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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

Croatia

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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

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Glossary

45Q – Section of the Internal Revenue Code of the United States of America regarding the credits for carbon oxide sequestration.

BIO CCUS – bioenergy with carbon capture, utilization and storage

CCfD – Carbon contract for difference

CCS – Carbon capture and storage

CCU – Carbon capture and utilization

CCUS – Carbon capture, utilization and storage

CHA - Croatian Hydrocarbon Agency

DOOR – Society for Sustainable Development Design

DSA – Deep saline aquifer

EC – European Commission

EDS - Strategy of Energy Development of the Republic of Croatia until 2030 with a View on 2050

e-fuels – electrofuels

EGR – Enhanced gas recovery

EOR – Enhanced oil recovery

ETS – Emissions Trading System

EU – European Union

EUA – European Union Allowance

FSB – Faculty of Mechanical Engineering and Naval Architecture

GDP – Gross domestic product

HERA – Croatian Energy Regulatory Agency

HF – Hydrocarbon field

HRK – Croatian Kuna, currency

IRB – Institute „Ruđer Bošković“

LCA – life cycle analysis

LCS - Strategy of Low-carbon Development of the Republic of Croatia until 2030 with a View on 2050

LNG – Liquefied Natural Gas

MINGOR – Ministry of Economy and Sustainable Development

Mt – Mega ton

NECP - Integrated National Energy and Climate Plan for the Republic of Croatia for the Period of 2021-2030

NGO – non-governmental organization

OG – Official gazette

OPEX – Operative expenditures

ORC – Organic Rankine cycle

P2G – Power to gas technology

PtL – Power to liquids technology

RGNF – Faculty of Mining, Geology and Petroleum Engineering

TRL – Technological readiness level

UNIZG – University of Zagreb

WAG – Water alternating gas

ZA – Zelena Akcija

Chapter 1. CCS and CCU: current state and past experiences in Croatia

Croatia is a country at the crossroads of Central and Southeast Europe on the Adriatic Sea. It borders Slovenia to the northwest, Hungary to the northeast, Serbia to the east, Bosnia and Herzegovina and Montenegro to the southeast. It shares a maritime border with Italy to the west and southwest.

Croatia is subdivided into 21 counties (in Croatian, *županije*). Each county is headed by a county government which in turn is led by a county prefect.

The economy of Croatia is a developed, high-income service-based economy, with the tertiary sector accounting for 60% of total gross domestic product (GDP). Average GDP differs substantially among the Croatian counties. While in the city of Zagreb GDP per capita was about € 22 000 in 2018, most other counties only featured GDP levels of around 10 000 €.

While Croatia depends heavily on importing oil and gas, it covers substantial demand from its own oil and gas fields located in Pannonian Basin. Offshore, there are several natural gas fields, but they are near the end of production and probably will be abandoned in the next ten years.

1. Description of relevant domestic economic sectors

Relevant domestic sectors are generally involved in:

1. Industries that emit CO_2,
2. Parties interested in utilization of CO_2,
3. Companies that can provide transport infrastructure for CCU/CCS, and
4. Companies that can perform analysis and monitoring of suitable storage sites, design and implement compression, well-completion and injection of CO_2.

By observation of available emissions at point-sources, the emitters can be divided into two categories:

1. Emitters with significant emissions which are available for capture, compression and transport of CO_2
2. Smaller companies - emitters that, at current state, cannot find (economically) feasible scenario for CO_2 capture, and after that for joining some transport system/network and joining some CCU/CCS cluster

1.1. Carbon-intensive sectors of the Croatian economy

Carbon intensive sectors can be sorted out (those that are included in EU ETS in Croatia are bolded):

1. **Ammonia and nitric acid production (fertilizer plants)**
2. **Cement**
3. **Chemicals (plastics production etc.)**
4. Food processing
5. **Glass manufacture**
6. **Iron and steel**
7. **Lime manufacture**
8. **Ceramics manufacture**

9. **Mineral wool manufacture**
10. Mining and quarrying
11. **Non - ferrous materials (e.g., aluminum)**
12. Oil and gas production
13. **Oil and Gas refining**
14. **Power**
15. **Pulp and paper**
16. Textile industry
17. Other

In Annex A the list of all facilities that are included in EU ETS in Croatia are provided. The most emissions (and the most perspective for CO_2 capture) are from electric power generation, oil and gas refining and cement industry and fertilizer plant as well (Figure 1.1.)

