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

CCS National Roadmap

Croatia

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PROO

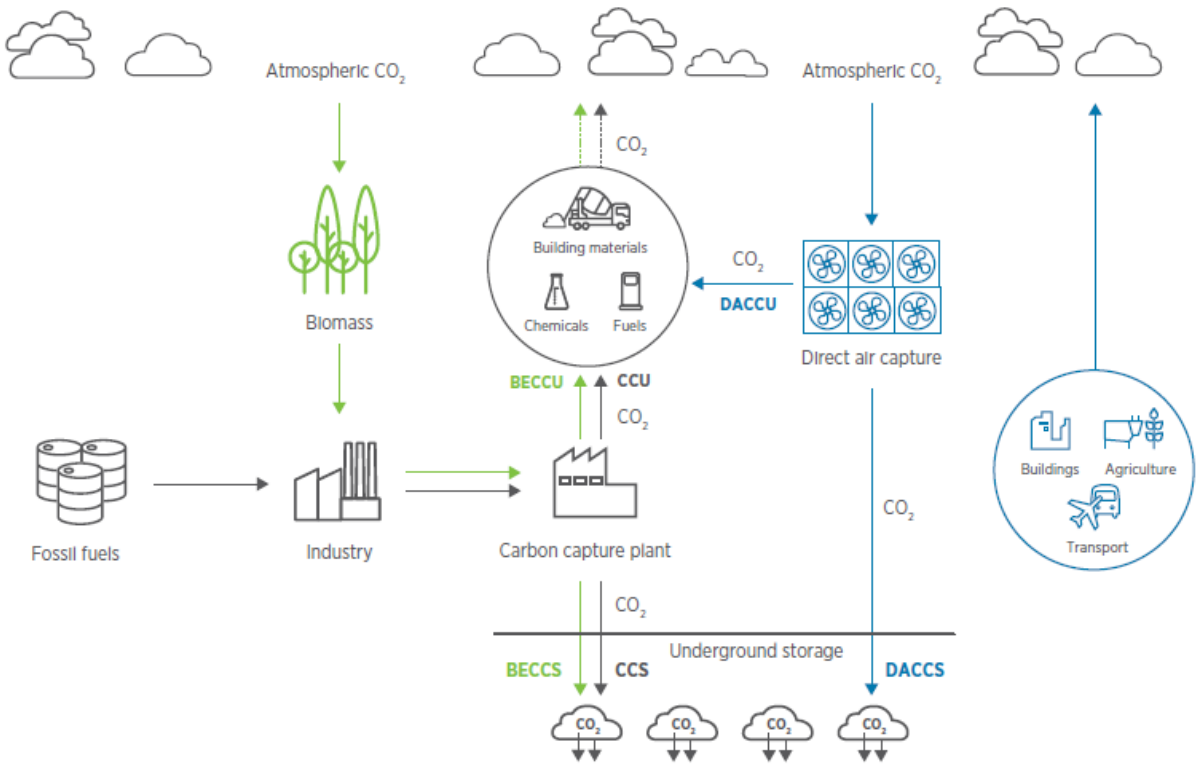
Chapter 1. Role of CCS in decarbonisation pathways

In 2019, the EU launched the European Green Deal to transform the EU into a modern, resource-efficient and competitive economy, cut GHG emissions by at least 55% by 2030 and reach net-zero emissions by 2050. Many 1.5°C compatible scenarios have assessed these targets and shown that a credible but narrow pathway exists and will require the use of all decarbonisation tools available. **Renewables and energy efficiency** are key components of that pathway and account for 80% of emissions reductions and provide solutions to many sectors including power, transport and energy-intensive industries. But to reach net-zero renewables and energy efficiency, they **need to be supplemented by CO_2 capture and storage (CCS) and utilisation (CCU) and carbon dioxide removal (CDR)** (particularly bioenergy with CCS/CCU (BECCS/BECCU)) **technologies** (Figure 1), in sectors such as power and heat, cement, steel, chemicals production and waste incineration. In addition, to address emissions from other sources as well as historic emissions, direct air capture with storage (DACCS) or utilisation (DACCU), can also be deployed. These technologies together can mitigate **20% of global CO_2 emissions**, but to do so, **the scale has to increase significantly** (Figure 2), from the current 0.04 Gt of CO_2 per year to circa 8.5 Gt of CO_2 per year in 2050 (IRENA, 2021).

The benefit of CDR processes is that they remove CO_2 from the atmosphere, they do not simply reduce what was added, and in combination with long-term storage can result in negative emissions. As such they are a critical component of net-zero pathways in the European Green Deal and most recently in line with the Glasgow Climate Pact. There are preconditions to be assessed: biomass for BECCS needs to be sourced sustainably, while DACCS requires access to cheap renewable energy.

