section 3, some of Slovakia's storage sites lie close to the Austrian border). Furthermore, areas permitted for geological surveying are subject to environmental impact assessments, with storage absolutely banned in protected landscape and water areas, and priority is given for the storage of hydrocarbons and

[234] GCCSI, 2011. CCS regulatory test toolkit for Romania.
[235] Jozon, Monika, 2011. Case studies on the implementation of Directive 2009/31/EC on the geological storage of carbon dioxide: Romania. University College London
[236] Jozon, Monika, 2011. Case studies on the implementation of Directive 2009/31/EC on the geological storage of carbon dioxide: Romania. University College London
[237] REX-CO_2, 2019. Database development and the preparation of the national study for Stage 1, 2019 https://rex-CO2.eu/index.html
[238] GCCSI, 2011. Permitting Report to the Global CCS Institute, Getica CCS Demo Project Romania.
[239] Jozon, Monika, 2011. Case studies on the implementation of Directive 2009/31/EC on the geological storage of carbon dioxide: Romania. University College London

waste, geothermal utilisation or other energy supply. The Act bans the use for CO_2 storage of repositories which are preferred for these alternative uses, and ones which hold significant groundwater reserves, including naturally occurring mineral resources suitable for therapeutic use, such as peats, bogs and muds.[240]

In terms of competent authorities, the Ministry of Economy oversees the utilisation of geological structures, while the Ministry of Environment updates yearly the map of areas feasible for CO_2 storage surveys. Permitting procedures are handled by the Mining Office.

Regulations relevant for the deployment of CCS in Slovakia are shown in Table 11.

Act on the Protection and Utilisation of Mineral Resources (Act 44/1988)	Assigns competence for oversight of mineral resources and geological structures formed by oil or natural gas extraction (and suitable for further storage) to the Ministry of Economy.
Act on Geological Works (Geological Act) (569/2007)	Assigns competence for updating and publishing the map of areas feasible for CO_2 storage to the Ministry of Environment.

Table 11. Overview of national legislation relevant for CCS/CCU in Slovakia.

The major regulatory barriers to the deployment of CCS in Slovakia are the absence of an implementing decree, meaning that no direct steps can be taken for deployment, other than research projects and the restrictions placed on areas suitable for geological exploration.

Slovenia

Slovenia transposed the EU CCS Directive into national legislation in February 2012 via the Energy Act (EZ-1), with CCS addressed in Chapter 10. The country has declared that it "does not foresee and does not plan CO_2 storage capacities on its territory" but recognized that the need for CO_2 transport may arise, in the context of connecting Slovenian manufacturing plants with storage sites abroad or connecting the CO_2 pipelines of two neighbouring countries.[241] As such, Chapter 10 of the Energy Act states the provisions for enabling CO_2 transport and assigns competence to the Energy Agency of Slovenia. However, storage of CO_2 in Slovenia (onshore and offshore) is prohibited by the Environmental Protection Act (Article 66a).

The main regulations relevant for the CCS deployment in Slovenia are shown in Table 12.

Decree on environmental tax on carbon dioxide emissions	Slovenia has a carbon tax, currently standing at €17.3/tCO_2 and applicable only to companies not included in the EU ETS. It is planned that the tax will increase by least 5% per year and approach EUA prices by 2030.
Environmental Protection Act	Regulates all environmental protection which directly or indirectly affects GHG emissions.

Table 12. Overview of national legislation relevant for CCS/CCU in Slovenia.

Slovenia's outright ban on CO_2 storage is the single biggest hurdle to CCS deployment in the country. However, the country does acknowledge the potential need for CO_2 transport and has provisions for pipeline transport of CO_2.

Ukraine

Currently, Ukraine has no legislative framework on CCS. However, it has transposed some EU regulations which indirectly relate to CCS, such as the Directive on energy end-use efficiency and energy services. Although these documents do not determine the direct

[240] CCS4CEE country report: Slovakia. Available on the CCS4CEE project website.
[241] CGS Europe, 2013. State of play on CO2 geological storage in 28 European countries.

legal status of participants in the process and the market of carbon capture and storage, they form a conceptual framework that simplifies the further development of legislation.

After consulting with the State Service of Geology and Subsoil of Ukraine, the Ministry of Ecology and Natural Resources concluded that separate legislation for CCS is necessary. According to the State Service of Geology and Subsoil of Ukraine, such regulation should be based on similar European regulation and features of the Ukrainian landscape.

A list of other national legislation relevant to CCS deployment in Ukraine is shown in Table 13.

Mining Law of Ukraine	Although it does not mention CO_2 storage, the Mining Law may have future implications on CCS regulation in Ukraine, including responsibilities placed on subsoil users for ensuring full geological exploration and disclosure of information, amongst other aspects.[242]
Technical regulation of gas in the transmission system	Ukraine's new technical regulation implies the concentration of CO_2 in the gas transmission system must not exceed 2.5% after 2025, as required by transit contracts with the EU and European gas traders. This may incentivise gas mining companies to consider various options to capture, store and utilize the CO_2 which they are legally required to remove from their gas stream before injection into the transmission system.
Ukrainian carbon tax (Law No 2755-17) and upcoming ETS	Although not subject to the EU ETS, since 2010 Ukraine has had a carbon tax on large stationary emitters. At UAH10/tCO2 (€0.31/tCO2, one of the lowest in Europe),[243] this tax was considered insufficient to reach Ukraine's climate goals. A national Emissions Trading Scheme was approved in 2020 to support the fulfilment of Ukraine's obligations under the Association Agreement with the EU.[244] Ukraine will develop separate legislation for an ETS based on three years of data[245], and reporting started in 2021. Implementing a national ETS with an adequate cap and allocation system may incentivise exploration of CCS options for large emitters.
Large Combustion Plants Directive and the Industrial Emissions Directive	Ukraine is a signatory to the Large Combustion Plants Directive and Industrial Emissions Directive, enshrined in the Energy Community Treaty.

Table 13. Overview of national legislation relevant for CCS/CCU in Ukraine.

The complete lack of a transposed directive or implementing decree on CCS in Ukraine means that, for now, the regulatory environment is unsuitable for CCS deployment.

5.4. From legislation to implementation: how practical is CCS in CEE regulatory environments?

Overall, the transposition of the EU CCS Directive and characteristics of other relevant legislation in partner countries paint a picture fairly similar to that of the 2019 CCS Legal and Regulatory Indicator of the CCS Readiness Index. Estonia, Latvia and Slovenia, given their prohibition of CO_2 storage on their territories, score the lowest of all partner countries (Figure 16). Similarly, Poland's ban on onshore CO_2 storage, as well as its limitation to demonstration projects, makes for a relatively low score (51 out of 100), although this score should increase if relevant legislation is amended as indicated (Section 5.3.). Despite the lack of prohibition, as well as its detailed transposition of the Directive and specialized authority for CO_2 storage, Romania scores lower than Poland, possibly due to

[242] Thomson Reuters Practical Law. Mining in Ukraine: overview.
[243] Tax Foundation, 2021. European Countries with a Carbon Tax, 2021.
[244] Enerdata, 2021. Ukraine intends to create a GHG emissions trading scheme in 2025.
[245] GIZ. Introducing an emissions trading scheme (ETS) in Ukraine.

the low activity of the NAMR and as-yet-undetermined role of some institutions, such as the Ministry of Economy. The Czech Republic and Slovakia both permit CO_2 storage (limited to 1 Mt in the former) but lack implementing decrees. Given its comprehensive regulatory and procedural framework for CO_2 storage CCS, Croatia scores the highest of partner countries. Hungary is the second-highest scorer, given the enforcement of its transposition of the EU CCS Directive and the active role of the Geological Survey of Hungary.

However, some discrepancies between the indicator and findings of the CCS4CEE project are noted. Firstly, it is unclear why Lithuania's score is 56, equal to that of Hungary, given the outright ban on CO_2 storage (both onshore and offshore) stipulated in the Law of the Depths of the Earth. It is possible that the 2019 amendment to this Law, prohibiting CO_2 storage, was passed after the compilation of the 2019 CCS regulation indicator. Secondly, given its restrictions on storage locations, it is unclear why Slovakia's score is so close to that of the Czech Republic.

From the information shown above, it is useful to extract key aspects of countries' regulatory frameworks, which offer a bird's-eye view of regulatory gaps and opportunities in partner countries. Table 14 summarizes the key aspects of CO_2 storage legislation in partner countries, the most prominent regulatory topic relevant to CCS. For CO_2 transportation, only Poland and Slovenia have provisions in place for pipeline transport beyond what is required by the transposition of the EU CCS Directive.[246] On carbon capture, all partner countries must abide by the EU requirement that all large or new combustion units are assessed for CCS readiness. No partner countries have discernible legislation in place for CO_2 utilization, and none have established funding schemes for supporting the deployment of CCS projects.

As can be seen in Table 14 and Figure 18, some countries which permit CO_2 storage have restrictions limiting it, and some are missing a decree to implement the transposed EU CCS Directive. Aside from Ukraine, all partner countries have assigned a competent authority on CO_2 storage (and in some cases, CO_2 transport); however, the level of activity of these authorities is questionable in most countries. Furthermore, the interaction of CO_2 storage legislation with other regulatory frameworks is in some cases destructive (for example, Slovakia and the Czech Republic) and in others confusing (the Baltic States).

Country	**CO_2 storage permitted?**	**Implementing decree in place?**	**Competent authority identified?**	**Interaction with other legislation[247]**
Croatia	Yes	Yes	Yes	Petroleum and mineral resource exploitation laws, given role of oil companies; establishment of CCS development society
Czech Republic	Up to 1 Mt	No	Yes	Act 44/1988 restricts CO_2 storage to non-EOR or non-EGR
Estonia	Up to 100 kt, R&D only	No	Yes	Conflicting acts on CO_2 storage prohibition
Hungary	Yes	Yes	Yes	Mining Act stipulates need for concession tendering
Latvia	No	N/A	Yes	Conflicting acts on CO_2 storage prohibition
Lithuania	No	N/A	Yes	Conflicting acts on CO_2 storage prohibition
Poland	Onshore, demonstration only	Yes	Yes	Environmental regulation restricts CO_2 storage to offshore locations.

[246] The EU CCS Directive includes requirements for Member States to ensure that 1) CO_2 streams meet CO_2 composition criteria (to prevent damage to the infrastructure, environment or human health), and 2) that CO_2 transport networks are open to third parties.
[247] In most partner countries, even those which have banned CO_2 storage, CCS legislation interacts at minimum with environmental legislation, mostly in the form of requirements for environmental impact assessment and permitting at proposed storage sites.

Romania	Yes	Yes	Yes	Petroleum laws govern use of abandoned wells
Slovak Republic	Yes	No	Yes	Act 569/2007 restricts CO_2 storage depending on priority uses and protected area status.
Slovenia	No	N/A	Yes	Unknown
Ukraine	Not explicitly	No	No	Unknown (potentially Mining Law)

Table 14. Summary of regulatory environments relevant to CO_2 storage in partner countries.

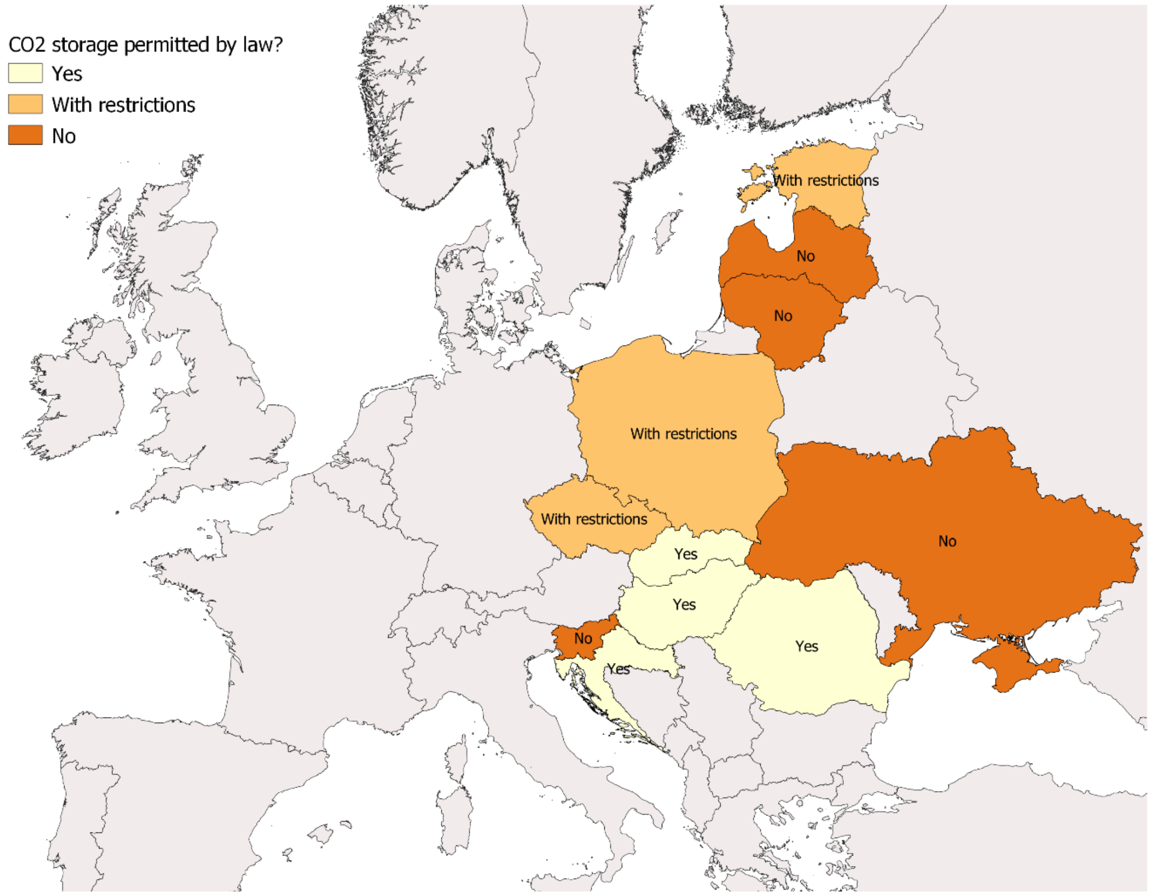

Figure 18. Restrictions on geological CO_2 storage in partner countries. Source: EPG via CCS4CEE country reports. Note that Ukraine does not explicitly permit CO_2 storage on its territory, rather than banning it outright.