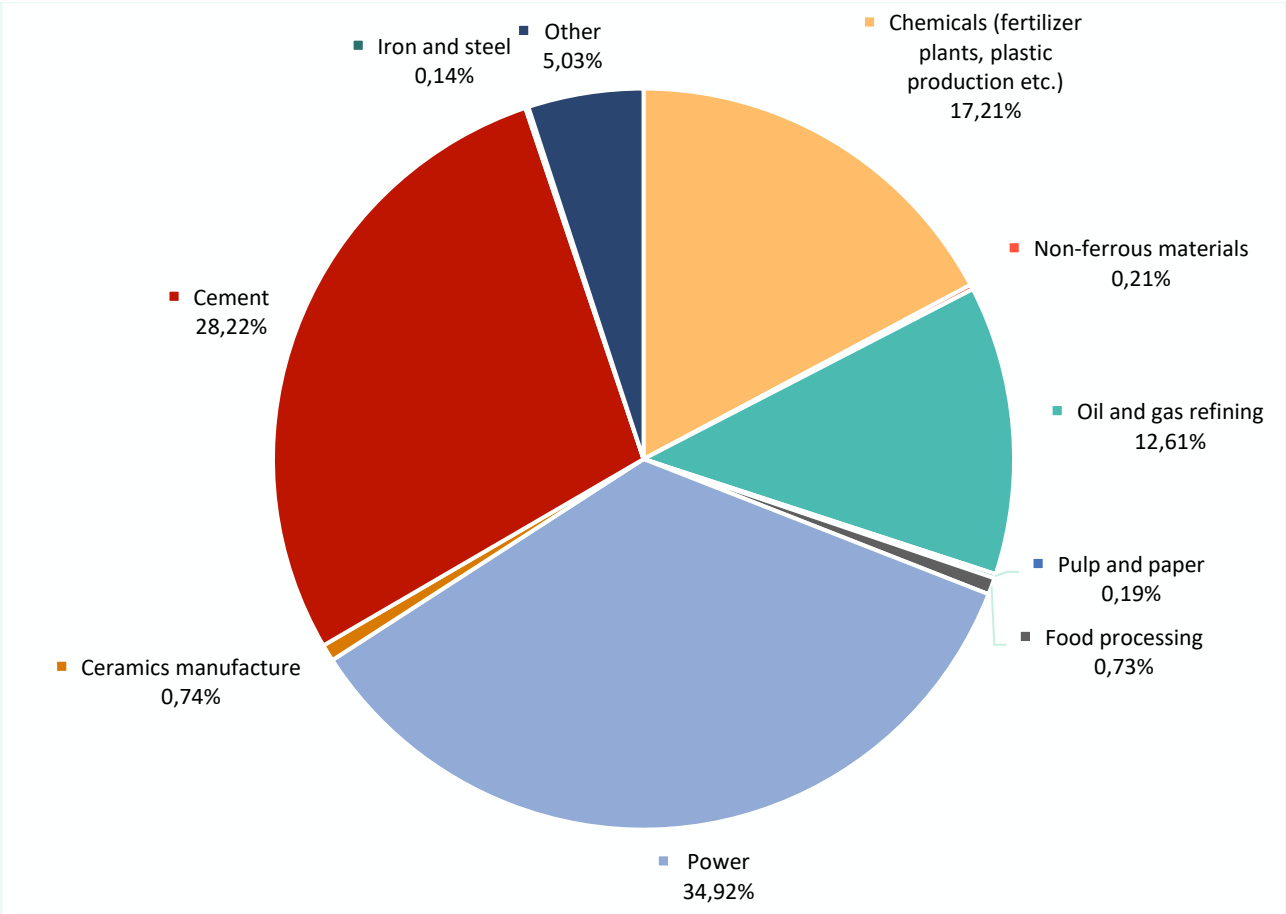

FIGURE 1.1. VERIFIED EMISSIONS WITHIN EU-ETS IN CROATIA (DATA FROM CROATIAN ENVIRONMENTAL POLLUTION REGISTER, 2019)

1.2. Major CO_2 emitters in Croatia

CO_2 emissions in 2019 for emitters that emitted more than 100 kt in the last 5 years are presented in Table 1.1. while the Figure 1.2 depicts the trend of their emissions in the last 5 years.

TABLE 1.1. LARGEST CO_2 EMISSION SOURCES IN CROATIA (DATA FROM CROATIAN ENVIRONMENTAL POLLUTION REGISTER, 2019)

Emitter	2015 (kt/year)	2016 (kt/year)	2017 (kt/year)	2018 (kt/year)	2019 (kt/year)
Power Plant Plomin	2.028	2.255	1.229	1.158	1.349
Oil Refinery Rijeka	992	983	983	1.005	708
Petrokemija Fertilizer Factory	819	795	852	750	822
CEMEX Cement Factory "SVETI JURAJ"	745	602	755	687	642
NEXE Cement Factory	522	517	601	645	667
Combined Heat and Power Plant Borovje (TE-TO Zagreb)	411	440	836	551	649
Oil Refinery Sisak	328	318	361	312	308
Holcim Cement Factory Komoračno	267	329	335	326	329
Central Processing Unit for Natural Gas Molve	267	234	317	295	249
Combined Heat and Power Plant Sisak (TE-TO Sisak)	123	152	352	284	299
Power Plant Trešnjevka (EL-TO Zagreb)	262	243	254	210	206
CEMEX Cement Factory "SVETI KAJO"	261	229	320	204	157
Calucem Cement Factory	108	105	94	114	117
Glasswear Manufacturer Vetropack Straža	103	108	107	106	105
Combined Heat and Power Plant Osijek (TE-TO Osijek)	91	99	96	110	107
LIKA ENERGO EKO Cogeneration	295	30	30	17	25
Cogeneration Biomass Plant Uni Viridas	N/A	96	95	102	101
Fractionation facilities Ivanić Grad	40	61	66	74	134
Total	7662	7596	7683	6950	6974