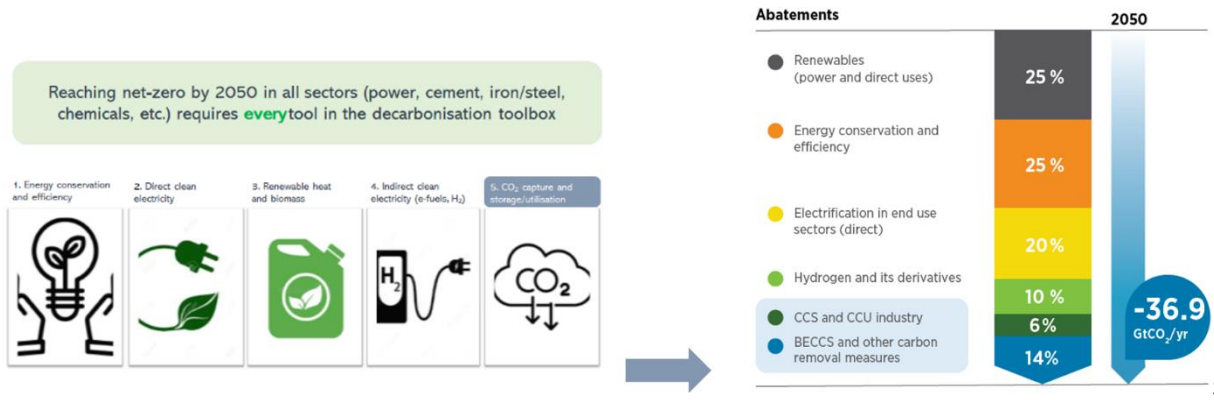
All these technologies utilise the same components of the value chain: the CO_2 transport, storage and utilisation.

Figure 1: Carbon cycle with the use of CCS/CCU, BECCS/BECCU and DACCS/DACCU technologies[1]



Source: (IRENA, 2021)

Figure 2: Carbon capture and storage as a part of the global decarbonisation toolbox[2]



Source: Based on IRENA (2021)

The pace of progress in validating and deploying these technologies across sectors has been slow to date and in many cases with significant costs overruns. There are currently many commercial CCS, CCU and CDR plants globally

[1] https://irena.org/-/media/Files/IRENA/Agency/Technical-Papers/IRENA_Capturing_Carbon_2021.pdf

[2] Ibid.

capturing 40 Mt of CO_2 per year (IRENA, 2021), with many more being developed and an increasing number of pilot and demonstration projects that focus on safety issues, environmental impacts and economic costs, while generating lessons learned to be used to further improve these technologies and bring their costs down.

This current momentum to speed up energy and industrial transition considers these technologies as its necessary component of the transition and **activities at the national and regional levels** may help to **enhance the collective understanding** of the issues surrounding CCS, **build confidence** and **scale up their deployment** to **reduce costs** of these technologies and related infrastructure.

Chapter 2. Opportunities and barriers for deployment of CCS and its related technologies in Croatia

According to data from 2020 primary energy production in Croatia decreased compared to the previous year, which can be mostly attributed to significant reduction in crude oil and natural gas production. The structure of the primary energy production in Croatia in the year 2020 is shown in Figure 3.

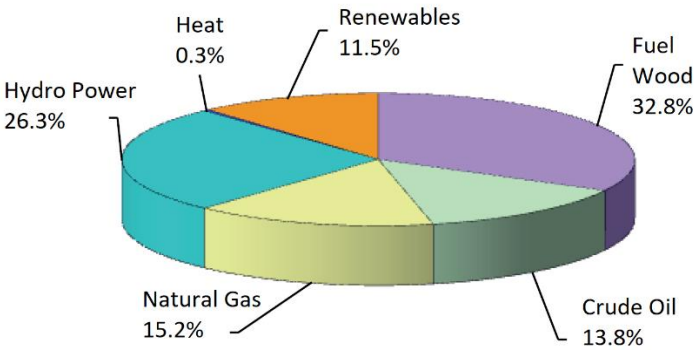


Figure 3. Individual energy forms shares in the total primary energy production (Energy in Croatia 2020, EIHP)

The carbon intensive sectors in Croatia are: mining and quarrying, oil and gas refining, iron and steel, chemicals (fertilizer plants, plastics production, etc.), pulp and paper, non-ferrous metals, food processing, cement, ceramics production, and electricity generation.

Preliminary results for the year 2020 show that stationary and mobile emission sources emitted 14.4 million tons of CO_2, with stationary emission sources accounting for 60.3% (Energy in Croatia 2020, EIHP).

Most emissions come from power generation (35%), oil and gas refining (13%), cement industry (28%), and fertilizer plants (17%). Carbon intensive industry is declining and CO_2 emissions from industries (CO_2 point sources) that are best suited for CCS technologies (i.e., emitting over 100 ktpa CO_2) have fallen below 29% of total emissions. Croatia is among the lowest GHG emitters in the EU, both per capita (fourth from the bottom) and (taking into account the population of EU member states) among the smallest total emitters in the EU.

In 2019, total GHG emissions amounted to 23.6 $MtCO_2eq$, with energy sector and industrial processes and product use sector together accounting for 81%. In 2019, overall GHG emissions coming from the energy sectors in Croatia amounted to 16418 $ktCO_2eq$, while industrial processes and product use sector accounted for 2735 $ktCO_2eq$.

Major emitters[3] in Croatia are presented in Table 1.