5.5. Looking to the future: CCS in long-term plans and strategies

Whether or not CCU or CCS is included in countries' long-term plans and strategies is an indicator of potential future favourability to its deployment. According to the GCCSI, CCS was included in the strategies of the European Union, Czech Republic, Slovakia and

Ukraine, as of November 2020.[248] In the following section, we review the presence of CCS in documents of nationally strategic significance, such as energy strategies and national climate plans.

Croatia

CCS is mentioned in several of Croatia's strategic documents. In the Strategy of Energy Development until 2030, CCS is mentioned as a future possibility, given the expected increase in EUA prices. Croatia's National Energy and Climate Plan (NECP) mentions CCS as particularly important and highlights that CCS/CCU projects can apply for funding from the EU Innovation Fund. In the NECP as well as the Strategy for Low-carbon Development until 2030 (LCS), two enabling measures for CCS are highlighted: the establishment of a platform for the collection, use and storage of CO_2 (2021-2030, including financing) as well as the production of biofuels using CCS (through Innovation Fund financing worth €350 million, 2021-2026). In the LCS, CCS is highlighted as a transition solution, particularly implementation in the cement industry and gas-fired power plants, in the scenario of accelerated energy transition.

Croatia's Zero Scenario for the Energy Sector highlights CCS as a possible solution for unavoidable emissions from industrial processes. It stresses the role of the oil and gas sector and states that CO_2 removal should also be considered through utilization, including EOR and EGR and the food and beverage industry. The Scenario also promotes industrial clusters for CCU, connecting emitters to synthetic fuels producers.

Croatian laws also provide for funding CCS/CCUS projects. For example, the Law on the Fund for Environmental Protection and Energy Efficiency supports scientific projects on CO_2 mitigation, such as CCS/CCUS. The Croatian government is currently discussing a new plan for using financial resources from the emission allowance auctions for both scientific and industrial projects (including CCS projects).

Czech Republic

CCU/CCS is mentioned in the Czech Republic's NECP only as a possibility in combination with natural gas or synthetic gases (including hydrogen). It is also mentioned in the National Hydrogen Strategy (in draft form in June 2021), in conjunction with blue hydrogen production (including SWOT analyses of specific use cases). However, the Strategy states that CCS is currently not profitable, and the Czech Republic does not have suitable geological conditions, whereas CCU is even less mature. CCS is completely omitted in the Czech Republic's Recovery and Resilience Plan.

Estonia

CCS is mentioned in Estonia's NECP, with the Ministry of Environment launching a project to analyse opportunities for climate change mitigation using CCS and CCU, assessing the suitability of capture technologies and develop scenarios for implementation in the Estonian oil shale industry.[249] Given that Estonia plans to phase out its use of oil shale (see Section 2), it is unclear what the impact of this project will be.

Latvia

Latvia's Strategy for Climate Neutrality by 2050 mentions CCS as a main driver of GHG emissions reduction but highlights the low efficiency for developing CO_2 storage. It also highlights the potential for deploying CCU technologies. CCS is also briefly mentioned in Latvia's NECP. It highlights CCU as a priority area for the energy sector; however CCU and CCS are not priority areas in Latvia's Strategic Energy Technology Plan for R&D activities, in which CCUS has a target investment value of only 2% for 2021-2027 (compared to 38% for energy efficiency).

[248] GCCSI, 2020. Global Status of CCS Report.

[249] Estonia's 2030 National Energy and Climate Plan (NECP 2030).

Lithuania

Lithuania's National Climate Plan promises Innovation Fund financing of more than €10 billion to support five strategic areas between 2020 and 2030 – two are directly related to CO_2 storage. The Comprehensive Plan of the Territory of the Republic of Lithuania states that Lithuania should continue assessing the prospects for CO_2 storage.

Hungary

Hungary's second National Climate Change Strategy (NCCS-2, 2018-2030) outlines that the objectives of a "nuclear-coal-green" energy scenario can only be achieved with CCS, stating that Hungary's geological capacity would be sufficient to store its emissions for more than a century. The Strategy also stresses the aim to support R&D and innovation in CCS, and notes as specific medium- and long-term actions the continuation of geological research for storage, continued technological innovation for CCUS in the energy sector, and innovation and testing in CCU.[250]

In the National Energy Strategy 2030, Hungary mentions that CCS may be important for the continued use of fossil fuels in Hungary's energy mix, following a deficit created by the decommissioning of the Paks nuclear power plant, and sums up Hungary's 2050 energy landscape as revolving around CCS, amongst other technologies. However, it states that CCS technologies are currently immature, and notes that unless a technological or commercial breakthrough in these technologies is achieved, they will only be implemented with substantial government support. The Strategy does highlight the potential of CO_2-EOR or EGR, classifying it as a substantially greater business opportunity than natural gas storage.[251]

Despite the importance of CCS highlighted in the National Energy Strategy 2030, Hungary does not devote significant attention to CCS in its NECP, mentioning only that the country is represented in a technical working group on CCUS of the EU's strategic energy technology (SET) plan.[252] The NECP mentions CCS as a potential technology for reducing CO_2 emissions, but does not provide detail on implementation, aside from the fact that power stations with CCS will only be available after 2030.

On the other hand, according to Hungarian stakeholders, the relative apathy of national authorities towards CCS has also changed since the NECP; the working document of Hungary's National Clean Development Strategy highlights that climate neutrality will not be achievable without the widespread deployment of CCUS technologies. This indicates that after many years of relative silence, there is political will to revive the discussion on CCUS.[253]

Poland

CCU/CCS are referred to in several Polish national strategic documents. Poland's National Energy and Climate Plan (NECP) mentions CCU/CCS within its research and innovation dimension and advises developing CCU technologies. The Energy Policy of Poland until 2040 presents CCU/CCS as an enabler of coal phase-out in the Polish energy mix and a component of blue hydrogen production. However, the Policy makes limited provisions for the financing of CCS – it states that CCS will be financed from the Connecting Europe Facility, but that this fund will be shared between various energy infrastructure projects.

Other strategies include the Hydrogen Strategy, which states that a blue hydrogen production installation will be put into operation by 2030 (subject to public consultation), and the social agreement between the government and mining unions (not legally binding), which includes CCS in its plans for the phase-out of hard coal mining by 2049. The CCS projects included in the social agreement will be realized between 2023 and 2029, but no specific details are given.

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[250] Hungarian Ministry of Technology and Innovation, 2018. National Climate Change Strategy (2) section III.5.8. (in Hungarian)
[251] Ministry of National Development. Hungarian Energy Strategy 2030.
[252] European Commission, 2020. Commission Staff Working Document: Assessment of the final national energy and climate plan of Hungary.
[253] CCS4CEE country report: Hungary. Available on the CCS4CEE project website.

Romania

CCS and CCU are notably absent from Romania's national energy strategy and its NECP. Two CCU projects were proposed as part of Romania's Recovery and Resilience Plan, proposed as hydrogen combustion demonstrators with CO_2 capture and utilization in greenhouses. The rationale behind these projects is unclear and they have been criticized for a lack of transparency in establishing the implementing consortia. After criticism from the European Commission, direct financing for these projects was subsequently removed from the Plan, and a competitive tender will take place in lieu of the proposed pre-established consortia and projects.

Slovakia

Slovakia's NECP mentions the possibility of CCS deployment in the future. The Veľké Kapušany Underground Gas Storage Facility is projected as a future large-scale storage hub; however, the priority is not given to CCS. The plan also counts on and includes complementing legislation of the national CCS act. Another important underground storage facility mentioned in the plan is the Dolní Bojanovice facility in the Czech Republic, which also supplies Slovakia. Such transboundary gas infrastructure could be useful in case of international CO_2 transport and storage. Nevertheless, CCS is still only mentioned once in a hypothetical scenario.

The National Hydrogen Strategy (as of June 30th in draft form only) mentions CCS among the indicative list of research projects for CCS to meet the requirements for the production and use of blue hydrogen. However, CCS is completely omitted in the Recovery and Resilience plan submitted by Slovakia to the European Commission.

Slovenia

Slovenia's NECP notes that CCS may become commercially interesting if emission allowance prices rise to €40-60/tCO_2, but that this is not expected before 2040.[254] It highlights that CCS does not make sense for installation on units 4 and 5 of Šostanj thermal power plant, but in the long term there is scope for CO_2 capture from unit 6, between 2035 and 2050. It highlights investment costs of €375 million (2040) – €400 million (2035) for 90% CO_2 reduction of a typical coal dust unit.

In July 2021, Slovenia adopted its Resolution on a Long-Term Climate Strategy until 2050. This Strategy does not mention CCS but anticipates the use of CCU (in the most optimistic development scenario) for reducing process emissions after 2040, particularly in the cement and metal industries.[255]

Ukraine

Ukraine's National Strategy of Low-Carbon Economy Development highlights the capture, storage and reuse of carbon as an innovative technology which will support its emissions reduction efforts in the period of 2020-2050. The country's Nationally Determined Contribution (NDC)[256] also notes the importance of CCUS technologies, but identifies them only as potential tools and does not provide detail on the impacts and costs of implementation.

It is worth mentioning the inclusion of CCS technologies the strategy of the Naftogaz group of companies (the state-owned monopolist in the gas production in Ukraine). The company's environmental safety strategy section includes the use of CCS technologies. As the company plans to achieve carbon neutrality by 2040, and gas production and purification technologies provide for large volumes of CO_2, the use of CCS technologies could be unavoidable.[257]

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[254] Slovenia's NECP was published in February 2020, when EUA prices were just over €20/tCO_2. Currently, these prices are just under €65/tCO_2 (8th of October 2021).
[255] Resolution on Slovenia's Long-Term Climate Strategy until 2050 (ReDPS50).
[256] NDCs are climate action plans which must be submitted by countries who are signatories to the Paris Agreement, a legally binding international treaty on climate change adopted by 196 countries in 2015. Source: UNFCCC: Nationally Determined Contributions (NDCs)
[257] CCS4CEE country report: Ukraine. Available on the CCS4CEE project website.

5.6. Summary

All partner countries (aside from Ukraine) have transposed the EU CCS Directive into national legislation. However, the comprehensiveness of this transposition varies between countries: in Croatia, for example, it has been fully transposed and poses no legal barriers, while the Czech Republic and Slovakia are missing implementing decrees for the national legislation. In Romania, the CCS Directive was transposed rapidly to facilitate the Getica CCS Demonstrator project, but lacks substance in terms of procedures. This indicates that although transposition of the CCS Directive is an important step, most partner countries (perhaps aside from Poland and Croatia) require more work to issue implementing decrees and align with comprehensive procedures for CO_2 storage.

The most significant difference between partner countries in their legislative frameworks is that some have completely banned CO_2 storage (Latvia, Lithuania and Slovenia), and others restrict it in terms of volume injected (the Czech Republic and Estonia) or location (Poland – although this is likely to be eliminated in the near future). In Ukraine, it is not clear whether CO_2 storage is permitted or not, as no specific provisions are made in Ukrainian legislation for this type of geological exploration or activity.

All partner countries have legislation relevant to CCS outside of the transposition of the CCS Directive, for example petroleum laws and environmental regulation. In some partner countries, these legislations conflict with provisions of the transposed CCS Directive: in Latvia and Lithuania, CO_2 storage is prohibited in some legislative acts, but permitted in others. In other partner countries, regulations restrict or make challenging CO_2 storage – for example, through requiring concessions to be obtained for conducting storage projects. In Slovakia, stringent environmental protection regulations put CO_2 at the bottom of the priorities list when it comes to the use of geological resources.

No partner country has legislation on CO_2 capture (aside from requirements to comply with Environmental Impact Assessment legislation). Furthermore, there are no discernible provisions on whether CO_2 injected through CO_2-EOR or EGR are considered as CO_2 storage, aside from legislation in the Czech Republic which specifically excludes CO_2-EOR and EGR from the scope of CCS. This subject is unclear even at EU level.[258]

When it comes to policy support, several partner countries mention CCS in their long-term energy and climate strategies, but many caution that it is an immature and expensive technology and may be suitable only in the medium or long term, or as a transition solution. Interestingly, in spite of their bans on CO_2 storage, Lithuania and Slovenia do show some policy support for CCS – Lithuania through allocating Innovation Fund financing to CO_2 storage projects, and Slovenia highlighting in its NECP that there is scope for carbon capture from the unit 6 of the Šostanj thermal power plant. Estonia and Latvia also mention carbon capture and CCS, respectively, in their NECPs, and Ukraine in its National Strategy of Low-Carbon Development. Overall, CCU and CCS are relatively sparsely mentioned in national strategies, and relatively absent from countries' Recovery and Resilience Plans (aside from Romania), likely due to the long timescale of potential projects.