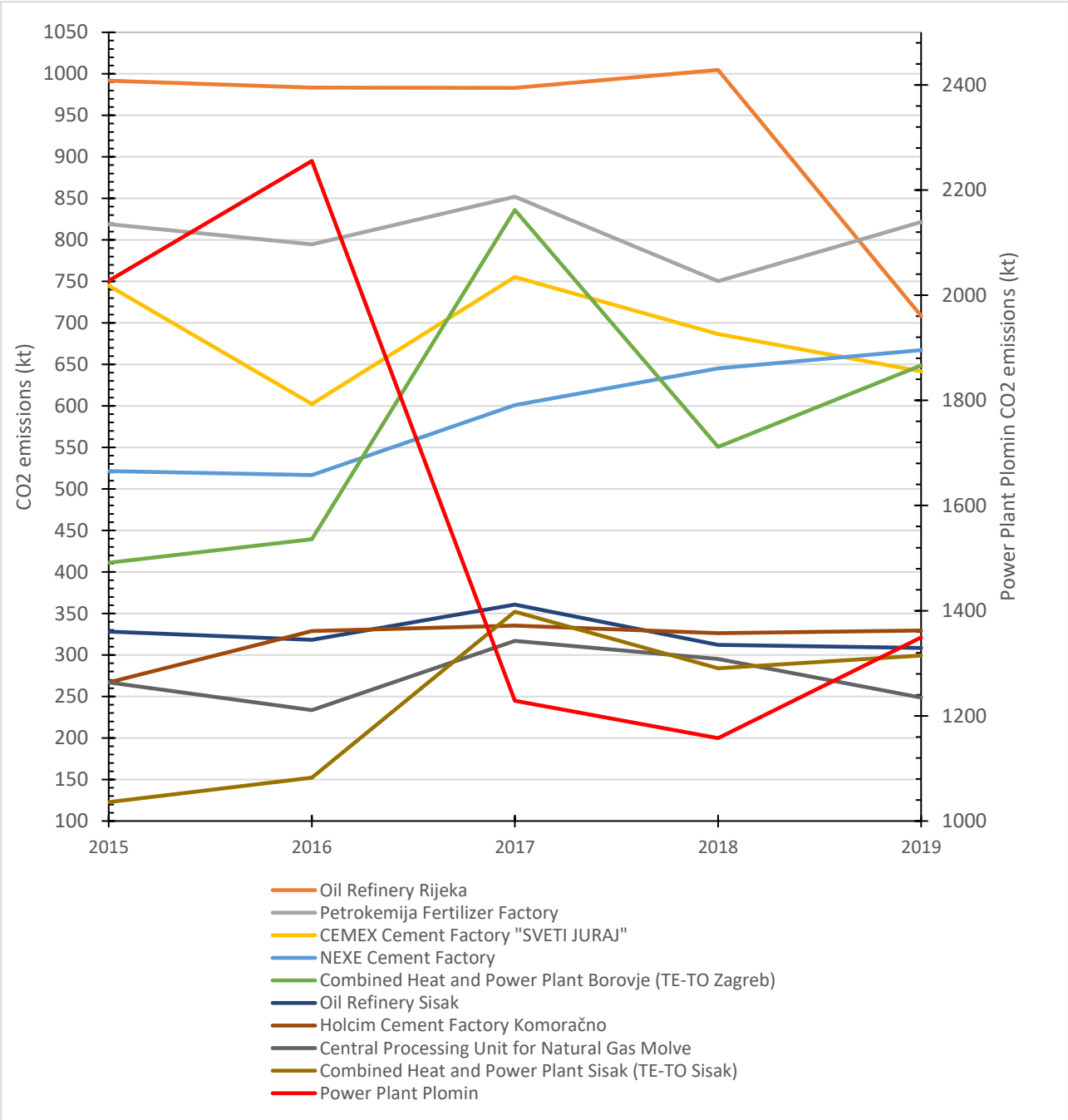

FIGURE 1.2. CO_2 EMISSIONS FOR 10 LARGEST SOURCES IN THE LAST 5 YEARS

For better understanding of the industry sector impact on Croatian economy, GDP structure is presented by the Table B.1 (Annex B) and Figure 1.3.