[3] Other emitters identified as possible actors if CCS clusters were formed: INA – NiP, Ivanić Grad (92 kt), Strizivojna woodworks (41 kt), Univerzal (Waste to Energy, 32 kt), INTERCAL (lime production 50 kt)

Table 1. Top 15 CO_2 emitters in Croatia (National registry of emissions, 2020)

	Company name	Facility name	Sector	emissions ($ktCO_2$)
1	Petrokemija d.d. tvornica gnojiva	Proizvodnja gnojiva	Fertilizer	868
2	NAŠICECEMENT Tvornica cementa, dioničko društvo (NEXE d.d.)	Našicecement d.d.	Cement	667
3	HEP-PROIZVODNJA d.o.o.	TE-TO Zagreb	Power	774
4	INA-Industrija nafte, d.d.	Rafinerija nafte Sisak	Refineries	36
5	INA-Industrija nafte, d.d.	Objekti prerade plina Molve	Oil & gas Processing	247
6	HEP-PROIZVODNJA d.o.o.	TE-TO Sisak	Power	487
7	HEP-PROIZVODNJA d.o.o.	EL-TO Zagreb	Power	201
8	HEP-PROIZVODNJA d.o.o.	TE-TO OSIJEK	Power	88
9	Vetropack Straža d.d.	Vetropack Straža d.d.	Glass	95
10	UNI VIRIDAS društvo s ograničenom odgovornošću za energetiku	Kogeneracijsko postrojenje Viridas Biomass	Power	103
11	HEP-PROIZVODNJA d.o.o.	TE Plomin	Power	1022
12	INA-Industrija nafte, d.d.	Rafinerija nafte Rijeka	Refineries	770
13	CEMEX Hrvatska d.d.	CEMEX Hrvatska d.d.	Cement	647
14	Calucem do.o.	Calucem do.o.	Cement	121
15	Holcim Hrvatska d.o.o.	Holcim Hrvatska d.o.o.	Cement	360

The *Integrated National Energy and Climate Plan for the Republic of Croatia for the period 2021-2030* barely considers CCS, stating that coal and natural gas power plants "will not be technologically advanced except in the context of the development of carbon capturing and storage, CCS". Considering that this is the only time CCS is mentioned in the document and due to the sentence structure, it can be concluded that CCS is only considered pro-forma.

European CCS Directive (from 2009) was implemented without country-specific changes, which again leads to the conclusion that CCU/CCS technology is insufficiently mentioned in the strategic documents of the Republic of Croatia.

The Low Carbon Strategy (NN 63/21) envisages the application of CCU/CCS technology in gas-fired power plants and in the cement industry after 2040 as part of the Accelerated Energy Transition (NU2) scenario, while the NU1 scenario is feasible without the use of CCUS technology. Croatia, being a member of the EU, shares the European Commission's European Green Deal targets, and envisages a 55% reduction in greenhouse gas emissions, this level of CCUS technology is insufficient. A framework for scenario building that forms the basis for such strategies is not

based on adequate CO_2 life cycle assessments (LCA) and realistic technology readiness levels (TRL) together with realistic learning factors (LF).
Croatia's hydrogen strategy by 2050 (NN 40/2022) considers CCS in connection with hydrogen production from fossil fuels, and it is stated that CCS technology and infrastructure would join the existing industry centres (e.g., refineries and petrochemical facilities) by using the storage potential of hydrocarbon fields.

On the one hand, there is strong activity by the oil company INA MOL towards geothermal, zero-emission CO_2 EOR, making it technologically ready for permanent storage of CO_2. It is estimated that the two currently active commercial CO_2-EOR projects Ivanić and Žutica permanently retain (injected minus produced) more than 0.65 million tonnes of CO_2 per year (Strategy CCUS project, 2020). There are several other CO_2-EOR candidates and there is interest from petrochemical/fertiliser company (National Recovery and Resilience Plan 2021-2026), cement companies, and power generation companies in CO_2 injection, especially in north-eastern Croatia (Eastern Slavonia). Cement company NEXE's project under the name "Implementation of CCUS" is at the feasibility study level (with Norwegian partner Aker Carbon Capture) and will reduce emissions by 70% (400 ktpa). The company CRODUX has invested in the project for the construction of a hybrid power plant with a total capacity of 500 MW (CCPP) in combination with CCUS (Carbon Capture, Utilisation and Storage) and the production of hydrogen through electrolysis. INA MOL has also launched the Bio-Refinery - Industrial Capture and Underground Storage project in Sisak, which is currently in the demonstration phase and reduces CO_2 emissions by 60 ktpa, with a potential of over 300 ktpa in the future.

As far as is known, there is no direct funding of such projects by the Republic of Croatia.

On the other hand, various aspects of CCS have been considered in a number of scientific research projects, most of which were aimed at exploring the storage potential (Faculty of Mining, Geology and Petroleum Engineering: EU FP and H2020 projects: EU GeoCapacity, CGS Europe, ENOS, Strategy CCUS, and the national research project ESCOM).

As far as is known, there are no CCS projects financed by the structural funds of the Republic of Croatia.

CO_2 capture. Following the example of CRODUX and its gas-fired power plant project, it is likely that new fossil fuel power plants will be equipped with CO_2 capture systems.

CO_2 transport. For the CO_2 emitters in northern Croatia, transport is almost entirely possible via pipelines (existing gas network). Transport from the city of Rijeka (and Istria) is also possible, although the distance from the emitters to one of nearest storage sites is up to 200 km. Emitters in Dalmatia are even further from onshore sites with the greatest storage potential.

CO_2 storage. The highest storage potential is estimated in northern Croatia and amounts to 176 Mt in depleted hydrocarbon fields (17 units) and 3 186 Mt in deep saline aquifers (six units). Due to the rising CO_2 prices in the EU ETS last year, the company INA MOL, as an oil and gas operator that has already developed and built several CO_2 injection facilities, estimates that the break-even price for pure storage has already been reached (source: private conversation)

CO_2 utilization. Cement companies are intensively studying the possibilities of CO_2 utilization through storage and reuse of CO_2 from exhaust gases and biological CCUS through the cultivation of algae using CO_2.