[258] EOR is not explicitly included in the scope of the EU Directive on CO_2 geological storage, unless it is combined with geological storage of CO_2. Interpretations of this provision may however diverge.

6. Stakeholder perceptions of CCS in the CEE region

This section will present findings on stakeholder involvement with and perceptions of CCU and CCS in the partner countries. In many cases, the recorded stakeholder views and activity complement our findings regarding the context and opportunities for CCU and CCS in partner countries. In this chapter, we also outline several recommendations provided by stakeholders for furthering the deployment of CCS in the region.

6.1. Overview of stakeholders

This section will draw out key commonalities and differences between countries in the engaged stakeholder groups (e.g. prevalence of academic institutions). It will also highlight any differences in the feedback received from stakeholders, contouring an assessment of potential stakeholder involvement in actual CCS projects.

In Work Package 3, the CCS4CEE project engaged a total of 176 stakeholders from the 11 partner countries, through dedicated workshops and interviews. Of interview participants (148), more than half (80) were from the industry, followed by academia and research centres (34). Authorities and institutional representatives come third in line (27), while the lowest interaction comes from civil society, namely non-governmental organisations (NGOs) (seven). The number of workshop participants ranged from seven in Estonia to 22 in Romania.

6.1.1. Selection approach

The identification and contact of relevant stakeholders predominantly relied on the publicly available data which attested their involvement with CCS/CCU projects and studies. As a common feature for all partner countries, the list of key stakeholders emerged from a relevant literature review focused on CCS and climate change mitigation in each country.

The discussions about CCU/CCS prospects were not limited to or conditional on previous experience. Therefore, the exchange of views included stakeholders from relevant administrative bodies, large emitters and consultants and advisory bodies, with a potential role in overseeing or promoting CCS activities. The discussion was not limited to those stakeholders who have had an active role so far, but rather included those who may be interested in applying these technologies in the future. This is due to the fact that, despite the existence of a history of CCS research in partner countries, activity in this area is fairly new, as in most of Europe.

6.1.2. Representation

Stakeholders engaged in this Work Package mostly responded on their own behalf, save for several industry associations who represented specific industries or sectors. Industry stakeholders primarily came from oil and gas companies, followed by cement operators, chemicals producers, energy producers and district heat operators. Most stakeholders from authorities were from environment, economic and energy ministries, as well as energy regulators and geological survey institutions of national governments. Environment ministries seemed to be the most open to discussing CCS, albeit not having the strongest opinions on the matter (neither promoting nor discouraging CCS).

Nine partner countries registered opinions and views from their environment ministries; however, only Lithuania, Slovakia and Ukraine provided an official institutional standpoint from these ministries. Further ministries with attributions related to energy and climate change and engaged in the project were energy ministries (Romania and Lithuania), and economic and industries ministries (Poland, Slovakia, Czech Republic, Croatia, Latvia). Energy regulatory agencies (Croatia and Hungary) supplemented the opinion of national authorities.

Besides ministries, the list of authorities included representatives from several geological institutions, including national geological surveys, mining and geology governmental departments and geology and mineral resources services. Eight partner countries engaged with such stakeholders, whereas only three states (Poland, Latvia, Slovenia) did not reach public agencies, such as energy or extractive industry regulators.

In promoting technology developments and advancing new ideas, the academic sector proves to be fundamental, highlighted by the conversations with academic partners from universities and research centres. Only Ukraine did not record a position expressed by the academic or scientific communities. Universities with a technical profile or a technology focus shared numerous expert points of view based on their own previous research and experimentation on CCU/CCS. Most of this expertise was based on geology, but chemistry and chemical engineering academic representatives, working on capture technologies, also expressed opinions which were recorded in Poland, Slovenia, Romania and the Czech Republic.

Civil society engagement on CCS and CCU topic is less nuanced due to the fact that only six countries (Romania, Estonia, Croatia, Slovenia, Ukraine and Hungary) successfully approached and noted responses from NGOs.

To a large extent, stakeholders offered their points of view and opinions on CCU/CCS from a personal standpoint, rather than representing their institutions. This is partly a pragmatic decision (an academic representative cannot represent an entire university) but may also indicate that the debate on CCU/CCS is yet to reach maturity in partner countries, to the extent that most stakeholders hold no official position on the matter. In only four countries (Estonia, Hungary, Lithuania and Ukraine) did the answers on behalf of institutions and companies exceeded stakeholders' personal opinions. On the other hand, authorities in almost half of partner countries (Croatia, Estonia, Hungary, Lithuania, Slovakia and Ukraine) put forward official remarks on the topic. Official NGO positions emerged from Ukraine and Estonia, but the overall perception is negative towards CCS and CCU technologies deployment. In Romania and Croatia similar views were submitted, stressing that CCS and CCU are not a viable option since the technology prolongs the usage of fossil fuels.

It should be noted that stakeholder engagement in Estonia was challenging, reflected in the low number of workshop participants and relatively reduced number of interviews (ten). This is due to Estonia's restrictions on CO_2 storage and unsuitable geological conditions, as well as low overall emissions.[259] In contrast, in countries where CCS has a longer history, the number of stakeholders engaged was as high as 30 in Poland and 19 in Romania.

6.1.3. Prevalence of different stakeholder groups

Among the engaged stakeholders, industry representatives predominate, without exception, in all partner countries. Several differences occur for the number of institutions and academic stakeholders (universities and research centres) engaged in the project. In five countries (Romania, Estonia, Slovakia, Slovenia, Poland), more academic stakeholders were engaged than institutional stakeholders. Conversely, in Ukraine, Lithuania and the Czech Republic the project more engaged stakeholders from public administration than from academia.

From a total of 71 interviewed business sector representatives, 14 large emitters (with emissions higher than 1 Mt CO_2 in 2020, as recorded in the EU ETS) provided their input: energy producers, chemical and petrochemical companies, oil and gas companies, cement producers and steel producers.

Of industrial stakeholders, the oil and gas sector was present in the stakeholder engagement of nine countries (Croatia, Czech Republic, Estonia, Hungary, Lithuania, Romania, Poland, Slovakia and Ukraine). This sector was, therefore, the most commonly prevalent in CCS discussions in partner countries. It was followed by cement operators, included in the stakeholder engagement of eight partner countries, and chemical operators, from seven countries. This indicates the importance of the oil and gas sector in the CCS debate in partner countries, many of them with a rich history of oil and gas exploitation and experimentation with CO_2-EOR and, in some cases, EGR; Hungary, Romania and Croatia are good examples of countries where the oil and gas sector has been an essential participant in CCS activities. The district heating sector was represented in four countries (Latvia, Lithuania, Czech Republic, Romania), although

[259] CCS4CEE country report: Estonia. Available on the CCS4CEE project website.

many did not express a concrete interest in CCS given the possibilities of transitioning to biomass or other forms of clean energy. The coal mining industry participated in the CCS and CCU debate only in three countries (Poland, Slovenia and Ukraine).

Romania, Slovenia and Ukraine also engaged and recorded opinions from the metallurgy sector (steel and aluminium).[260] In Ukraine in particular, the significant emissions and economic contribution of the iron and steel sector indicate that these producers may be key in further discussions on CCU/CCS deployment in the country. Among other interviewed industry operators, it is worth mentioning biofuel producers in the Czech Republic, hydrogen producers and glass producers from Croatia, the construction sector in Latvia, and a pulp producer in Estonia. These variations in industry stakeholder engagement can serve as a starting point for identifying potential levers for future discussion on CCS.

6.1.4. Engagement level and prospects for cooperation

Collecting the outcomes of national workshops conducted as part of this Work Package, an exploratory level of engagement among stakeholders can be estimated based on the presence of stakeholders from various sectors, their overall attitude towards CCS and CCU, and expressed or implicit willingness to collaborate further on CCS4CEE and other CCS-related projects.

First and foremost, the workshops were attended by industry representatives and authorities in all partner countries. The academic and research sector notably contributed to the workshop debates, with the exception of Ukraine and Lithuania, where only private and institutional stakeholders contributed. Representatives of NGOs barely attended the workshops, with their presence being recorded only in Romania and Croatia; and even in the workshops of these countries, they remained inactive during the discussions.

Broadly, stakeholders acknowledged that CCS and CCU technologies can deliver several benefits. Given the uncertainties on the role of natural carbon sinks for emissions reduction (e.g. afforestation activities), coupled with increased attention to the area of negative emissions, stakeholders perceive that the role and importance of CCS and CCU technologies will advance. However, the current overall impression on CCS potential was mostly sceptical, although no stakeholder expressed concrete reluctance towards CCS and CCU. Large industry emitters were found to be rather ambivalent towards CCS, and many still consider the technology to be at an experimental stage.

Stakeholders engaged through workshops stressed the collaborative manner in which forthcoming discussions related to CCS and CCU should happen. Regional cooperation plays an essential role, alongside advancing viable solutions based on the overall potential of different countries.

Following the workshops, attendees expressed their interest to further engage on the topic of CCU/CCS. More concrete actions emerged from Ukraine, where the State Service of Geology and Mineral Resource proposed to set up a working group, coordinated by the Ministry of Environment and Natural Resources. Croatian stakeholders also proposed to establish a national CO_2 Club, similar to those already existing in France and Romania.

6.2. Prospects and barriers for CCS in CEE countries

This section will consolidate findings on the views of stakeholders on CCS in the partner countries. It will highlight the general level of optimism about CCS deployment, and key commonalities and differences in the views of proponents and opponents of CCS across partner countries. It will also draw out key barriers identified by stakeholders across countries, categorized by topic (e.g. financial, regulatory, knowledge) and highlight countries or barrier categories which require more attention to remove barriers for CCS deployment.

[260] It should be noted that in Romania only a secondary steel producer took part in an interview, with major iron and steel representatives participating in the workshop only, with little input into the CCS discussion.

6.2.1. General views

Across participant countries, the overall prospects for CCS and CCU envisaged by stakeholders are moderate. The confidence level varies between countries; the majority of engaged stakeholders could be classified as "proactive" (actively supporting the deployment of CCS) in five countries (Croatia, Czech Republic, Hungary, Poland and Ukraine) (Figure 19). Of course, this may be partly due to an interest bias – stakeholders accepting to engage in the CCS4CEE project may be more inclined to be involved in CCS activities. However, sceptical voices (stakeholders opposing the deployment of CCS) were also present, being noted in six countries (Croatia, Estonia, Romania, Lithuania, Slovakia, Slovenia). In Latvia, Slovakia and Slovenia, the majority of engaged stakeholders were neutral (neither actively supporting nor opposing CCU or CCS), while in Hungary and Lithuania an equal number of stakeholders were proactive and neutral.

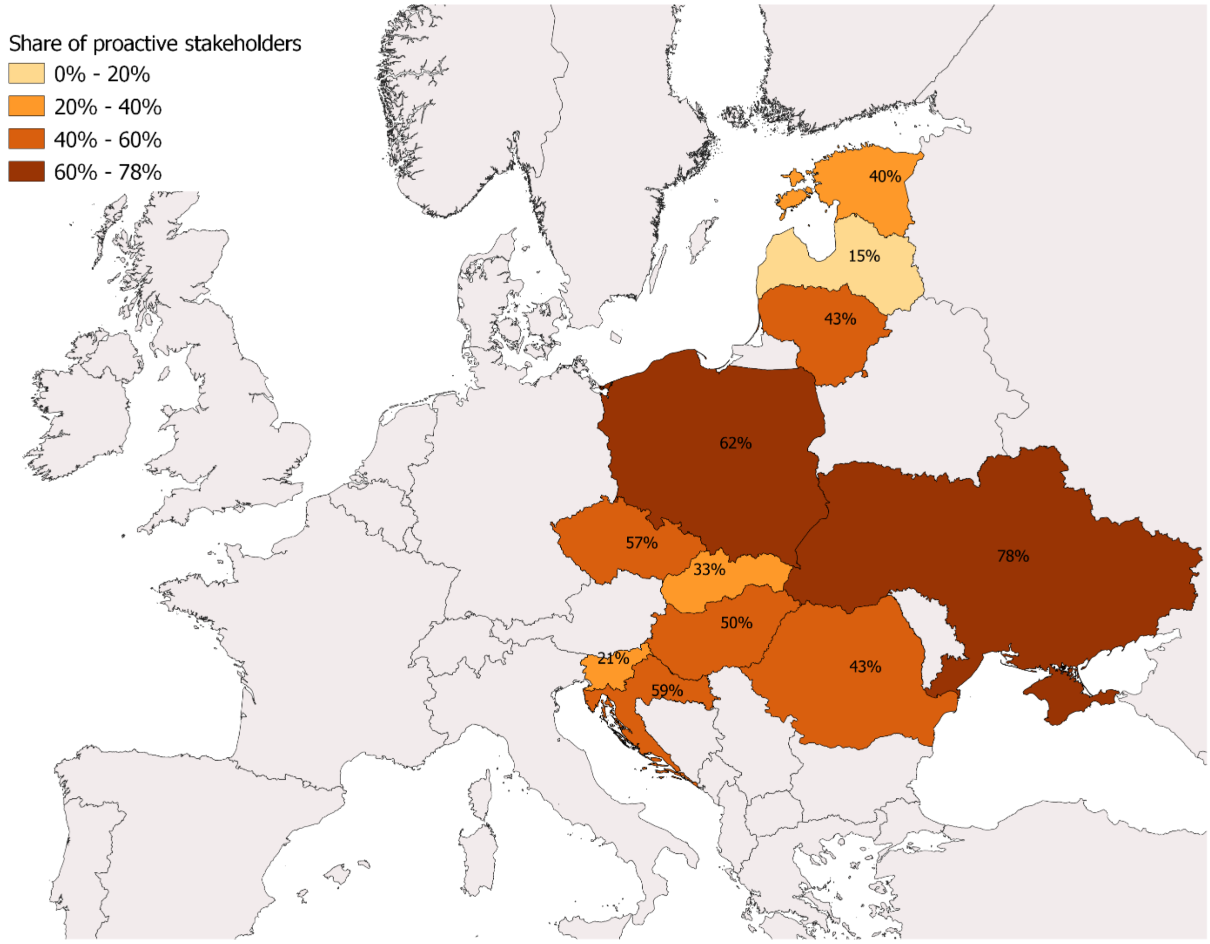

Figure 19. Share of proactive stakeholders, as assessed in the CCS4CEE project, in partner countries. Source: EPG via CCS4CEE country reports.