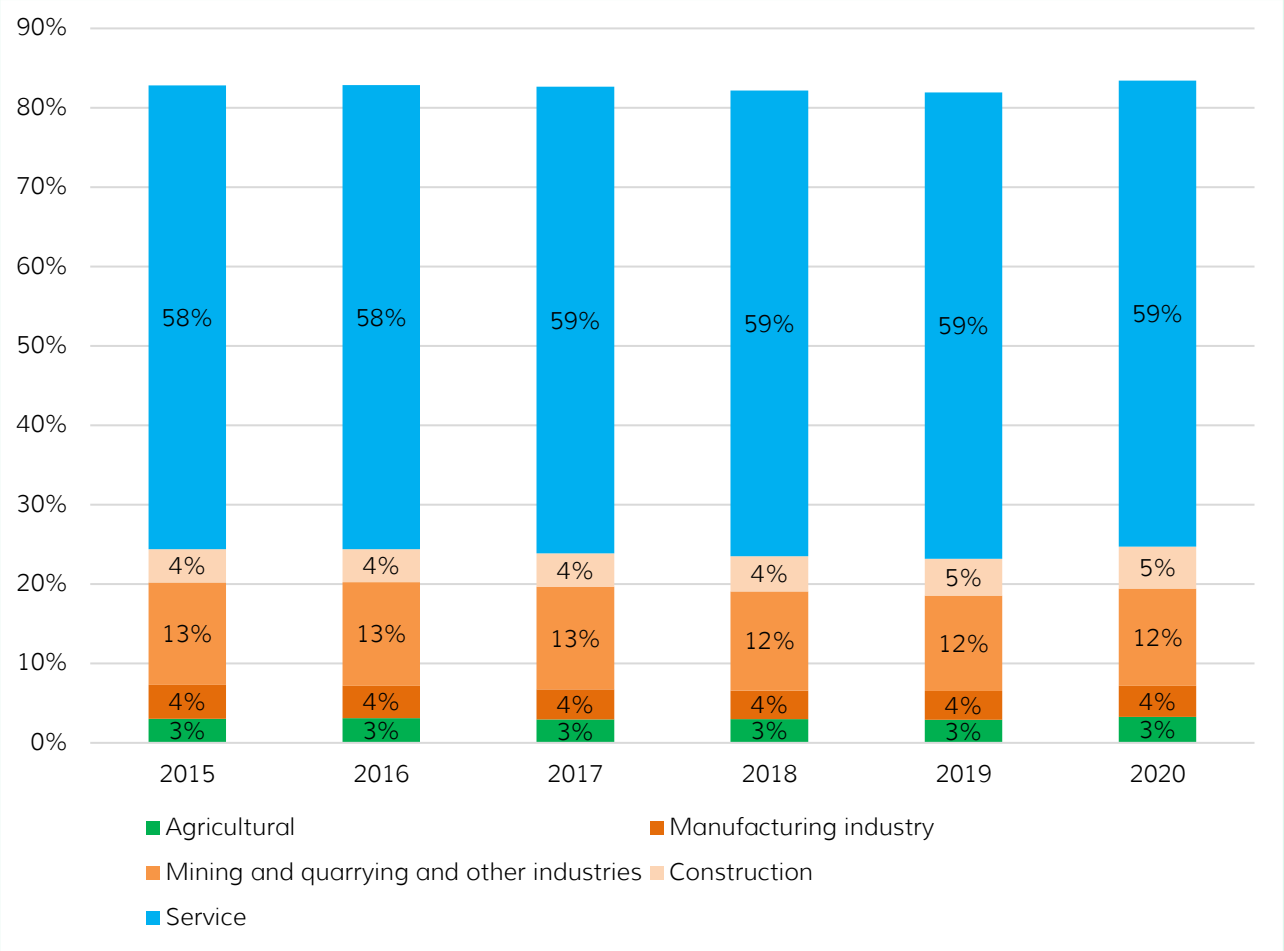

FIGURE 1.3. PERCENTAGE OF CROATIA'S GDP PER SECTOR (SOURCE: CROATIAN BUREAU OF STATISTICS, 2021)

In the Figure 1.3., industrial sector is divided into three subsectors (shades of orange). In the last 5 years, industry's GDP ratio varied from 20,26 % to 21,45 % with a decreasing trend (exception is 2020). All of the subsectors in the industry could mitigate their CO_2 emissions by deploying either CCS or CCU and therefore, complete industry's share in Croatia's GDP represent a share which can be affected by CCS/CCU implementation. Highest yield in GDP is related to tertiary sector (service sector) which is understandable since Croatia's GDP mainly depends on and is driven by tourism and its related activities.

Another approach for grading carbon intensive industry in Croatia is to observe its carbon intensity, i.e., mass of CO_2 emitted per unit of GDP (Figure 1.4.).

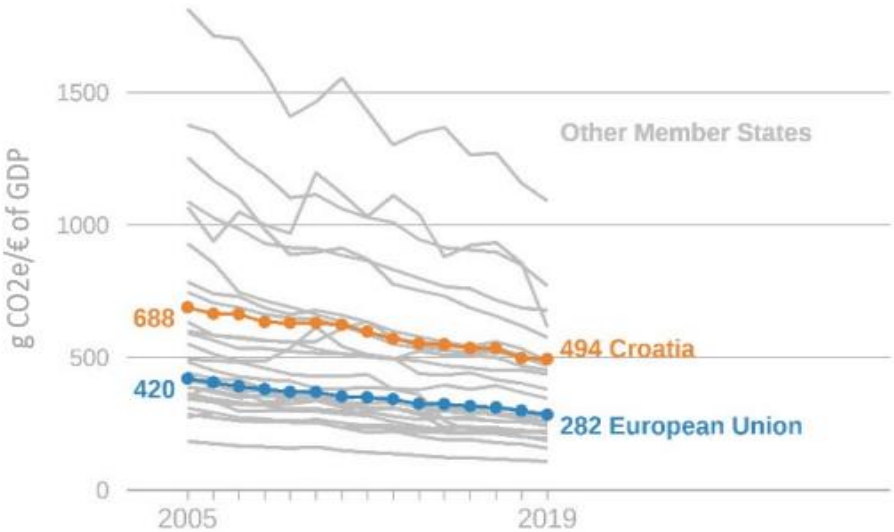

FIGURE 1.4. CARBON INTENSITY OF THE CROATIAN ECONOMY (CLIMATE ACTION IN CROATIA, 2021)

From the Figure 1.4. can be concluded that Croatian industry is below EU average regarding environmental efficiency.

2. Assessment of geological potential for CO_2 storage

Most of the CO_2 storage capacity potential in Croatia (over 90%) is in six regional deep saline aquifers (Table 1.3, Figure 1.5) related to the size of the aquifers in opposition to hydrocarbon field (HF) storage type size. It is important to emphasize that, due to many years of experience in oil and gas production, in the case of hydrocarbon fields, there are more data in the existing database of geological, geomechanical and geophysical data. For HF injection locations, there are some existing facilities and technology on-site, i.e., CO_2 injection can be implemented with less uncertainty at less capital cost. Hence, there is the most important difference between the two sums given below – 17 HFs are much closer to future development, while 6 mentioned deep saline aquifers (DSA) are only the theoretically available regional rock formations that still need to be properly explored in order to define the most prospective sites.