Since CO_2-EOR is already taking place commercially, to consider it as utilization and storage, there is a need to conduct full LCA analyses of CO_2, including CO_2 produced by combustion of additionally recovered oil.

New gas-fired power plants are planned to be developed with CO_2 capture systems[4] and will probably be accompanied by the production of hydrogen

During previous research (and discussions at previous workshops and seminars in Croatia) of public opinion and public acceptance of CCS technologies, several conclusions can be drawn:

- CCS technology (or storage) is typically associated with operations related to oil and gas production, making it unpopular.
- The interest in CCS technology is very low - the attitudes are repulsive and altering them is a big challenge.

The main stakeholders in the Republic of Croatia can be divided into those who are already actively contributing to accelerating the deployment of CCS (or CCUS) technologies, those who publicly support this contribution (at least to some extent) by attending the conferences, panels, seminars etc., and those who should be involved in the discussions, support and development of CCS but are in fact inactive, i.e. not interested.
Such a categorisation extends the list of institutional (table 2), private (table 3), academic (table 4) and other (table 5) stakeholders presented in the national report.

Table 2. Institutional stakeholders

stakeholder	***position***
Croatian Chamber of Commerce	pace-setters
Croatian Chamber of Economy	pace-setters
Croatian Energy Regulatory Agency (HERA)	pace-setters
Croatian Hydrocarbon Agency	pace-setters
Ministry of Economy and Sustainable Development	pace-setters
Ministry of Economy, Labour and Entrepreneurship	pace-setters
HROTE - Croatian Energy Market Operator Ltd. (CEMO)	pace-setters
North-West Croatia Regional Energy Agency (REGEA)	fence-sitters

[4] https://www.hybridpowerplantsb.com/en/
https://www.power-technology.com/marketdata/slavonski-brod-hybrid-combined-cycle-power-plant-croatia/

Table 3. Stakeholders from private sector

stakeholder	position	type
Calida Aqua d.o.o.	pace setter	consultant
Calucem d.o.o.	pace setter	CO_2 emitter
CEMEX Hrvatska d.d.	pace setter	CO_2 emitter
Coca-Cola HBC Hrvatska d.o.o.	fence-sitter	CO_2 user
CRODUX Energetika	pace setter	CO_2 emitter
HEP d.d.	fence-sitter	CO_2 emitter
HEP toplinarstvo d.o.o.	fence-sitter	CO_2 emitter
Holcim (Hrvatska) d.o.o.	pace setter	CO_2 emitter
INA d.d.	pace setter	CO_2 storage operator* / CO_2 emitter
Inženjering za naftu i plin	fence-sitter	consultant
Janaf	fence-sitter	oil and gas transport
LNG Hrvatska d.o.o	fence-sitter	oil and gas transport
NEXE d.d	pace setter	CO_2 emitter
Petrokemija d.d.	pace setter	CO_2 emitter
Valmet (Uni Viridas)	fence-sitter	CO_2 emitter
Vermillion Energy	fence-sitter	CO_2 emitter
Vetropack Straža d.d.	fence-sitter	CO_2 emitter
VIRIDAS biomass	fence-sitter	CO_2 emitter

** - The company expressed interest in injecting CO_2 for long-term storage.*

Table 4. Stakeholders from academic sector

stakeholder	position
Croatian Geological Survey	fence-sitter
Energy Institute Hrvoje Požar	pace-setter
Faculty of Mining, Geology and Petroleum Engineering, University of Zagreb	pace-setter
Ruđer Bošković Institute	pace-setter

Table 5. Other relevant actors

stakeholder	position	type
Energetika Marketing d.o.o.	fence-sitter	publisher (energy)
Obnovljivi izvori energije Hrvatske (Renewable Energy Sources of Croatia)	foot-dragger	Economic and Interest Association
PSP Okoli	fence-sitter	natural gas underground storage, owned by state

Stakeholders (table 4), which are pace-setters for CCU/CCS technology are on different level of understanding and do not share opinion with general public. General public is not informed about CCS technology so they do not take strong opinions, except when it is connected with fossil fuels (negative perception).

After the analysis of legislative and financial framework, emission data per capita trends and from organized seminars it can be concluded that general ambition of important stakeholders that are not CCS pace setters is to receive EU funds and switch as soon as possible to renewable energy sources (RES), having the support of generally not well-informed public. This places emphasis on political decisions and the changes in legislative and financial framework for decarbonization by discouraging investments in CCS and CCU technologies, relying on future national energy stability and employment in the country being maintained through economic emigration outside of Croatia.

Chapter 3. Policy roadmap for the scaled-up deployment of CCS and its related technologies in Croatia

The roadmap provides an overview of various ambitious policy actions along the innovation cycle, from research and development to potential commercialisation of these technologies in order to reach climate targets set by the EU and national strategies. While the roadmap aims to create an enabling environment to deploy CCS projects, it increasingly focuses on ways to develop transferable knowledge and skills by national stakeholders (governments, research organisations, academia, private sector) in one or more stages along the carbon capture, transport, storage and utilisation chain, and create linkages to gain knowledge and experience from more experienced stakeholders across the globe. It also underlines the importance of cross-border activities and joint regional demonstration projects to increase stakeholder access to funding considering their different geographies.