6.2.2. Positioning on CCS and CCU deployment

For various reasons, such as the prioritization of other climate change mitigation solutions or lack of motivation from the industrial emitters of CO_2, authorities do not play an active role in supporting CCS and CCU technologies. Instead, they prefer to adopt a neutral, observer approach in many countries (Estonia, Latvia, Slovakia, Slovenia, Czech Republic). In Croatia, Poland and Romania, public administration representatives were generally supportive of CCS; however, there are differences between these countries, for example the positioning of environment ministries (supportive in Poland but neutral in Romania). On the other hand, Lithuania is the only country where the Ministry of Environment remained unsupportive in this regard, due to the diminished opportunity for CCS as provided by national laws.

Industry representatives engaged comprehensively in the CCS and CCU discussions in all partner countries. The leading industrial sector, oil and gas, was mostly proactive in the Czech Republic, Croatia, Hungary and Poland, while neutral opinions were registered in Romania, Lithuania and Slovakia. Cement producers in the Czech Republic, Croatia, Latvia and Romania were proactive, whereas in four other countries they are less active for now (Poland, Lithuania, Slovenia and Ukraine).[261]

Coal and steel industry stakeholders did not show reluctance towards CCS and CCU technologies, but preferred to water down their enthusiasm. Conversely, operators in the chemicals sector from Lithuania, Croatia and Romania appreciated the viability and benefits of these technologies - particularly CCU, where these operators may already have experience (for example, in Romania).

Given their relevant research on CCS and CCU, academic stakeholders were broadly approving of this topic. In more than half of partner countries (Hungary, Latvia, Czech Republic, Romania, Poland, Slovakia), the interviewed academics and researchers offered a can-do approach to CCU/CCS. Less enthusiastic opinions from researchers were registered in Lithuania and Slovenia, where CO_2 storage is banned. The Faculty of Mechanical Engineering and Naval Architecture in Croatia is the critic of CCS from the academic environment, albeit approving of CCU if considered as a transitional option.

Environmental NGOs occupy a dissenting place among stakeholders' opinions. Although they acknowledge the role of CCS/CCU technologies in climate change mitigation, they raised concerns on the fact that such complex and costly technologies can prolong the life of carbon-intensive processes in heavy industries. These NGOs strongly advocate against prolonging the operating life of the largest emissions sources, such as fossil-based energy generation. This is the case for Romania and Estonia; however, despite the lack of general support, there are no ongoing or planned campaigns against CCU/CCS technologies (although given the circumstances of a project being proposed, this may change). A similar view is shared by NGO stakeholders from Ukraine, highlighting that if the safety of wells cannot be guaranteed by the national authorities, carbon storage is not worth being prioritized. In Hungary, engaged NGOs could not adopt a firm position on CCS, given their lack of knowledge; one think-tank highlighted that CCS could be an option for smaller emitters but that generally, Hungary is still at an early stage in the CCU/CCS discussion compared to northern and western Europe.[262]

6.2.3. CCS/ CCU PROSPECTS

There is an over-arching consensus among stakeholders that CCS and CCU technologies can contribute to attaining the EU's climate goals. Stakeholders also acknowledge that the development of industrial clusters with shared infrastructure will boost CCS technology implementation in the Europe. However, there is a general ambivalence towards the technologies themselves in most partner countries, with numerous stakeholders from all sectors waiting for European decision-makers to manifest their confidence and support towards CCU and CCS. Economic viability represents a sine qua non condition for CCS to advance on public and private sector agenda.

Some stakeholders also highlight that, with hydrogen being perceived as the "fuel of the future", development of CCS and CCU technology should be synchronous with the development of the hydrogen market. Classical methods for hydrogen production with simultaneous capture and sequestration of CO_2 (blue hydrogen production) may lead to the advancement of hydrogen technologies. Industrial integration is widely embraced by stakeholders, who appreciate that industrial clusters could lead to the establishment of new horizontal business opportunities, such as hydrogen valorisation or CO_2 transportation. Stakeholders in most partner countries indicated that the cement industry would be the most enthusiastic for implementing CCS and CCU, while the power sector may meet more challenges, including higher costs of energy and the availability of cheaper alternatives.

The existence of planned projects can be also interpreted as signs of favourability for CCS: authorities in Poland (currently implementing strategies for the development of carbon capture and storage, transport and utilization technologies and the pilot of the

[261] However, cement producers in Poland and Slovenia expressed favourable opinions of CCS.
[262] CCS4CEE country report: Hungary. Available on the CCS4CEE project website.

Polish CCUS Cluster) and industrial stakeholders in Hungary (one operator has already launched small-scale projects). Stakeholders in the Czech Republic, Poland, Slovenia and Romania are also preparing several carbon capture pilot projects, potentially indicating an optimistic view of stakeholders in these states (however, it should be noted that the Romanian government's proposal for carbon capture pilot projects has been criticized for lack of transparency).

Many stakeholders appear to favour CCU over CCS. Several engaged actors from Romania, Slovakia, Latvia and Poland argued that CCS implementation is rather difficult due to CO_2 storage-related leakage issues and also due to the fact that it requires complex storage infrastructure. Another reason for CCU being considered as a viable option for several industry representatives is the fact that CCS policy still needs to be developed and refined, before being implemented in European countries. Experience with CCU within the chemical industry (including fertilizer producers) is also a boost in confidence for some stakeholders to engage with these technologies, rather than CCS. Interestingly, several industrial and academic stakeholders in Romania and Slovakia vocally highlighted the "laissez-faire" mentality around CO_2 storage (leaving CO_2 to become a problem for future generations) as a main concern for CCS, directing more of their approval towards CCU.

For several private operators, Enhanced Oil Recovery using CO_2 (CO_2-EOR) is an engaging topic, especially for oil and gas companies in Czech Republic and Croatia (where one operator already has a CO_2-EOR project running). Two pilot installations using EOR and EGR (Enhanced Gas Recovery) have been run in Poland to date, with encouraging results. The Slovakian State Geological Institute considered EOR to be a real opportunity.

Even though the price of EUAs under the EU's carbon market is rising, a price of CO_2 of €100 – €120 per tonne seems to be the tipping point quoted by industry stakeholders to seriously consider CCS and CCU. Currently, stakeholders perceive CCS to be viable only when the cost per tonne of CO_2 produced is higher than the cost per tonne of CO_2 captured. In this regard, many relevant stakeholders in partner countries envisage 2030 – 2040 as the period for CCS and CCU to really advance.

6.2.4. Barriers to CCS and CCU deployment

In general, CCS is not endorsed as a priority for stakeholders due to the multiple challenges in deploying this technology. CCU is strongly considered as a viable option for several industry representatives due to the fact that CCS policy still needs to be developed, refined and implemented in countries across Europe. Table 15 highlights the barriers to CCS deployment most frequently identified by stakeholders in partner countries. The remainder of this section reviews different categories of barriers and overall stakeholder opinions in this respect.

Country	Barrier most referred-to by stakeholders
Czech Republic	**Financial**: **high CAPEX investments** Infrastructure: underdeveloped CCS chain Technology: perceived as immature
Croatia	**Financial**: **high CAPEX investments**
Estonia	**Financial: the cost of finding an alternative use to CO_2** Regulatory: CO_2 storage is not included in the regulatory framework (hence, it is prohibited)
Hungary	**Financial: high investment and operating costs for CCU than for CCS** Regulatory: lack of political willingness and visionary approach
Latvia	**Regulatory: CO_2 storage is not included in the regulatory framework** (hence, it is prohibited) Financial: concerns about the economic viability due to large investments required for new technologies and necessary infrastructure.
Lithuania	**Regulatory: CO_2 storage is not included in the regulatory framework** (hence, it is prohibited) Financial: considerable transportation and storage cost outside Lithuania
Poland	**Financial: insufficient financing opportunities for CC(U)S technologies** Regulatory: lack of regulatory framework regarding commercial transport and carbon sequestration
Romania	**Institutional: lack of governmental involvement and industry inertia** Financial: high CAPEX investments

Slovakia	**Financial**: **CC(U)S projects are not economically feasible** Institutional: CC(U)S deployment is massively lacking political support Regulatory: lack of regulatory framework
Slovenia	**Financial: lack of governmental funding for initial CO_2 capture projects** Social: public mistrust and potential opposition
Ukraine	**Regulatory: absent regulatory framework**

Table 15. Main barriers identified by stakeholders in partner countries.

Financial

For many stakeholders, the economic barriers of high CAPEX investments and underdeveloped CCS value chains and models seems insurmountable. The lack of financial frameworks for CCS and CCU at EU level was repeatedly mentioned by various actors in partner countries.[263] Currently, the economic viability of such projects is questionable, due to the fact that high cost and long investment timeframes which may impact the product's final price. Other stakeholders also highlighted the issue of loss in competitiveness due to price increases (something which the EU may address through the Carbon Border Adjustment Mechanism) and the impact of passing on these cost increases to customers, for example energy consumers.

Institutional

The immaturity of the CCS and CCU debate is a common feature in partner states' institutions, whose positions on these technologies are still quite vague in many cases. CCS is placed by several authorities at the bottom of the list in in terms of possibilities to attain a future with net zero emissions. The inclusion of CCS and CCU in national strategies and recovery plans is scarce, which confirms the more reactive, rather than proactive, approach from national governments, as well as a general lack of prioritization for CO_2 reduction possibilities. The lack of expertise and know-how on CCS from administrative bodies is also seen as an impediment to deployment.

Regulatory

Another barrier that undermines CCS and CCU deployment is the missing or inconsistent regulatory framework. In more than half of partner countries (Croatia, the Czech Republic, Estonia, Latvia Lithuania, Slovakia, Slovenia and Ukraine), CO_2 storage is currently prohibited or restricted. Most stakeholders in these countries strongly underlined the challenges posed by this barrier to deployment of all parts of the CCS chain. The second most referenced regulatory impediment concerns the administrative burden of obtaining storage exploration licenses, which are seen as a lengthy and disincentivizing practical application – the need to obtain concessions for permitting exploration of potential CO_2 storage sites poses challenges in Hungary and Poland, among others (although in Poland this requirement may be relaxed in an effort to enable CCS deployment – see Section 5.3).

Infrastructure and technology

Stakeholders highlighted that CO_2 transportation and storage are fundamental issues that must be addressed and elaborately planned for a long-term period. An analysis of the pipeline routes within the storage regions should be based on masterplans, development strategies and other planning documents. The monitoring process of the storage sites following CO_2 injection also deserves in-depth consideration. Effective legislative acts, as seen in Poland, stipulate that the operator's duty includes monitoring the underground storage site for 50 years. With no shared responsibility regarding the monitoring process or the possibility to split the costs, such projects will likely remain unattractive.

Social

The major societal concern around CCU/CCS is related to the safety and permanence of underground CO_2 storage, mainly due to limited or inexistent knowledge about the technology. Even though well-designed and in-depth analysis of the reservoirs would be

[263] Financial frameworks are further detailed in the "Current state of CCS technologies and the EU policy framework", written by Bellona Foundation as part of the CCS4CEE project (available on the CCS4CEE website).

carried out, some stakeholders believe that it is rather unfair for future generations to bear the burden of massive CO_2 deposits. Only in Poland did stakeholders highlight that onshore CO_2 storage may receive lower public acceptance compared to offshore storage.

6.3. Stakeholder recommendations for CCU and CCS deployment

Engaged stakeholders offered several recommendations for accelerating CCU/CCS deployment in partner countries. Table 16 outlines the most frequently referred-to recommendations by stakeholders, and the remainder of this section discusses different categories of recommendations and the main points addressed by stakeholders in each partner country.

Country	Most referenced recommendation
Czech Republic	**Financial: develop national and international financing frameworks as to support CCS deployment**. The infrastructure should also be adapted and extended with European financial support.
Croatia	**Financial: CC(U) projects should be recognized as of strategic relevance for the order to increase the funding rate from national and European level**
Estonia	**Financial: incentivize, through financial frameworks, pilot projects conducted by companies** Institutional: governmental support for specific CO_2 capture devices and CO_2 cleaning technology
Hungary	**Regulatory: remove administrative barriers in order to facilitate general licensing process, infra-structure development** Financial: provide EU or national financial support for pilot projects
Latvia	**Financial: make available national subsidies, grants, EU funding for pilot projects development** Institutional: establishment of an inclusive working group, with largest emitters as members
Lithuania	Financial: provide grants for pilot projects as to incentivize companies to continue CC(U)S deploy-ment
Poland	**Financial: create new financing opportunities (loans, guarantees, tax exemptions), plus a common standard for CO_2 emissions accounting** Infrastructure: support the launching of pilot installations
Romania	**Financial: set up national financing framework to access EU structural innovation funding** Infrastructure: mapping the geological potential Regulatory: mapping and testing the current regulatory framework as to identify potential bottle-necks
Slovakia	**Regulatory: establish the implementing decree for CO_2 storage** and harmonize the regulatory framework
Slovenia	**Financial: co-financing projects through governmental subsidies for initial projects** Social: increased support from the government for communication activities related to the technol-ogy
Ukraine	**Regulatory: develop regulatory framework (the national government should focus on the poten-tial use of the existing infrastructure**)

Table 16. Recommendations most frequently referred to by stakeholders in partner countries.