TABLE 1.3. CROATIAN CO_2 STORAGE CAPACITY PER STORAGE TYPE

Storage type	Number of units	Storage capacity (Mt)
Hydrocarbon field	17	175
Aquifer	6	3 186

Main features of potential aquifer and hydrocarbon field storage sites are presented in Table 1.4. More than 80% of storage capacity is located onshore (Figure 1.5.). So far, the capacity of only one offshore aquifer and three offshore gas fields has been estimated. On the other side, roughly 50% of emissions occur in the continental Croatia and 50% in the littoral, which increases the importance of the transport system (because littoral emitter would need to be connected to onshore sites) and at the same time means that the early starters projects are likely going to happen inland.

The most of storage potential (141 Mt CO_2) in hydrocarbon fields is in gas fields (Figure 1.6.). In the case of implementing enhanced gas recovery (EGR) / enhanced oil recovery (EOR), CO_2 storage capacity at the end of the EGR/EOR project would increase proportionally to the additionally produced quantities of hydrocarbons.

TABLE 1.4. CHARACTERISTICS OF POTENTIAL CO_2 STORAGE UNITS (DATA FROM EU GEOCAPACITY, 2009 AND STRATEGY CCUS, 2020)

Storage unit name	Storage type	Content	Onshore / offshore	Lithology	Depth (m)	Storage capacity (Mt)
Poljana	Aquifer	-	Onshore	Sandstone	1450	251,6
Okoli	Aquifer	-	Onshore	Sandstone	2000	229,0
Iva	Aquifer	-	Onshore	Sandstone	2050	55,1
Drava	Aquifer	-	Onshore	Sandstone	900	1.938,9
Osijek	Aquifer	-	Onshore	Sandstone	1000	109,9
Dugi Otok	Aquifer	-	Offshore	Sandstone	1515	601,7
Kloštar	Hydrocarbon field	Oil	Onshore	Sandstone / Granite	973	2,7
Ivanić	Hydrocarbon field	Oil	Onshore	Sandstone	1619	5,5
Žutica	Hydrocarbon field	Oil	Onshore	Sandstone	1699	10,1
Okoli	Hydrocarbon field	Gas	Onshore	Sandstone	1750	7,3
Stružec	Hydrocarbon field	Oil	Onshore	Sandstone	727	1,7
Lipovljani	Hydrocarbon field	Oil	Onshore	Sandstone	1026	3,2
Gola Duboka	Hydrocarbon field	Gas	Onshore	Carbonate	2521	5,8
Molve	Hydrocarbon field	Gas	Onshore	Breccia/Carbonates/Metamorphic rocks	3100	42,8
Kalinovac	Hydrocarbon field	Gas	Onshore	Carbonates/Metamorphic rocks	3054	31,6
Stari Gradac	Hydrocarbon field	Gas	Onshore	Clastics / Carbonates / Metamorphic rocks	3450	3,5
Beničanci	Hydrocarbon field	Oil	Onshore	Carbonate breccia	1700	8,8
Boksić	Hydrocarbon field	Gas	Onshore	Sandstone	1519	13,7
Legrad	Hydrocarbon field	Gas	Onshore	Sandstone	1635	4,1
Šandrovac	Hydrocarbon field	Oil	Onshore	Sandstone	750	2,9
Ida	Hydrocarbon field	Gas	Offshore	Sandstone	870	10,5
Ika	Hydrocarbon field	Gas	Offshore	Sandstone/Carbonate	1300	11,9
Marica	Hydrocarbon field	Gas	Offshore	Sandstone	1010	9,7

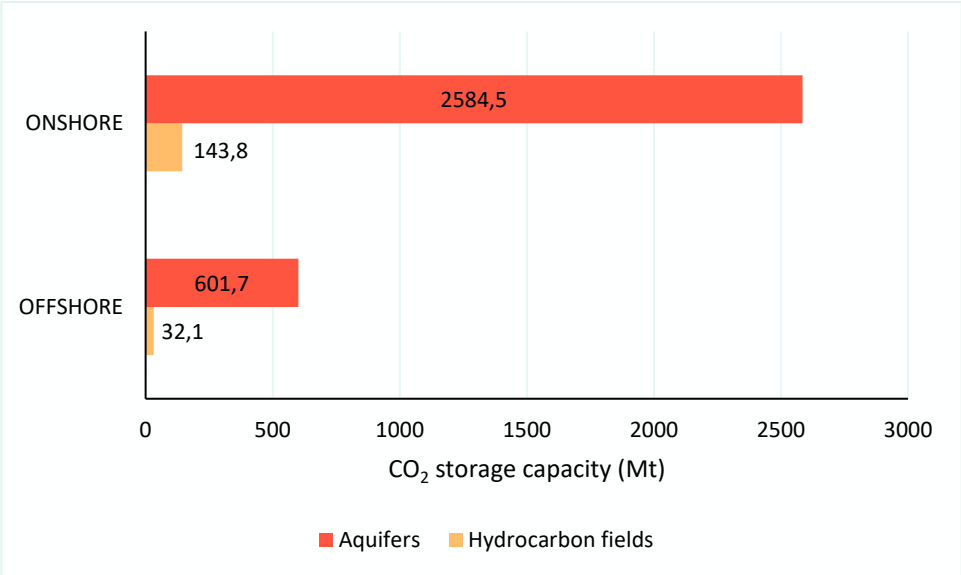

FIGURE 1.5. OFFSHORE AND ONSHORE CO_2 STORAGE CAPACITY (MT) PER STORAGE UNIT TYPE

FIGURE 1.6. CO_2 STORAGE POTENTIAL (LEFT, IN MT) AND NUMBER OF PERSPECTIVE STORAGE LOCATIONS IN CROATIAN HYDROCARBON FIELDS (RIGHT)