A) Scaling-up RD&D activities and building national knowledge and experience

Key action	Number	Approach	Stakeholders	Timeline
Knowledge platforms	A1.1	Establish a community **Advisory Board** for CCS that would be the formal advisor to the government, and responsible for communication regarding new technological opportunities, new activities that affect the implementation of CCS in Croatia and nearby regions, and detecting new target communities	Representatives from authorities (involved in legislative framework development, e.g. Croatian Hydrocarbon Agency) and Croatian Chamber of Economy Representatives from R&D and academia (faculties, institutes such as EIHP, IRB, HGI, start-ups, etc with background of CCS research) Representatives from new, emerging industries (with background of CCS research)	Short-term with continuous efforts
	A1.2	Government should establish an **on-line knowledge platform** (web page) where all interested parties (stakeholders, members of the Advisory Board, and other interested parties) would register, possibly with several different types of roles that would ensure different levels of access to data	Private sector, academic and research institutions, NGOs, civil societies, public sector (ministries)	Short-term with continuous efforts
Engagement with international fora	A2.1	As Croatia's engagement in international forums (such as SET Plan, ZEP Platform or IEAGHG) is rather low, greater involvement in such organisations should be encouraged by entities that are currently members of some associations, namely	Government representatives (at least one Ministry), Croatia's Energy Transition Council,	Short-term with continuous efforts

Key action	Number	Approach	Stakeholders	Timeline
		cement companies, and the Faculty of Mining, Geology and Petroleum Engineering (involved in the CO_2 GeoNet)	Croatian Chamber of Economy, Croatian Hydrocarbon Agency Representatives from the existing and new industries (cement companies, transport operators, and potential storage operators) Representatives from academia (e.g. Faculty of Mining, Geology and Petroleum Engineering, Faculty of Electrical Engineering and Computing, Faculty of Chemical Engineering and Technology, Energy Institute Hrvoje Požar, etc.)	
Identifying industrial hubs/clusters/CO_2 transport networks	A3.1	The Government should encourage clustering and connecting to hubs, firstly by enacting strategic documents with clearly defined taxonomy and describing all possible roles in clusters. All interested parties should be able to explore the available clustering options by accessing the on-line platform.	Government and all interested actors (CEMEX, Petrokemija Kutina, Biorefinery Sisak, INA d.d., HEP, CEMEX - Kaštel Sućurac, Holcim, INA rafinerija, INA NGPP Molve, JANAF, Crodux Energetika, NEXE, UNI Viridas,…)	Short-term with continuous efforts

Key action	Number	Approach	Stakeholders	Timeline
	A3.2	The use of established knowledge platform to facilitate easily accessible “round table” discussions, consultations or workshops with relevant stakeholders’ representatives. The ideas and opinions collected will be useful to agree on crucial aspects that should be covered in strategic documents	Government and all interested actors (CEMEX, Petrokemija Kutina, Biorefinery Sisak, INA d.d., HEP, CEMEX - Kaštel Sućurac, Holcim, INA rafinerija, INA NGPP Molve, JANAF, Crodux Energetika, NEXE, UNI Viridas,…)	Short-term with continuous efforts
	A3.3	In the future strategic documents, the Government should clearly define the role and goals of CCS pilots and demonstration projects, encourage the field testing by dedicating special funding (from some of the existing or future Funds) or providing incentives for such ventures (tax reductions for companies involved in pilot testing)	Government and all interested actors, especially R&D representatives	Medium-term
	A3.4	Possibilities of waste-to-energy (WtE) coupled with CCS in cities/municipalities (as another form of hub/cluster) must be explored	Private sector, government, NGOs, civil societies, local communities, institutes, universities	Short-term with continuous efforts
Funding and financial support for RD&D projects	A4.1	On the national level, ETS revenues should be directed mostly to financing CCS projects (as opposed to the current distribution of these revenues). Funding bodies, financing instruments and opportunities should be promoted on the knowledge platform, where it should be possible to apply for each funding option (establishing a centralised, bottom-to-top funding information platform)	Government Croatian Science Foundation (HRZZ) Ministries, funds and agencies related to education, financing, regional development and EU funds, economy and sustainable development, eg.: • Ministry of Economy and Sustainable Development, • Croatian Chamber of Economy,	Short-term with continuous efforts

Key action	Number	Approach	Stakeholders	Timeline
			• HAMAG BICRO - Croatian Agency for SMEs, Innovations and Investments • The Environmental Protection and Energy Efficiency Fund (EPEEF)	
	A4.2	Government (ministries) should promote funding programs through their websites and presentations in several forms and advertise on the potential knowledge platform. The amount of time CCS is covered on TV and radio news and shows should be greatly expanded.	Government	Short-term with continuous efforts
	A4.3	Collaborate with responsible bodies in neighboring countries to establish funding for joint projects	Government	Medium-term with continuous efforts
	A4.4	On the EU level, existing funding sources (Innovation Fund, Horizon Europe, Connecting Europe Facility,…) should be in-creased	European Commission	Short-term with continuous efforts
	A4.5	Set up a clear criterion on the LCA (Life-cycle assessment), LCCA (Life-cycle cost assessment), and TRL (technological readiness level) and/or Tier to prove that a project (proposal) is viable for future implementation to get the support to increase bankability of projects (e.g. by EIB and similar loan guarantees)	European Commission, Government, existing and future funding bodies	Short-term with continuous efforts
	A4.6	In order to facilitate large-scale international CCS projects and request for funds, multi-disciplinarity covering all aspects (tech-nical – mechanical, software, geoscientific, etc., engineering; economic; regulatory; QHSE) should be encouraged in project applications, and cross-border cooperation should be estab-lished to research how to extend the possibilities for more cost-efficient clustering. Establish stronger links between the bodies that can fund differ-ent aspects of CO_2 abatement technologies, to collect the	European Commission, Gov-ernments, exist-ing and future funding bodies (such as Croa-tian Science Foundation and the Environmen-tal Protection and Energy Efficiency Fund)	Medium-term with continuous efforts