6.3.1. Regulatory

The deployment of CCU and CCS comes down to the political agenda and government support for these technologies. The main idea stressed by stakeholders was the need for a clear, transparent and predictable legal framework designed both for the inclusion of renewables and the deployment of CCU/CCS.

Even though all partner countries have transposed the EU CCS Directive, comprehensive primary and explicit secondary legislation is missing from several countries (such as Slovenia and Romania). Many stakeholders highlighted the need for filling these legislative gaps, which are particularly pressing in countries where carbon storage is banned, to frame a way forward for stakeholders interested in CCU, carbon capture or CO_2 transportation. Interestingly, in some countries where CO_2 storage is banned, stakeholders did not perceive any regulatory barriers to CCS deployment (for example, Slovenia).[264]

A widely held view among stakeholders is that the simple transposition of the EU CCS Directive will not be efficient unless CCS and CCU technologies are promoted in the national legislation as a priority for a low-carbon economy. This indicates a need for strategic and policy support as well as regulatory support and could frame a way forward for countries where legislation is currently absent – for example Ukraine, which is currently not subject to the EU CCS Directive.

Beyond the prioritization of CCS and CCU technologies in national strategies and legislation, the operationalization and administration of CCS regulation was also highlighted. For the purpose of amending current legislation, or even drafting and enacting new legislation, stakeholders suggested a dedicated working group coordinated by high-level public administration. Importantly, this working group should draw on public servants and experts from across ministries and departments, to mirror the multitude of technical, economic, business and social aspects of full-chain CCU and CCS which must be considered for project implementation. With all relevant public administrators and experts in the same room, articulate answers may arise for operationalizing CCU or CCS as a CO_2 emission reduction pathway.

In terms of CCU, stakeholders highlighted that the regulatory framework should focus on administrative facilitation for infrastructure deployment, assuming CCU is straightforwardly embraced by relevant actors.

6.3.2. Financial

First and foremost, financial frameworks and grants for pilot projects are perceived as the main drivers for companies as to prioritize and include CCS and CCU projects in their agendas, followed by national subsidies and European funding programs and schemes. As the increase for EUA prices is anticipated to continue, the EU ETS seems to be the main driver for CCS and CCU project development; Ukraine is also currently piloting a national ETS system. It has been recommended that the revenue from EUAs be earmarked for the further deployment of CCS and CCU technologies.

With the existing infrastructure being currently unsuitable for CO_2 transportation, stakeholders highlighted that significant investments are required for almost all countries, in the form of national subsidies and European financing instruments. In the meantime, the European Commission should decide which types of carbon utilization (including CO_2-EOR) will be accepted within the EU ETS.

Finally, many stakeholders highlighted that funding should be particularly allocated for research, to further incentivize the progress and understanding of CCS and CCU technologies.

6.3.3. Technology and infrastructure

The focus on long-term CO_2 emissions reduction and technology advancements are interdependent. As long as distinct emitters from industry sector have predictably significant volumes of emissions, it is recommended that they further investigate and test different methods of CO_2 capture and purification technologies. In this regard, pilot projects are strongly encouraged by stakeholders from all levels of representation and sectors. For those countries with storage potential, storage sites are not always close to emitters. As a consequence, transport plays a crucial role in making CCS and CCU deployment a reality.

Even though stakeholders unanimously agreed that sustained efforts for decarbonization are the responsibility of all, the private sector still considers CCU and CCS technologies to be immature, and the infrastructure far from ready. As a starting point, many stakeholders suggest refining the mapping of geological patterns and storage capacities, and re-evaluating CCS and CCU potential in each country on a continuous basis.

[264] CCS4CEE country report: Slovenia. Available on the CCS4CEE project website.

The tailored solutions for a diminished risk of leakage from storage sites emerged as a priority and was widely recommended by stakeholders. Private and governmental investors need to be convinced by pilot storage projects that the entire process is safe and reliable.

Interestingly, stakeholders in Hungary highlighted that direct air capture of CO_2 (DAC) is the optimal technology for clustering capture and storage sites close together. They maintain that only DAC can be built in logistically optimal locations close enough to potential storage sites, without investing in huge CO_2 transportation infrastructure.[265]

6.3.4. Cooperation and inter-sectoral integration

According to stakeholders, cooperation seems to be key for the deployment of CCU and CCS. No further developments are envisioned in the absence of collaboration between sectors and even countries. Sector integration and a common shared infrastructure are considered essential for the future development of CCS and CCU, and integrating larger systems over a wider area would bring more economic benefits and potential for further system development. The Vienna Basin and Upper Silesian Basin, according to previous research activities, offer a possibility for future cooperation between different countries. The Central Bohemian Upper Paleozoic Basins are suitable for a transport and storage cluster (Czech Republic); therefore, it was recommended to start building a pipeline to transport CO_2 from the stationary emission sources in the area. In Lithuania, the largest emitter in the country has already started collaborating with university researchers aiming to explore CCU options, primarily focusing on creating products for construction or other related sectors. This practice of know-how transfer between different actors was highly encouraged.

6.3.5. Social

Sustained efforts aiming to widespread knowledge about CCS and CCU are crucial, and transparency remains the key word for efficiently promoting the technologies to distinct communities or citizen groups. Among recommendations commonly referred-to by stakeholders were public consultations, regular debates about CCU/CCS at EU and national level. As discussions will intensify, they must rely on factual data, therefore an active contribution from scientists and experts in the field is considered to be of tremendous importance. Promoting a better understanding of CCS and CCU through communication campaigns on general or targeted media outlets should not be entirely based on technical aspects, but to also to acknowledge the emotional aspects related deployment.

6.4. Summary

Most stakeholders who engaged with the CCS4CEE project were industrial representatives, namely from the oil and gas, cement, energy production, steel and chemicals sectors. Of the large emitters in partner countries identified in this report, 14 provided input into the project. Authorities such as ministries and regulatory agencies also engaged with the project, however to a lesser extent in many countries than industrial stakeholders. Stakeholders from the academic environment were well-represented, however NGOs and civic organisations were much less engaged.

There was consensus among stakeholders on the benefits that CCS and CCU technologies can deliver, with the rising prices of EUAs being a frequently-quoted driver. However, many stakeholders are still cautious about the deployment of these technologies, citing high costs, unclear government support and lack of financing, as well as challenging administrative procedures and energy or efficiency penalties for installations retrofitted with CO_2 capture. Many stakeholders looked to the EU for more clarity on the direction of CCS to deliver incentives for deployment, for example through Innovation Fund financing. Authorities generally adopted a neutral position towards CCU/CCS, further reinforcing the relative lack of clarity on government support– with notable exceptions in Poland and Croatia, where the government has put forward explicit support for CCS. The same may happen in Ukraine.

One important aspect to note was the tendency to favour CCU over CCS by many stakeholders. In several countries, including Poland, stakeholders highlighted issue related to CO_2 leakage and the requirement for complex infrastructure. Notably, stakeholders in Romania and Slovakia who favoured CCU raised the issue of CCS risking to “leave stored CO_2 as a problem for the next generations”. This highlights potential inertia towards storage, although it should be noted that in Romania industrial stakeholders from the cement

[265] CCS4CEE country report: Hungary. Available on the CCS4CEE project website.

and fertilizer industries are supportive of CCS. CO_2-EOR was also a point of interest for oil and gas companies in several partner countries.

Financial, regulatory and institutional barriers were among the most-highlighted by stakeholders, with the lack of economic feasibility, poor inclusion in regulatory frameworks and lack of government involvement and industry inertia emerging the most strongly. Understandably, the lack of inclusion in regulatory frameworks was the most-cited barrier in Latvia, Lithuania and Ukraine, while low economic feasibility and high capital costs were noted as important barriers in the Czech Republic and Slovakia. A lack of financing was also noted as a very important barrier in Poland and Slovenia, and stakeholders in Estonia found it difficult to manage the costs of finding alternative uses for CO_2 (in the absence of permission for storage in this country, this may indicate a poor market for CO_2 utilization). In Romania, disappointment in the wake of the “on-paper” transposition of the EU CCS Directive and waning government support in the subsequent decade has led to institutional inertia being quoted as the most frequent barrier, alongside lack of involvement from industry. Virtually all stakeholders agreed that social acceptance of CCU and CCS technologies is also plagued by extremely limited knowledge of the technologies.

In terms of recommendations for deployment, the importance of regional and inter-sectoral cooperation for CCS was highlighted by virtually all stakeholders. In many partner countries, the development of financing opportunities and frameworks was the most-cited recommendation. Stakeholders in Ukraine, Slovakia and Hungary were most the pressing on regulatory recommendations, focusing on removing administrative barriers and harmonizing legislation (and in the case of Ukraine, developing a regulatory framework in the first place). Most stakeholders also highlighted the importance of increasing public knowledge on CCS, which must also include institutional actors, particularly local authorities, who may prove supportive of the project but must be informed and involved from the outset of any potential CCS projects. Some stakeholders offered interesting recommendations: “simulating” an approval process for CO_2 storage to identify administrative bottlenecks (Romania), establishing a working group of large emitters (Latvia) and granting government support for specific CO_2 capture and purification technologies (Estonia).

7. Social acceptance of CCS in the CEE region

Despite positive assessments of the efficiency of CCS technologies, the number of existing projects is currently limited. As such, public awareness of CCS and its potential impacts is also limited. However, the spread of CCS technologies directly depends on the public approval of these technologies, and community acceptance is as vital to success as the financial, physical and infrastructure elements of any CCS project. On the other hand, the degree of public approval is determined by the level of public awareness on this issue.[266] This section will review public acceptance levels and issues in partner countries, as well as acceptance by institutions and companies and narratives used in the media.

7.1. Public acceptance

In partner countries, the level of public awareness of CCS is extremely limited. The 2011 Eurobarometer survey on attitudes towards CO_2 storage covered three of the partner countries and highlighted an overall reduced level of awareness of CCS; only 4%, 6% and 7% of total respondents in Romania, the Czech Republic and Poland, respectively, knew what CCS actually is.[267] However, over half of respondents in all countries believed that storing CO_2 would help combat climate change (as high as 59% in Romania), and around half of respondents believed that it was an effective way to fight climate change (42% in Romania, 49% in Poland and 56% in the Czech Republic). Even more strikingly, 77% of respondents in the Czech Republic and 65% in Romania believed that CCS should be compulsory for new coal-fired power plants (50% in Czech Republic and 60% in all respondent countries). Many respondents perceived benefits in terms of improved air quality (as high as 71% in the Czech Republic) and, interestingly, lower water pollution (as high as 45% in Romania), as well as job creation and a lower price of electricity.

When it comes to the location of storage projects, respondents in Poland, the Czech Republic and Romania all indicated a preference for sparsely populated and offshore areas, aside from the Czech Republic where there was a slight preference for storage near the emitting power plant. The risks of underground storage were prescient to respondents – the vast majority in all countries would be concerned if a storage site was located within 5 km of their homes. Major risks to their region were considered to be an increase in electricity prices and possible air and water pollution, as well as general negative environmental impact. Respondents also wanted to be involved in the planning and implementation process, with around a third wanting to be directly consulted in Poland and Romania (up to 44% in Romania). This reinforces the idea that local communities should be engaged at an early stage of CCS project deployment.

It should be noted that the proportion of respondents answering "I don't know" to CCS-related questions in the Eurobarometer survey was significant. A decade on, public knowledge still seems to be sparse, as indicated by stakeholders engaged in the CCS4CEE project (see Section 6.2.4) and enhanced by the fact that no major actions aimed at raising awareness of CCS have been undertaken in partner countries**.** Additionally, public acceptance of CCU or CCS must be nested in a prior analysis of social perceptions of climate change and emissions reduction, as there are "two contextual conditions for CCS acceptance: climate change should be recognized as a problem, and significant CO_2 reduction as the only solution"[268]. As such, it is important to also review public attitudes to climate

[266] Yurii Vasilev et al. Energies 2021, 14, 1408. Promoting Public Awareness of Carbon Capture and Storage Technologies in the Russian Federation: A System of Educational Activities.
[267] Eurobarometer, 2011. Public Awareness and Acceptance of CO2 Capture and Storage.
[268] H. de Coninck, J. Anderson, P. Curnow, T. Flach, O.-A. Flagstad, H. Groenenberg, C.Norton, D. Reiner, S. Shackley. Acceptability of CO2 capture and storage; A review of legal, regulatory, economic and social aspects of CO2 capture and storage. Energy Research Centre of the Netherlands, 2006.

change, as an indicator of how the public discourse on CCS can be shaped in the future. The 2021 Eurobarometer survey on public attitudes towards climate change is a good data source for this.[269]

The 2021 Eurobarometer survey revealed several important characteristics of partner countries' attitudes towards climate change (Ukraine was not included in this survey). Firstly, a lower percentage of respondents believed that climate change is the most serious problem facing the world as a whole, as low as 7% in Romania and 8% in Hungary, compared to the EU-27 average of 18%.[270] Aside from Croatia, Hungary and Lithuania, all partner countries also had lower average perceptions that climate change is an extremely serious problem – this was particularly obvious in Estonia, Latvia, Poland and the Czech Republic (Figure 20). Furthermore, all partner countries aside from Hungary and Slovenia have a higher proportion of respondents who believe that recovery funding should be invested in the traditional fossil fuel-based economy, as high as 34% in Romania and 33% in Latvia, compared to the EU-27 average of 15% (Figure 21). Most partner countries also *disagreed* that innovation driven by climate action would make EU companies more competitive (as high as 33% in the Czech Republic) and that more financing should be given to the green economy at the expense of fossil fuel subsidies (as high as 29% in Latvia). In general, attitudes towards climate change in partner countries appear to be less trusting in the benefits of climate action and generally less worried about the seriousness of climate change.