As part of the Strategy CCUS project (D2.2), the CO_2-EOR potential of oil fields in Croatia was (re)assessed using the water alternating gas (WAG) injection strategies (Table 1.5.). Field oil production and both injected and produced quantities of CO_2 vary in time. Therefore, the minimum, maximum and average yearly values of mentioned parameters over 15 years period are observed (Table 1.5.). In the case of CO_2-EOR, the CO_2 is separated from produced petroleum gas and oil stream and then re-injected together with CO_2 brought to the CO_2-EOR facility. However, the economic feasibility of CO_2 reinjection is questionable, and operating costs will be volatile (depending on CO_2 price and oil price), especially in periods after CO_2 breakthrough to producing wells, during which the production of oil decreases and production of CO_2 increases. The uncertainty about the feasibility of CO_2 reinjection is due to the fact that the timing of CO_2 breakthrough and the amount of CO_2 to be captured can be difficult to predict. The need for CO_2 for CO_2-EOR is significantly higher than what is available / emitted by Croatian largest emitters (6974 kt in 2019) close to the utilization (hydrocarbons production) site. Consequently, full development of CO_2-EOR technology would require a capture and transport system to be built which could also include building the cross-border connections for CO_2 transport.

TABLE 1.5. CO_2 EOR POTENTIAL IN CROATIA

Oil Field	CO_2 injected (kt/year)			CO_2 produced (kt/year)			Oil produced (kt/year)		
	min	max	average	min	max	average	min	max	aver-age
Beničanci	3 881	11 820	8 543	828	11 368	5 291	100	600	288
Ivanić	3 743	8 215	5 890	15	7 815	3 501	100	300	138
Kloštar	2 640	5 713	3 958	1 046	5 490	2 519	58	155	91
Lipovljani	152	433	276	0	197	80	155	155	155
Šandrovac	2 206	3 940	2 980	605	2 735	1 274	100	117	102
Stružec	4 373	7 683	5 892	911	7 403	3 593	100	400	250
Žutica	1 223	2 797	1 850	29	2 257	769	100	300	181

To conclude, Croatia has a significant CO_2 storage capacity of 3362 Mt. When accounting for CO_2 emissions in 2019 (for sources larger than 100kt/y) which are equal to approximately 7 Mt, timespan of continuous operations of underground CO_2 storage is 480 years. Considering the certainty level of available data and the activity of INA oil and gas company, CO_2 storage will primarily take place in hydrocarbon fields (capacity of 175,9 Mt) meaning that timespan of the adjacent CO_2 storage is 25 years.

95 % of CO_2 storage capacity in Croatia is represented by deep saline aquifers while the rest 5 % is represented by hydrocarbon fields. 81 % of the potential storage sites are located onshore, while the rest 19 % is located offshore. Since almost equal amounts of CO_2 emissions come from continental and littoral part of Croatia, connection of littoral CO_2 sources with inland storage units via pipelines should be considered.

2.1. CO_2 Transport infrastructure

For the transport of CO_2 in Croatia (and cross-border transport), there are four possibilities:

- Onshore pipeline transport
- Offshore pipeline transport
- Ship Transport
- Railroad

The transport infrastructure represents a key connection parameter of the emitters and storage units (Figure 1.7.).