Key action	Number	Approach	Stakeholders	Timeline
		information on how each technology is financially supported (international projects, domestic funds), and (if necessary) adjust funding according to the weighted impact on the specific target (in this case CO_2 reduction). Funding should focus on demonstration/pilot projects and strategically chosen R&D projects.		
Storage site exploration	A5.1	Provide funding for CO_2 storage characterization and TRL improvement on national and EU level. The existing (onshore) hydrocarbon fields are rather explored but aquifer characterization level is low so this should be further investigated and encouraged through funding possibilities. Offshore potential should be assessed along with geomechanical properties.	Croatian Hydrocarbon Agency Ministries related to education, financing, regional development and EU funds, economy and sustainable development etc. Research institutes (EIHP, Croatian Geological Survey) Academia representatives (the Faculty of Mining, Geology and Petroleum Engineering)	Short-term with continuous efforts
	A5.2	Use the knowledge platform to communicate the latest funding opportunities and research results related to new potential storage sites	Government and all interested actors, including R&D representatives	Medium-term with continuous efforts

Key action	Number	Approach	Stakeholders	Timeline
Bridging the valley of death	A6.1	Establish a regulatory framework/oversight and business model for CO_2 transport and storage network. If required, discuss and negotiate with the relevant EU regulatory body certain changes in laws and regulations, particular to Croatia in comparison to other EU nations, in order to establish a quickly available and viable business model for CCS).	Authorities (e.g. Croatian Hydrocarbon Agency, Croatian Energy Regulatory Agency)	Short-term with continuous efforts
	A6.2	Provide initial financial support for the CO_2 network operator to build out the network, with a view of recuperating the investment via e.g. revenues resulting from the commercial usage of the CO_2 transport and storage infrastructure by the emitters.	Government, private sector	Short-term with continuous efforts
	A6.3	Uncertainty in the assessment of revenues and costs should be minimized through financial instruments and risk compensation should be ensured .	Government	Medium-term with continuous efforts
	A6.4	Costs for concessions, data collection and permits should be comparable to similar costs of other processes related to underground development and exploitation in Croatia.	Authorities (e.g. Croatian Hydrocarbon Agency)	Short-term with continuous efforts

Key action	Number	Approach	Stakeholders	Timeline
	A6.5	The regulatory framework should be continuously improved: the relevant oversight institutionsal bodies should ensure that they are practically involved (on site) in the construction of CCS facilities (as a monitoringcontrol body), but also during CCS operations, so that they are able to report which parts of the regulatory framework are not effective	Authorities (e.g. Croatian Hydrocarbon Agency)	Medium-term with continuous efforts
	A6.6	CO_2 transport and storage could be developed at industrial scale based on business models that would/should be presented within the regulatory framework, encompassing items such as liability transfer, third-party access etc.	Authorities (e.g., Croatian Hydrocarbon agency, Croatian Energy Regulatory Agency)	Medium-term with continu-ous efforts

B) Policy, standards and regulations

Key action	Number	Approach	Stakeholders	Timeline
Policies	B1.1	The first step in de-risking investments and enabling the upscaling of CCS projects would be to cover all CCS aspects in the existing and future strategic documents, and define the relations between all key actors in the CCS chain (from capture, through transport to storage). This would further enable the development of the CO_2 market. The government should follow the evidence (reports by IPCC, IEA, etc.) regarding the role of CCS in achieving climate-neutrality and amend the future climate strategy accordingly	European Commission, Government, Croatian Hydrocarbon agency	Short-term with continuous efforts
	B1.2	Norway and UK can be taken as countries with policies that are useful to follow as the most mature examples. Outside Europe, lessons from 45Q (USA) can be taken, and developments of Investment Tax Credit for CCUS in Canada should be followed.	European Commission, Government, Croatian Hydrocarbon agency	Short-term with continuous efforts
Guidelines and standards	B2.1	Define a clear CCS taxonomy after the participation to the ISO technical committees (as participants or observers to gain more knowledge about major issues related to the deployment of the technologies)	European Commission, Government (Croatian, but also of neighbouring non-EU countries)	Short-term
	B2.2.	Create CCS permitting workflow with clearly designated responsible entities for each step to ensure the standardisation of the CCS projects, which would eventually lead to higher reliability of projects and higher chance of success.		