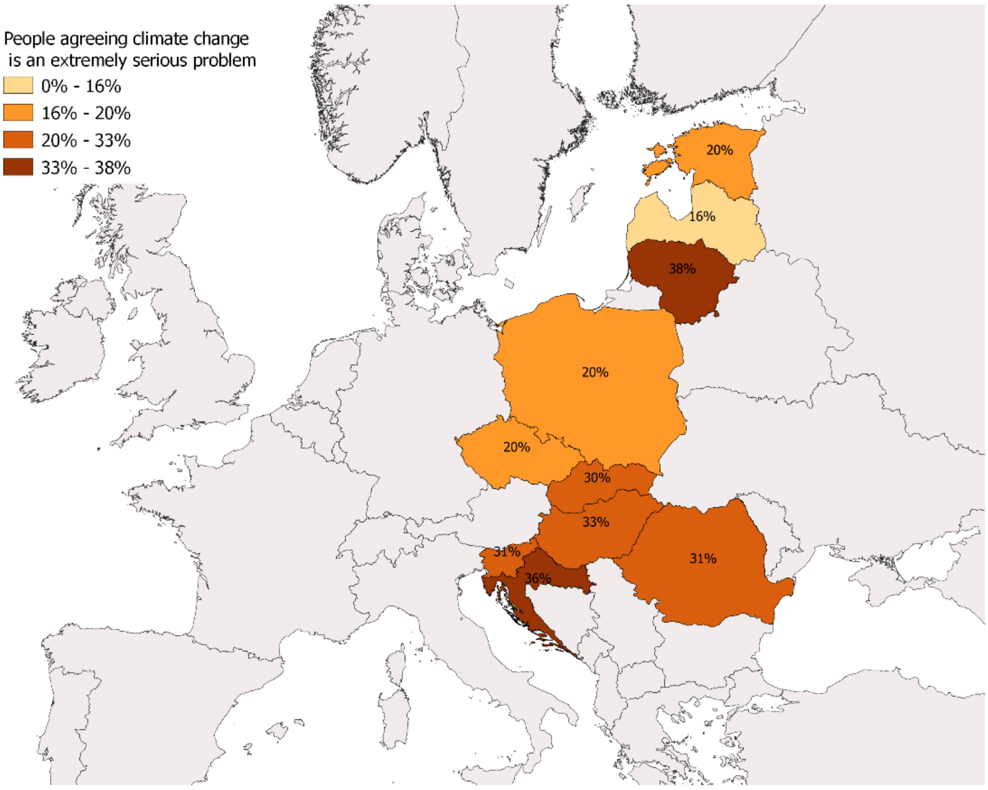

Figure 20. Percentage of survey respondents agreeing that climate change is an extremely serious problem. The EU-27 average is 32%. Source: EPG based on Eurobarometer 2021 results.

[269] Eurobarometer, 2021. Climate Change.
[270] As this survey was conducted after the exit of the United Kingdom from the European Union, the EU-27 average was reported.

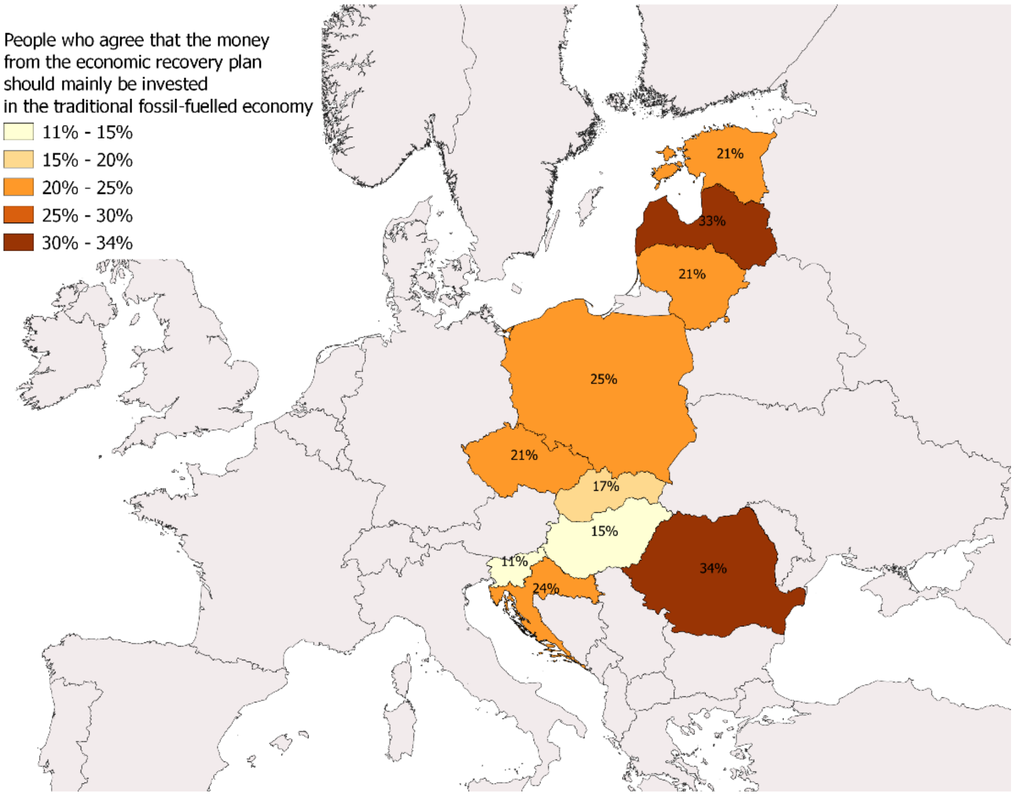

Figure 21. Percentage of survey respondents agreeing that money from the economic recovery plan should mainly be invested in the fossil-fuelled economy. Source: EPG based on Eurobarometer 2021 results.

Few partner countries have conducted studies to actually assess public opinion on CCU/CCS. In the Czech Republic, the potential issue of conflict regarding pipeline construction and environmental protection was briefly highlighted in the conclusions of the ENOS project. Overall, there is no visible negative perception of CCS technologies or CO_2 storage in the Czech Republic, however until pilot projects exist, social acceptance is difficult to assess.

In Poland, a 2011 survey of three villages found generally negative views on the effectiveness of CCS as a climate mitigation tool, although 80% believed it could help. An online focus group within the NearCO_2 project (2011) found low knowledge of CCS, as did a 2016 survey of three cities on CCS and CO_2-EOR. A survey of residents of the Załęcze-Żuchlów region in 2011-2012 found low awareness as well as possible misconceptions of CCS technologies. Overall, public acceptance of CCS in Poland is low, tends to increase with higher knowledge of the topic, and focuses on CO_2 leakage as the main risk, preferring offshore storage in that respect.

Perhaps the most poignant example of public CCS attitudes in partner countries comes from Poland – namely, the abandoned Bełchatów CCS demonstrator project (see adjacent box).[271] The Bełchatów experience highlights that the attitude of "Not-In-My-Backyard" (NIMBYism) is a challenge which cannot be ignored, even when overall knowledge of CCS is low.

[271] CCS4CEE country report: Poland. Available on the CCS4CEE project website.

In Romania, the European Align-CCUS project assessed social perceptions of CCUS in 2020. It found that most respondents from the industrial area of Oltenia (south-western Romania, the location of the Oltenia Energy Complex and the site of the 2011 Getica demonstrator) believed in both the environmental and economic benefits of CCS, whereas respondents from Bucharest considered the environmental benefits to be more important. Both groups of respondents identified risks related to leakage and funding, and challenges related to the involvement of industrial and institutional actors. In another survey conducted within the ECO-BASE project, 38% of respondents knew what CCUS is (respondents were likely a more expert audience in this case). Finally, the Getica CCS project conducted a series of educational and information activities as part of its proposal, identifying that public acceptance was not an insurmountable barrier, but that it would require significant funding and continuous social engagement to overcome the sparse knowledge of climate change and GHG emissions, as well as CCS itself. The public was also concerned with storage sites being located near their homes, similar to the findings of the 2011 Eurobarometer survey.

In Croatia, a 2019 survey as part of the ESCOM project[272] found that around 80% of the public was not familiar with CCS or CCUS. Over half believed that CO_2 can be stored in depleted hydrocarbon reservoirs, but around a third believed it should not be stored in saline aquifers (even if there is no contact with groundwater). Interestingly, a higher share of respondents preferred onshore storage to storage offshore or abroad. Only 17% of respondents believed that the use of fossil fuels can continue with CCS, but nearly half of respondents agreed that emitters can sell their CO_2. However, only a third thought that CO_2 can be used for plastics production. These responses seem to indicate a tendency towards CCU and CO_2-EOR in Croatia, mirroring current activities by Croatian oil companies.

In most other partner countries, the general public sentiment is that climate change is not an immediate threat, and a significant number of people do not see the reduction of fossil fuels as a solution. Furthermore, no definite public opinion of CCS/CCU has been formed, given the low maturity of the sector in partner countries. However, in some partner countries a tendency towards a negative public opinion can be discerned: in Lithuania, negative statements towards CCS and CCU from the Ministry of Environment and NGOs may have affected public opinion.[273] Conversely, in Ukraine, public interest in CCS may have actually been growing recently, with media coverage of the topic increasing since 2020.

Where the notion of CCS is not well-known to the public, it is useful to consider parallels regarding social acceptance of interventions similar to CCS. The Czech Republic's proposed lithium mining project in the Cínovec village has led to public opposition (with little effect), spurred by fears of environmental degradation. Civil society has also organized itself against the proposed deep

Bełchatów: a practical example of social resistance to CCS

The CCS demonstration plant in Bełchatów was the only Polish CCS project sufficiently advanced to evidence public acceptance of CCS in practice. The events described below did happen a decade ago but are still worth reviewing in light of the continued challenges posed by NIMBYism today.

In virtually all communities where CO_2 from Bełchatów was planned to be stored, people expressed strong opposition by either voicing their discontent through local authorities or organizing themselves against the venture. In the village of Pabianice, residents formed the "Civil Committee Against Storing CO_2" and filed a petition against the project to the Prime Minister and the Minister of the Environment. Letters were also sent to the President of Poland asking if Pabianice could be withdrawn as a storage location.

Out of the 179 contracts with local inhabitants to secure access to their properties, 31 were unilaterally dissolved – residents requested termination of the contracts on the basis of misinformation. Some of them openly breached their contracts by refusing to allow the company's staff access to their land. This was the first time in Poland when a geophysical survey could not be performed because of social resistance. As a result, geological research in the area of Pabianice was called off. This happened even though from the very beginning of the Bełchatów project, the project developer tried to familiarize residents with the undertaking itself and with CCS technology in general.

It should be noted that the opponents of CCS in Bełchatów were actually in the minority, though a very important one. The scale of their success reminds us that the slightest social resistance should not be underestimated. However, in some cases nothing could be done to prevent protests. When respondents who opposed CCS or were uncertain were asked what could be done to make them more supportive, most indicated they did not know or that nothing would change their opinion.

[272] Evaluation system for CO2 mitigation.
[273] CCS4CEE country report: Lithuania. Available on the CCS4CEE project website.

and permanent storage of nuclear waste, and protests have been staged against the Turów coal-fired power plant in Poland, close to the Czech border, given the degradation in water and air quality due to coal combustion. Although Poland continued to operate the coal mine against the decision of Court of Justice of the EU, it now hopes to settle the row through an agreement with the Czech Republic.[274]

In Romania, Chevron's proposed fracking project at Pungești (2013) was ultimately withdrawn due to widespread opposition from the local community as well as the wider Romanian public, and negative media coverage. Despite geologists arguing that hydraulic fracturing is a common practice also for natural gas exploitation in Romania, the public feared it would destroy the groundwater. The Romanian fight against fracking is part of a bigger movement that includes opposition to the controversial Roșia Montană gold mining project, which was also proposed in 2013.

In Latvia, petitions against the Skulte LNG terminal and the Dobele wind farm have highlighted a significant involvement (and impact) from local initiative groups. Hungary has seen protests against the expansion of the Paks II nuclear power plant, and widespread national rejection due to fear of the dangers posed.

In Slovakia, public opposition is felt towards nuclear waste storage as well as waste dumps, with protests against the latter leading to closure of an illegal waste facility near a Slovak settlement. Significant opposition has also been manifested towards the planned LNG terminal in Bratislava and oil pipeline to Austria, with even the municipality of Bratislava, the Ministry of Economy and the Greens attempting to halt the projects. Public opposition to gold mining using cyanide in Kremnice also led to more environmentally-friendly mining technologies being deployed.