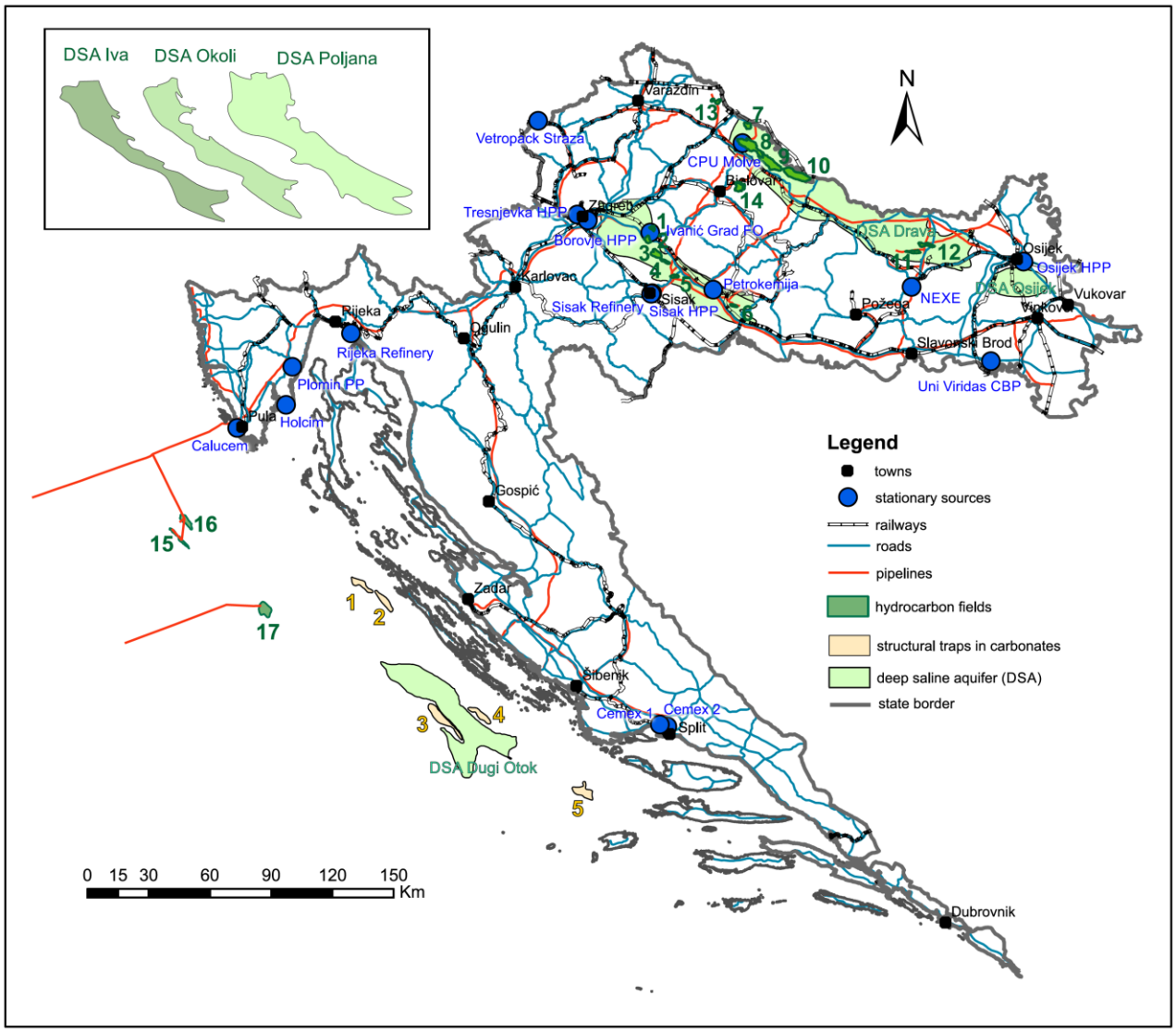

FIGURE 1.7. CO_2 SOURCES (100 KT/Y CRITERIA), POSSIBLE TRANSPORT ROUTES AND POSSIBLE STORAGE SITES (DSA'S IVA, OKOLI AND POLJANA COORDINATES MAINLY OVERLAP AND THEREFORE, ARE SEPARATELY PRESENTED IN THE UPPER LEFT CORNER)

Croatia has a good natural gas pipeline network, which is favorable mainly due to resolved (private) land ownership relations, which usually takes time to be legally prepared. The most important value of existing pipelines are transport routes, and it is expected, that for CO_2 transport technology new pipelines (treated for corrosion and dehydration of CO_2) should be installed near the pipelines for natural gas transport.

Two prospective inland areas emerge:

1. Ivanić and Žutica oil fields (central Croatia)

2. Beničanci oil field (eastern Croatia)

CO_2 EOR processes are underway in Ivanić and Žutica, and the Beničanci field is the largest oil field in Eastern Croatia, which is also close to the emitters in the area and almost certainly has the favorable parameters required for CO_2 EOR.

Most CO_2 emitters are concentrated within a radius of 100 km from their respective promising areas of storage and this distance criterion enables the clustering of relevant stakeholders. Several large CO_2 sources are concentrated near the city of Rijeka. Plomin power plant, as the largest CO_2 emitter in Croatia, is almost 200 km away from the most prospective CO_2 storage sites (northern part of Croatia) and to decarbonize this source some offshore locations would be needed. The three offshore gas fields included above (Table 1.3) would be the first candidates, but it should be noted that 2019 emissions of this source are so large (Table 1.1) that either all three locations will eventually become the storage sites, or additional capacity will have to be found in structurally defined carbonate aquifers that are both deeper and quite more distant from all littoral sources. Regional geology enables that, for details reader is referred to the paper by Saftić et al. (2019).

Offshore CO_2 storage is not considered as intensively as onshore storage because the costs of offshore storage are much higher, transport possibilities are limited and the most promising sites are gas fields (which are still producing, but only for a few years).

Regarding cement production (CEMEX) near the city of Split, there are few options for CO_2 transport and storage:

1. Building offshore transport facilities or
2. Using the existing transport routes and transport CO_2 for more than 300 km to northern Croatia.

Both options are very costly (compared to other regions); offshore option should include further research and development of CO_2 injection strategy into one of the three locations: deep saline aquifer (DSA) Dugi Otok, one structurally defined aquifer in Central Adriatic or connecting with the Ravenna Hub in Italy. In all these solutions, ship transport should also be considered.

Furthermore, there are two emitters in the mainland which might consider CO_2 pipeline transportation as problematic:

1. Uni Viridas cogeneration biomass power plant; Their CO_2 emissions are low and they are not near any existing gas pipeline infrastructure
2. Vetropack Straža glassware production; Pipeline infrastructure exists and connects the emitter with potential storage units, but due to their low emissions and large distance from storage units, economic feasibility is questionable.