Key action	Number	Approach	Stakeholders	Timeline
Regulatory framework	B3.1	The CCS Directive has been transposed and is part of the Croatian legal framework. However, the exploration and development fees should be lowered for CCS projects to become competitive to other energy-related projects.	Government	Short-term
	B3.2	There are already existing regulations regarding CO_2 storage that cover monitoring methods[5]. Long-term monitoring risk (due to the possibility that a company – the storage site operator – will go bankrupt or disappear) should be minimized by establishing a shorter, but financially more intensive liability period for the operator and a "Long-term risk reduction and monitoring fund" managed by CHA or another similar body, and financially supported by more than one source (e.g. not only storage operator).	Government, Croatian Hydrocarbon agency	Short-term with continuous efforts
	B3.3	CCS should be more encouraged through fiscal incentives (tax reductions for companies taking significant part in the CCS chain), financial incentives (funds) etc.	Government, private sector	Short-term with continuous efforts
	B3.4	London Protocol should be ratified	Government	Short-term
Strategies for CCS application for industrial decarboni-sation and climate	B4.1	Currently, CCS is not mentioned in any national strategy in the context of industrial decarbonization, and this could be changed if the EU agreed on a more strict but reasonable and realistic regulatory and policy framework regarding CCS as one of the most efficient means for the desired emission reduction.	Government, European Commission, Different ministries Croatia's Energy Transition Council	Short-term with continuous efforts

[5] According to the Croatian Hydrocarbon Agency, existing regulations regarding CO_2 storage cover even monitoring methods allowed and desired but this Ordinance (NN 95/2018) should be revised as to unambiguously define the bodies responsible for each step of the CCS chain

Key action	Number	Approach	Stakeholders	Timeline
neutrality of the economy				
	B4.2	There are no national strategies currently in force that explicitly support or encourage blue hydrogen production, bioenergy CCS, direct air CCS or waste-to-energy with CCS, and the awareness about these policies could be raised. Hydrogen strategy has been recently completed, and blue hydrogen (as a way to reduce CO_2 emissions from the use of natural gas) is not mentioned, only grey and green hydrogen were considered.	Government, Ministry of Economy and Sustainable Developmen, Croatian Hydrocarbon agency	Short-term with continuous efforts
	B4.3	Set mandatory LCA for all CO_2 removal, storage, utilization and avoidance projects, including projects of CO_2 injection to producing hydrocarbon fields as potential form of permanent carbon storage [6]	Government, Croatian Hydrocarbon agency	Short-term with continuous efforts
Enabling environment for CO_2 market	B5.1	Provide transport infrastructure for clusters including small emitters. Standardized emission estimates should be regularly checked.	Government, network operators, Croatian Energy Regulatory Agency	Medium-term with continuous efforts
	B5.2	More strict emission taxation to encourage emitters to get involved in the CCS chain[7]	Public and private sector	Short-term with continuous efforts

[6] This can be achieved by including in the legal framework the LCA and comparative studies of CO_2 storage during the production at the same hydrocarbon field, and CO_2 storage after the hydrocarbon depletion. CO_2 during HC production can be classified as CCS if such analyses show that the project is carbon negative (e.g., with CO2 retention of more than 60% and the ability to reinject all created CO2) (such as in some US states), providing better business earlier implementation opportunities for CO_2 storage.

[7] As, within the current circumstances, the emitters are the least motivated to invest, this should be coupled with incentives (e.g., national and EU funds distributed so that the majority of the foreseen budget is dedicated to installation of capture units, and the rest of the budget dedicated to transport and storage).

Key action	Number	Approach	Stakeholders	Timeline
Resilience of CCS strategies	B6.1	Define the rights and obligations (responsibilities, liabilities) of each actor in the CCS chain in the national CCS regulatory framework, including the time-frame within which these rights and obligations are effective for each actor	Government, Croatian Hydrocarbon agency	Short-term with continuous efforts

C) Stakeholder engagement, cooperation & know-how dissemination

Key action	Number	Approach	Stakeholders	Timeline
Engagement with stakeholders	C1.1	Official webpage (**online knowledge platform**) should serve as a gathering point for all interested parties as it could be organized so that different stakeholders have different roles. Furthermore, the Community Advisory Board could be a more exclusive group of stakeholders responsible for the communication with the policy makers and civil society	Government, all interested parties (NGOs, industry representatives, research and academia representatives, etc.)	Short-term with continuous ef-forts
	C1.2	Building trust among the key actors based on the transparency of business and clear contracts but the basis for this should be embedded in the national legislation. There should be an official document clearly defining the technological readiness levels, and setting up a criterion for assessing a project's overall feasibility through life cycle cost assessment (LCCA), including environmental aspects. All this should be clearly	Government, all interested parties (NGOs, industry representatives, research and academia representatives, etc.)	Short-term with continuous ef-forts

Key action	Number	Approach	Stakeholders	Timeline
		presented to stakeholders[8] using several universal indicators that show the risk level of the project and the range of potential financial gains, as well as a clear flowchart (or conceptual Gantt chart that includes the timeline for approval) for the actions required before the CCS chain starts.		
International/ regional cooperation	C2.1	Cross-border cooperation should be encouraged by bilateral or trilateral fundings on an international level, and international knowledge sharing through CCS platform. More public discourse on CCS is needed in general, particularly cross-border debate in the region.	Government (Croatian but also of neighbouring non-EU countries), European Commission	Medium-term with continuous efforts
	C2.2	Emitters should form clusters based on their location, and the transport network or infrastructure should be built to connect the sources to sinks in the most efficient way without state borders representing an obstacle (cooperation should imply undisrupted flow schedule of CO_2 no matter the transport means). Realistic and viable projects with clearly highlighted benefits should be presented to best utilise the opportunities offered by SET Plan/TEN-E/TEN-T/IPCEI/Innovation Fund at the EU level	Emitters, transport operators, storage operators	Medium-term with continuous efforts
Stakeholder cooperation towards CO_2 market	C3.1	All sectors could work together along the CCS chain: Smaller emitters can form clusters among each other (having in mind that not all emitters belong to the same industry) to reduce the costs and make agreements such as joint ventures, contracts with responsibility and costs allocation (in line with the legislation) with one big or several smaller CO_2 users. Transport operators would work both with emitters and storage operators.	Emitters, transport operators, storage operators	Medium-term with continuous efforts