In Slovenia, past experience with unit 6 of the Šoštanj thermal power plant has led to mistrust in proposed energy and climate policies, due to increasing costs and suspected corruption. Intense opposition from local communities to wind farms in eastern Slovenia has led to delays, and national opposition to the planned construction of new nuclear power units is likely to remain an issue (however, there is local support). Mistrust in industrial companies is also prevalent, particularly Salonit Anhovo and Lafarge Cement, due to perceived influence on the strictness of monitoring standards.

7.2. POSITION OF INSTITUTIONS

CROATIA

Croatia's Ministry of Economy and Sustainable Development has listed CCS in strategic documents as a technology helping to curb emissions. The Croatian Hydrocarbon Agency has positively positioned itself on CCS technology, implementing a platform for the collection, use and storage of CO_2. From the private sector, only oil company INA has explicitly positioned itself as a supporter of CCS, through its CO_2-EOR activities as well as plans for a biorefinery with CO_2 capture.

CZECH REPUBLIC

Some authorities have shown a reticent attitude towards CCS in the past, particularly towards onshore CO_2 storage. During the transposition of the EU CCS Directive in 2012, the Czech Mining Authority was not willing to accept responsibility for CO_2 storage in the Czech Republic. When it comes to private companies, energy provider ČEZ (involved in early CCS research) was planning two CCS demonstration plants in 2007, but eventually switched focus to other decarbonisation pathways such as nuclear and renewable energy.

ESTONIA

No information on the explicit positions of Estonian institutions on CCU/CCS was recorded. As shown in Section 6.2, most stakeholders consider opportunities for these technologies to be limited.

[274] CCS4CEE country report: Czech Republic. Available on the CCS4CEE project website.

Hungary

Explicit support for CCS from national authorities has waned – from a strategic tool in Hungary's National Energy Strategy of 2030 (2011) to a single-sentence mention in the NECP and the new National Energy Strategy. CCS does not fit with Hungary's ambition of widespread solar energy utilization. However, the upcoming National Clean Development Strategy to 2050 states that widespread use of CCUS will be necessary to achieve climate neutrality, and may indicate a revival of political support for CCS.

Latvia

Only Schwenk Latvija has publicly announced their ambitions for a CO_2-neutral cement plant, which could involve CCS. No other institutions have publicly expressed a position on CCU or CCS so far.

Lithuania

As mentioned above, institutional stakeholders in Lithuania have publicly issued negative opinions around CCS, including the Ministry of Environment. Several MPs have also publicly expressed their concerns regarding CCS, in terms of its risks and cheaper alternatives, as well as the lack of scientific research and advancement of private interests.[275] Akmenės cementas, one of Lithuania's largest emitters, has publicly indicated a possible future use of CCS/CCU. However, they find CCS technologies not yet widespread and appear to be monitoring their performance at other cement plants before engaging with them.

Poland

National authorities in Poland have positive attitudes towards CCU/CCS, with these technologies mentioned in key strategic documents, albeit not being treated as a serious alternative to coal. The Polish government is planning a CCS installation in the Upper Silesian Coal Basin and has launched a project to establish a Polish CCUS cluster. When it comes to local authorities, little is currently known – however, local councils and mayors played a key role in opposing the Bełchatów CCS demonstrator, now abandoned.

When it comes to private companies, Tauron and PGE, two of Poland's largest energy companies, have been implementing pilot projects and trying to deploy full-chain demonstration plants, respectively. Relevant research institutes are also favorable towards CCU and CCS. The current attitude of environmental NGOs is unknown.

Romania

Romanian institutions have, at best, vague positions towards CCS. Although the Ministry of Economy at the time supported the Getica project, the Ministry in its present configuration does not have a positioning on the matter; neither does the Ministry of Environment. Enquiries from MPs on the topic have generally been met with evasive answers from the government. Although the Ministry of Energy announced a partnership between Romgaz, Romania's largest gas producer, and ExxonMobil in the field of offshore carbon storage, no further detail has been released. As shown in Section 4.2, the two proposed CCU projects in Romania's recovery plan (led by the Ministry of Energy) have been subject to controversy.

Private companies' explicit support for CCS is also limited. Compared to the Getica-era discussions around CCS, led by energy companies, other industry sectors are now approaching with concrete proposals for CCU/CCS, such as the cement and chemical industries. The Oltenia Energy Complex, despite having been a consortium partner in the Getica demonstrative project, currently considers CCS development to be too expensive.

Environmental NGOs generally have no specific position on CCS; however Bankwatch, a Romanian NGO, firmly opposes the continued support of fossil fuels through CCS.

Slovakia

Institutional positioning on CCU/CCS in Slovakia is extremely vague. Since the last amendment to the Slovak CCS Act in 2017, the Ministry of Environment and the Ministry of Economy have taken no other steps. US Steel Košice, Slovakia's largest emitter, neither

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[275] CCS4CEE country report: Lithuania. Available on the CCS4CEE project website.

supports nor speaks about CCS. Only the Slovak Cement Union very recently mentioned the need for financing carbon capture and utilization technologies in cement plants in Slovakia.

Slovenia

Explicit support for CCS is given by the Ministry of Environment and Ministry of Infrastructure, translated into the inclusion of CCS in Slovenia's NECP. Slovenian research institutions continue to participate in research projects related to CO_2 capture. Within the private sector, however, only Salonit Anhovo has explicitly stated that it intends to develop CCU/CCS, intending to start with a pilot CCU plant. CCU/CCS is rarely mentioned in public discourse of NGOs, mostly focusing on drawbacks of these technologies.

Ukraine

As indicated in their engagement with the CCS4CEE project, the State Service of Geology and Mineral Resources of Ukraine is ready to publicly express their position on opportunities for CO_2 storage and provide tax incentives to industrial producers to stimulate CO_2 storage. However, considerable opposition is felt from environmental NGOs, with the prominent "Ecodia" NGO highlighting the less expensive decarbonization alternatives of renewable energy and energy efficiency, and the risks of fossil fuel lock-in and CO_2 leakage.

7.3. Media coverage

Media coverage of CCU/CCS in partner countries is sparse. Croatian media mostly translates global news on climate change (only 18% of climate change news are national).

Czech media is currently speculating on the future role of CCS, driven by the recent increases in the price of EUAs. In a recent article, the Mining Authority comments on the issue of CCS and its relative price to other technologies, stressing the relatively high capital and operating expenditures of CCS.[276]

Even with its history of CCS pilot projects and studies in Poland, the Polish media shows little interest in CCS. Even a decade ago, during the time of significant activity for CCS pilots and demonstrators, CCS was not attracting much in the way of media attention.

In Romania, an analysis by the Align-CCUS project found that media coverage of CCU/CCS is low, but relatively positive. Very few recent media articles mention CCS, with most simply reporting on the interest of a few private companies in engaging in CCS/CCU projects. In some cases, the issue of low CCS media coverage may be entrenched within a wider issue of low climate change media coverage.

In Slovakia, some media coverage refers to CCS as a decarbonization pathway for hard-to-abate sectors. Aside from a recent public interview with the Slovak Academy of Sciences, media output on CCS in Slovakia has been very rare.

On the proposed use of CCU/CCS technologies on unit 6 of the Šoštanj power plant in Slovenia (see Section 5.3.2), media narratives have mostly portrayed this investment as irresponsible, given the ban on CO_2 storage. CCU, however, has been mentioned sparsely in the context of climate change and the circular economy. There is limited mention of the application of CCU/CCS in the industry sector.[277]

Conversely, in Ukraine public interest in CCS has been growing since 2020, when Ukrainian media started covering the topic as a potential solution to decarbonization, mainly referring to the International Energy Agency (IEA) Energy Technology Perspectives report (2020).[278]

[276] Kristen, V., 2021. Konec uhlí v roce 2038? Kvůli rostoucí ceně emisních povolenek by mohl přijít i dřív, říká předseda báňského úřadu (in Czech)
[277] CCS4CEE country report: Slovenia. Available on the CCS4CEE project website.
[278] *International* Energy Agency, 2020. Energy Technology Perspectives.

7.4. Summary

The understanding of CCS technologies in partner countries remains overwhelmingly limited, even a decade on from the Eurobarometer survey on attitudes to CO_2 storage. Furthermore, attitudes towards climate change, a key narrative within which CCU and CCS are nested, are less urgent in partner countries than observed in western EU countries. This potentially indicates that partner countries and the EU envisage different pathways to climate neutrality. This division between East and West is not new; dating back to the Cold War, it allowed these regions to develop at different rates, both economically and socially. Decades on, attitudes towards climate and environment differ between EU member countries. While the western countries of Europe focus on the expansion of renewable energy, some of the eastern countries prioritize reliable energy supply. This is reinforced by the relatively positive attitude towards fossil fuels of respondents in partner countries, compared to the overall attitudes of the EU in the 2021 Eurobarometer survey on attitudes towards climate change.

Despite overall low public knowledge of CCS, opposing public attitudes have shown their potential to derail CCS projects. The most prominent example of public opposition is from Poland's attempt to establish the Bełchatów CCS demonstrator, where a vocal minority from local communities played a significant role in the project being delayed and eventually abandoned. Where public knowledge and narratives on CCU or CCS are absent, parallels can be drawn with other types of geological extraction or use activities which signal caution in assuming that the public will approve of CCS projects. Local action against gold mining in Slovakia and Romania, nuclear waste storage in the Czech Republic and fracking in Romania are some examples of the concretization of opposing public attitudes with significant impact on project implementation. In Slovenia, and likely in many other partner countries, mistrust of government and industry actors will also play a role in public acceptance of CCS. Indeed, in Romania only 17.2% of the population trust the government, well behind the Army, Church and Romanian Academy, as well as the EU.

In addition to low public knowledge, the positioning of institutions on CCU and CCS is, at best, vague. Some industrial actors have explicitly or implicitly declared interest in these technologies, but clear statements from national governments, serving to direct the market, are mostly absent. In some cases, the positions of national authorities are negative and conflicting: in Lithuania, the explicit position of the Parliament against CO_2 storage is at odds with the Ministry of Energy, which was exploring a CCS project at the time the ban on CO_2 storage was introduced.

It is apparent that the need for addressing social acceptance of CCU and CCS in partner countries is threefold: a robust position from leading and trustworthy institutions, concerted dialogue and education of the public on climate change and CCU/CCS, and relevant, factual media coverage. Given the socio-economic status of partner countries, where day-to-day struggles are plentiful for a large part of the population, transparency issues are common and the position of the media is often political, the social acceptance aspects of CCU and CCS may in fact be one of the underestimated challenges of deploying these technologies.

8. Conclusion and next steps

Work Package 3 of the CCS4CEE project assessed the current context of CCU/CCS in 11 countries in the CEE region (Croatia, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia, Slovenia, and Ukraine). Using reports from country experts and research conducted by the Energy Policy Group (EPG), it drew out key characteristics relevant to the future direction of CCS deployment in these countries.

Economically speaking, all countries have witnessed a steady increase in GDP and a shift towards service-based economies, since the end of their communist regimes. However, their GDP are still below EU average, and industry still plays a more important role than in western European economies. Manufacturing is a key sector, particularly the production of non-metallic mineral products (which includes cement, lime and glass production) and the production of metals. Given the unavoidable nature of process emissions in these industries (emissions which far outstrip the EU average in partner countries), the manufacturing sector could become fertile ground for CCU/CCS deployment in the CEE region.

The dependence of partner countries on fossil fuels for energy production, reflected in the carbon intensities of their economies, also outlines a potential role for CCU/CCS for thermal power plants. Indeed, proposed or completed CCS projects in Poland and Romania have focused on coal-fired power plants, and most large emitters in partner countries are fossil-based energy producers, some much older than the EU average. In Ukraine, emissions from the largest 14 coal-fired power plants and five steel plants alone are equivalent to 4.5% of all emissions in the entire EU ETS. This reliance on fossil fuels, coupled with sometimes distant or uncertain deadlines for emissions reduction targets, means that CCS/CCU for the energy sector cannot be ruled out in the CEE region.

When it comes to storage potential, Ukraine emerges as a potential vast source for geological storage of CO_2, followed by Romania and Poland – the latter which may be better-suited for transborder storage projects in partner countries, given that the bulk of Ukraine's assessed storage potential is in the Donbass region, on the eastern border of Ukraine and distant from other partner countries. On the other hand, the Baltic States have very low storage potential, with Estonia's being negligible. Most storage potential is in deep saline aquifers, but these have been poorly assessed compared to hydrocarbon fields and require more research and geological surveying to enable eventual pilot or demonstration projects. CO_2 sequestration through mineral carbonation may be possible in some areas (Lithuania and Ukraine) but require considerable developments before eventual deployment. CCU may also show potential in partner countries, given the importance of the oil and gas and chemicals sectors, which can use captured CO_2 for EOR/EGR and as a feedstock, respectively. However, it is still unclear what the actual contribution of the different types of CCU to emissions reduction is, and what the opportunities would be for regional CO_2 utilization clusters.