[8] As the market develops, actors will probably change their motivation, and different groups will have different opportunities to influence at different times but they should always have the access to know-how, and be engaged in the policy making process

Key action	Number	Approach	Stakeholders	Timeline
	C3.2	To enable and upscale the cooperation between various sectors, the authorities should propose a way of detecting and financially protecting the “weakest” actor in the chain considering the opera-tional uncertainty and sensitivity to market conditions	Authorities (e.g., Croatian Hydrocarbon agency, Croatian Energy Regulatory Agency)	Medium-term with continu-ous ef-forts

D) Social aspects and public support

Key action	Number	Approach	Stakeholders	Timeline
Build public support	D1.1	Have regular updates (technological, political, financial, research) on the webpage with annual appearances in the media and regular workshops/seminars/conferences presenting current state of the art.	Government, all actors from the CCS chain, media representatives	Medium-term with continuous efforts
	D1.2	Government should coordinate the whole initiative but everyone should have their role according to their share in the CCS chain	Government, all actors from the CCS chain, media representatives	Medium-term with continuous efforts
	D1.3	The importance of the already existing decarbonization strategies that include CCS in the pathway should be stressed out and disseminated in media[9]	Government and all interested parties	Short-term with continuous efforts
Building awareness	D2.1	Government should work on the promotion of CCS activities (including regular events) through their websites and other media, (TV, radio, influencers), but all the stakeholders should highlight their involvement in the chain on their websites.	Government, all actors from the CCS chain, Academia representatives , media representatives	Short-term with continuous efforts

[9] This can be done through (1) Workshops, seminars and discussion panels, with relevant actors, and other interested parties being organized by the forerunners in this field, (2) Media announcements and interviews with CCS experts, (3) Changes in curricula high-schools, adding new courses to university study programmes

Key action	Number	Approach	Stakeholders	Timeline
	D2.2	The fastest and inexpensive way for increasing the level of awareness of CCS technologies would be through social media promotion, preparing short, free but irresistibly inviting online presentations (videos). Politicians (who occupy the majority of television and radio time) should be obliged to frequently visit transitional technology awareness and soft-engineering seminars.	Government, all actors from the CCS chain, Academia representatives, media representatives	Short-term with continuous efforts
Improving fairness of the decision-making process	D3.1	Potentially affected communities should have insight into development and progress of each project, and have some influence on further decisions regarding the implementation of those projects	Municipalities, private sector, NGOs	Medium-term
Communication of costs, risks and benefits of CCUS projects	D4.1	The method for feasibility assessment should be clear and straightforward, and the final presented result should comprise of easily understandable indicators.There should be a person (or department) for communication and public informing about costs, benefits and risks of particular low-carbon projects, including CCS.	Policy makers, Ministry of Finance	Short-term
	D4.2	There is a long-lasting experience of engineering and activities related to research of deep underground formations in Croatia, and this should be systematically emphasized for population of wider, so far uninteresting areas to accept that it is not dangerous, and could also be beneficial	Media representatives, government on their social media	Short-term, until it is accepted

Key action	Number	Approach	Stakeholders	Timeline
Making sure the CCS project fits within the local context	D5.1	Local and regional spatial plans should be accordingly adjusted to align specific CCS projects within the local context, but this can be supported and accelerated by government decisions	Government, local authorities	Medium-term
Building trust in decision-makers and other relevant stakeholders	D6.1	Decision-makers should fully involve other stakeholders in the decision-making process and receive their regular feedback on how it works in practice, and in case something that sounded good in theory showed to fail in practice, be ready to react and adapt their decision.	Policy makers, emitters, transport operators, storage operators, academia, public	Medium-term
	D6.2	The level of knowledge should be raised through educational but interesting video-clips, quizzes, games, competitions. Methods, such as a “climate change awareness” test, the results of which might be regarded a positive in job applications, should be used.	Policy makers, emitters, transport operators, storage operators, academia, public	Medium-term

Chapter 4. Next and immediate steps

The lack of knowledge about CCS technologies is the biggest obstacle for their faster development in Croatia. The text in previous chapters reveals that inconsistent and unbalanced resources and focus for different decarbonization concepts lead to inefficient strategies, funding, financial schemes and legal framework. All of this is to say that explicit and consistent LCCA procedures, as well as consistent TRL estimations, should be required in legal documents, and the findings should be properly provided to the knowledge platform.

Public awareness should be increased through clearly presented quantities of CO_2 avoided or CO_2 removed by using CCS and other low-carbon technologies, emphasizing climate impact (in case of CCS, CO_2 emission reduction is in the order of magnitude of hundreds metric megatonnes), but also analyzing socio-economic (e.g. number of jobs created or lost, industrial competitiveness, increase of taxes to private persons, income to local communities etc.), and financial aspects.

Clustering of smaller emitters is crucial part of CCS implementation, meaning there should be fiscal system in place, possibly even national CCS market, cross-border business opportunities and information sharing which will help assembling critical mass of stakeholders with similar interests.

Given that CCS implementation necessitates the development of new types of experts in a variety of sectors (from emitters to transport and storage operators), a trustworthy, financially secure, and transparent system should be developed, with the most practical element being the availability of a permitting flowchart, along with cheat-sheets for the steps required to obtain financial support, begin CCS exploration, and finally begin operational CCS chain..

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