Beyond a promising potential for geological storage in some partner countries, most countries also have a history of research (and occasionally testing) of CCS. Future CCS projects would be supported by an existing ecosystem of know-how and experience with international cooperation, particularly given the presence of partner countries in international consortia – with Poland and the Czech Republic standing out.[279] Private sector experience with CO_2-EOR and -EGR in countries such as Hungary, Romania and Croatia, and with CCU across the whole CEE region, could also accompany the existing history of academic research. However, neither the economic dependency on industries with unavoidable process emissions, nor the promising geological potential, nor the existence of research expertise are sufficient to drive CCU/CCS deployment without support from national regulations and policies. As found in this report, the regulatory environments of partner countries vary widely in terms of enabling CCU/CCS, particularly on storage and transportation. Any regional cooperation in the short term would thus rely on using countries with favourable regulations for CO_2 storage as storage "hubs" for emissions from countries where commercial storage is restricted, or downright banned (the Baltic States and Slovenia). Beyond these discrepancies, CCU is relatively absent in the national regulations of all partner countries, and their long-term national strategies and plans rarely mention CCU or CCS as the recipients of concrete action plans or funding, or even as priorities for emissions mitigation. Those countries which do mention CCS in their long-term strategies caution on its high costs

[279] "Regional cooperation for CCS/CCU deployment", a report written by WiseEuropa as part of WP3 in the CCS4CEE project.

and low maturity and may perceive it as a transition solution only. Interestingly, despite their bans on CO_2 storage, Lithuania and Slovenia support CCS in their long-term policy plans.

The second crucial factor in determining whether economic need and favourable storage conditions lead to CCU/CCS deployment, is the attitude of stakeholders, institutions and the public towards these technologies. Indeed, many stakeholders in partner countries are cautious about deploying CCS technologies, due to the high costs, lack of clear government support (evidenced by the neutral stance towards CCS of most authorities in partner countries) and financing, and challenging administrative procedures (for example, the requirement to obtain a concession for exploration in Hungary). Many stakeholders also tended to favour CCU (including CO_2-EOR) over CCS, raising issues related to CO_2 leakage from geological storage, as well as the complexity of the required storage infrastructure. Virtually all stakeholders engaged in the CCS4CEE project highlighted the importance of regional and inter-sectoral cooperation, a promising note on which to continue the CCS4CEE project in partner countries. In some cases, however, enabling CCS through regulation is a necessary predecessor to stakeholder engagement in projects, including transborder ones.

When it comes to public and institutional acceptance of CCU/CCS, the overall lack of knowledge of the subject matter emerges as one of the most important features of partner countries (though this is likely not unique to just the CEE region). In contrast to the rest of the EU, attitudes towards climate action in partner countries are also less favourable. Furthermore, a history of opposition to other similar projects (fracking in Romania, for example) or even CCS projects (the Bełchatów CCS demonstrator) compounds the potential issues posed by low social acceptance to CCS technologies. The risk of CO_2 leakage from geological storage areas is a particularly contentious aspect for public acceptance. Finally, whereas a strong positioning from institutions and adequate media coverage may contribute to enhancing knowledge on CCS, neither of these are present in partner countries.

The assessment of contexts for CCU/CCS in partner countries has several limitations. Firstly, as a non-Member State, Ukraine had lower data availability when it comes to emissions (especially its industrial emissions sources). Ukraine has only recently launched a reporting system ahead of opening a domestic ETS in 2025, and verified emissions are only just starting to be reported – further work in the CCS4CEE project will be necessary to improve the understanding of how Ukraine may fit into the CEE region in terms of CCS potential. Secondly, there was variation in the levels of engagement of stakeholders in various partner countries, a feature of the overall landscape and history of CCS in these states. For example, given its ban on CO_2 storage and plans to phase out the use of its most important fossil fuel, Estonia has limited potential for CCS – and this was reflected in the willingness of stakeholders to engage in the CCS4CEE project. Finally, mobility restrictions due to the Covid-19 pandemic meant that most stakeholder engagement activities were held virtually, potentially detracting from the full potential of discussion on topics as yet not hotly debated in partner countries, such as CCU and CCS.

Following the end of Work Package 3, the next phase of the CCS4CEE project will use the assessment presented in this report as a foundation for building national and regional roadmaps for CCU/CCS deployment in the CEE region. Further information can be found on the CCS4CEE project website, or by contacting info@ccs4cee.eu. Individual country partners can be contacted via the "Contact Us" page on the project website.

Annex A. List of large stationary emitters in partner countries

Country	Installation name	Verified emissions (2020) (Mt CO_2)*	NACE code
Poland	Bełchatów power station	30.09	35.11: Production of electricity
Poland	Kozienice power station	10.46	35.11: Production of electricity
Poland	Opole power station	9.70	35.11: Production of electricity
Ukraine	Burshtyn power station	8.75	Production of electricity*
Ukraine	Starobesheve power plant	7.54	Production of electricity*
Poland	Turów power station	5.81	35.11: Production of electricity
Ukraine	Kurakhov/Kurakhove power station	5.71	Production of electricity*
Ukraine	Zaporizhia power station	4.90	Production of electricity*
Poland	Połaniec power station	4.56	35.11: Production of electricity
Czech Republic	Počerady power station	4.55	35.1 Electric power generation, transmission and distribution
Slovakia	US Steel Košice	4.39	24.1: Manufacture of basic iron and steel and of ferro-alloys
Hungary	Mátrai power station	4.19	35.11: Production of electricity
Ukraine	Vuglegirska/Vuhlehirska power station	3.93	Production of electricity*
Romania	Liberty Galați steel plant	3.90	24.1: Manufacture of basic iron and steel and of ferro-alloys
Ukraine	Ladyzhyn power station	3.77	Production of electricity*
Slovenia	Šoštanj power station	3.76	35.11: Production of electricity
Czech Republic	Tušimice 2 power station	3.73	35.1: Electric power generation, transmission and distribution
Ukraine	Slaviansk/Sloviansk power station	3.50	Production of electricity*
Poland	Kozienice power station (block 11)	3.32	35.11: Production of electricity
Poland	Dąbrowa Górnicza CHP plant*	3.30	35.11: Production of electricity
Czech Republic	Vřesová power station	3.26	35.3: Steam and air conditioning supply
Romania	Rovinari power station (Oltenia Energy Complex)	3.10	35.11: Production of electricity
Poland	Pątnów power station	3.08	35.11: Production of electricity
Poland	Łaziska power station*	3.03	35.11: Production of electricity
Ukraine	Zmiivska/Zmiiv power station	3.02	Production of electricity*
Ukraine	Trypilska/Trypillia power station	2.90	Production of electricity*
Czech Republic	Prunéřov 2 power station	2.85	35.1: Electric power generation, transmission and distribution

Czech Republic	Třinec Iron and Steel Works	2.84	24.1: Manufacture of basic iron and steel and of ferro-alloys
Poland	Rybnik power station	2.81	35.11: Production of electricity
Poland	Jaworzno III power station	2.77	35.11: Production of electricity
Poland	Siekierki combined heat and power station	2.73	35.3: Steam and air conditioning supply
Poland	Górażdże cement plant	2.71	23.51: Manufacture of cement
Poland	PKN Orlen combined heat and power plant, Płock	2.61	35.0: Electricity, gas, steam and air conditioning supply
Poland	PKN Orlen refinery	2.57	19.2: Manufacture of refined petroleum products
Lithuania	Achema fertilizer plant	2.52	20.15: Manufacture of fertilisers and nitrogen compounds
Poland	Pątnów II power station	2.40	35.11: Production of electricity
Ukraine	Ilyich iron and steel works	2.35	24.1: Manufacture of basic iron and steel and of ferro-alloys
Czech Republic	Liberty Ostrava steel plant	2.34	24.1: Manufacture of basic iron and steel and of ferro-alloys
Poland	Łagisza Power Station	2.29	35.11: Production of electricity
Poland	ArcelorMittal blast furnace, Dąbrowa Górnicza*	2.26	24.1: Manufacture of basic iron and steel and of ferro-alloys
Czech Republic	Chvaletice power station	2.24	35.1: Electric power generation, transmission and distribution
Romania	Turceni power station (Oltenia Energy Complex)	2.24	35.11: Production of electricity
Czech Republic	Unipetrol refinery	2.23	20.14: Manufacture of other organic basic chemicals
Ukraine	Zuevskaya/Zuivska power station	2.22	Production of electricity*
Poland	Dolna Odra power station	2.22	35.11: Production of electricity
Slovakia	Ferroenergy power plant	2.22	35.11: Production of electricity
Czech Republic	Ledvice power station	2.21	35.1: Electric power generation, transmission and distribution
Ukraine	Dobrotvir power station	2.17	Production of electricity*
Poland	Grupa Azoty Puławy fertilizer plant	2.13	20.15: Manufacture of fertilisers and nitrogen compounds
Ukraine	Azovstal iron and steel works	2.10	24.1: Manufacture of basic iron and steel and of ferro-alloys
Poland	Żerań Power Station	2.10	35.3: Steam and air conditioning supply
Ukraine	Ilyich iron and steel works	2.04	24.1: Manufacture of basic iron and steel and of ferro-alloys
Poland	Ożarów cement plant	1.99	23.51: Manufacture of cement
Ukraine	Zaporizhstal	1.89	24.1: Manufacture of basic iron and steel and of ferro-alloys
Ukraine	Pridniprovska power station	1.85	Production of electricity*

Czech Republic	Kladno power station	1.75	35.11: Production of electricity
Romania	AzoMures fertilizer plant	1.74	20.15: Manufacture of fertilisers and nitrogen compounds
Estonia	Eesti power station	1.65	35.11: Production of electricity
Czech Republic	Tameh Czech power station	1.65	35.3: Steam and air conditioning supply
Hungary	MOL refinery, Dunai Finomító	1.60	19.2: Manufacture of refined petroleum products
Poland	Warta cement plant	1.57	23.51: Manufacture of cement
Poland	PGE heat plant 1, Krakow	1.56	35.3: Steam and air conditioning supply
Czech Republic	Třinec power station	1.55	35.11: Production of electricity
Ukraine	Kryvorishska/Kryvorizka/Kryvyi Rih power station	1.54	Production of electricity*
Romania	Brazi Combined-Cycle Co-generation Plant	1.54	35.11: Production of electricity
Poland	Grupa Lotos refinery, Gdansk	1.52	19.2: Manufacture of refined petroleum products
Lithuania	Orlen Lithuania refinery	1.48	19.2: Manufacture of refined petroleum products
Poland	Ostrołęka B power station	1.48	35.11: Production of electricity
Poland	Combined cycle power plant Płock	1.46	35.3: Steam and air conditioning supply
Czech Republic	Opatovice power station	1.46	35.11: Production of electricity
Ukraine	Luganskaya/Luhansk power station	1.37	Production of electricity*
Czech Republic	Mělník 1 power station	1.35	35.3: Steam and air conditioning supply
Ukraine	Dnieper Metallurgical Combine	1.28	24.1: Manufacture of basic iron and steel and of ferro-alloys
Poland	Puławy combined heat and power plant	1.28	35.1: Electric power generation, transmission and distribution
Croatia	Petrokemija fertilizer plant	1.26	20.15: Manufacture of fertilisers and nitrogen compounds
Czech Republic	Počerady 2 power station	1.26	35.1: Electric power generation, transmission and distribution
Hungary	ISD Power Plant, Dunaújváros	1.24	35.11: Production of electricity
Slovakia	Nováky power station	1.21	35.11: Production of electricity
Poland	Chorzów power station	1.19	35.11: Production of electricity
Poland	Karolin II combined heat and power station	1.18	35.11: Production of electricity
Poland	Gdansk combined heat and power station	1.17	35.3: Steam and air conditioning supply
Poland	Lafarge cement plant, Bielawach	1.15	23.51: Manufacture of cement
Poland	CEMEX cement plant, Chełm	1.14	23.51: Manufacture of cement
Poland	Skawina power station	1.12	35.11: Production of electricity

Poland	Wrocław combined heat and power station	1.10	35.3: Steam and air conditioning supply
Poland	ArcelorMittal steel mill, Dąbrowa Górnicza	1.07	24.1: Manufacture of basic iron and steel and of ferro-alloys
Romania	Petrobrazi refinery	1.05	35.1: Electric power generation, transmission and distribution
Romania	Holcim Câmpulung cement plant	1.05	23.51: Manufacture of cement
Romania	Holcim Aleșd cement plant	1.04	23.51: Manufacture of cement
Hungary	MOL Petrolkémia Zrt/Tiszai Vegyi Kombinát chemical processing plant	1.04	20.14: Manufacture of other organic basic chemicals
Slovakia	Duslo fertilizer plant	1.03	20.15: Manufacture of fertilisers and nitrogen compounds
Croatia	Plomin power station, block B	1.02	35.11: Production of electricity
Slovakia	Slovnaft refinery	1.01	19.2: Manufacture of refined petroleum products
Poland	Lafarge cement plant, Małogoszcz	1.00	23.51: Manufacture of cement

Table A. 1. List of emitters with emissions over 1 Mt in most recent available year (2019 for Ukraine and emitters marked with asterisks, 2020 for all other partner countries). Emitters are sorted by the volume of emissions in the most recent year (CO_2 for Ukraine, GHG emissions in CO2-eq for all other partner countries).

The *Building momentum for the long-term CCS deployment in the CEE region* project is funded by Iceland, Liechtenstein and Norway through the EEA and Norway Grants Fund for Regional Cooperation.

Implemented by: WiseEuropa, Bellona Europa, EPG Energy Policy Group, Civitta, Institute for European Integration
Supported by: Europeum Institut pro evropskou politiku / Institute for European Policy
Co-financed by: NIW
Sfinansowano przez Narodowy Instytut Wolności - Centrum Rozwoju Społeczeństwa Obywatelskiego ze środków Programu Rozwoju Organizacji Obywatelskich na lata 2018 – 2030
PROO