Since most of the emitters and most importantly largest ones, are located near the existing natural gas pipeline network, in authors' opinion, building the trunkline system (Trunkline option in further text) would be an optimal solution for CO_2 transport on the national level. The logic behind Trunkline option is to use the existing route of natural gas pipeline network to build a new, higher capacity pipeline for CO_2 transport which will gather captured CO_2 from emitters' locations and afterwards direct it towards the storage units. Advantages of this approach are:

- Property legal relations are resolved,
- Some parts of the existing network can be repurposed for CO_2 transport after the demand for natural gas drops.
- Higher capacity than dedicated pipeline, which offers the interested parties who want to transport their CO_2 lower specific costs.
- Emitters and storage operators would mainly need to invest in the construction of the connecting pipeline to the trunkline system.
- The state invests in the construction of the trunkline system (partially funded by the EU financial instruments)
- The trunkline system would be operated by state-owned or private sector operator and thus, its activity would be regulated by Croatian Energy Regulatory Agency meaning that equal conditions for all interested parties would be ensured.

2.2. Connection between sources and sinks - possibilities for CCS and for CCU/CCS (CCUS) through CO_2-EOR

Finally, emitters listed in previous chapters can be included into CCS/CCU system if economic feasibility is certain. That certainty primarily depends on good prediction of emission trends and adjacent EU ETS allowance prices, CO_2 transport capacity, distance from CO_2 sources (Figure 1.7.), and on maximum CO_2 quantities (injection rates) for storage needs and injectivity into storage sites (including CO_2-EOR).

Overall, the networking efforts, studies commissioned and the agreements reached by the industrial stakeholders show that it is most likely that the activities towards CCS/CCU clustering between the oil industry and the cement and fertilizer industry in Northern Croatia will be intensified.

3. Description of implemented and planned projects

There are several projects and project studies regarding CCS/CCU in Croatia, financed by industry and/or by structural funds (Table 1.6.), and two of them (private/industrial investment) are commercially ongoing: CO_2-EOR at Ivanić and Žutica oil fields (operator INA d.d.) and geothermal power plant Velika Ciglena (MB Holding). For other projects, it is hard to estimate storage potential and technological readiness level (TRL), as the public data about projects is very limited, and probably the substantial measurements and data collection was not performed yet, so the TRL numbers are given just as rough estimate.

TABLE 1.6. PROJECTS FINANCED BY INDUSTRY AND STRUCTURAL FUNDS

Project Name	Project type	CO_2 captured /storage potential	Expected starting date (operation)	project status	Project investor/initiator	TRL[1] (for CO_2 use or/and storage)
CO_2 EOR Project Croatia	CO2-EOR	0,560 Mt/y	2014	In operation	INA/MOL	10
Velika Ciglena	Geothermal Binary (Organic Rankine Cycle/ORC) Plant	0,15 Mt/y	2018	In operation	MB Holding	8
Bio-Refinery Project	Industrial Capture and Underground Storage	0,06 Mt/y (additional potential 0,3-0,4 Mt/y)	2024	Signed contracts for design and technology selection	INA MOL	5
Draškovec	Geothermal Plant with CO_2 Re-injection	0,05 Mt/y	2018	Operation delayed from unknown reasons	AAT Geothermae	3
iCORD	Industrial Capture followed by CO_2-EOR	Approx. 1 Mt/y	2025	Feasibility Study should have been prepared by the end of 2020.	INA/MOL	6

3.1. CO_2-EOR projects

From 2001 to 2006, a pilot project CO_2-EOR (WAG) injection on the Ivanić oil field was carried out, and in that period over 5 000 m^3 of oil was produced, which confirmed the success of the pilot project (Novosel et al., 2018). The infrastructure necessary for the implementation of the project was built and the wells were equipped for injection. CO_2 injection in Ivanić started in 2014 and in the northern part of the Žutica field in 2015. The projected quantities of carbon dioxide injection into Ivanić are $400 \cdot 10^3$ m^3/day (around 0.72 kt/day), and for the northern part of the Žutica field $200 \cdot 10^3$ m^3/day. In the Ivanić field, CO_2 is injected into 5 of the 7 reservoirs of the Gamma series (stacked Miocene sandstones), using 12 injection wells, and in the Žutica field, CO_2 is injected through 8 wells into 3 reservoirs of the Gamma series. Over twenty-five years, over $5 \cdot 10^9$ m^3 (around 9 Mt) of CO_2 will be injected into the reservoirs,

[1] Authors' assessment

and according to the results of numerical simulations, and recorded data from the field so far, it is expected that more than 50% of injected carbon dioxide will be permanently stored (Novosel et al., 2018).

It is important to point out that before the CO_2 injection in the Ivanić field, the reservoir pressure was 140 to 150 bar, which is lower than the minimum miscibility pressure, but it was still decided to start the injection under these pressure conditions. From the beginning of injection, until the end of 2017, over 366,85 · 10^6 m^3 of CO_2 (0,73 Mt) were injected and an additional 28,63 · 10^3 m^3 of oil and 7,51 · 10^6 m^3 of gas were produced through the project (Novosel et al., 2018). When the share of CO_2 in the produced gas on some wells increased drastically, it was decided to shorten the periods of CO_2 injection near production wells, which led to a deviation from the original plan for implementing WAG process. In the Žutica North field, the reservoir pressure before injection was 190 bar, which is equal to the minimum miscibility pressure. From the beginning of injection in the Žutica field until the end of 2017, 179,09 · 10^6 m^3 of CO_2 (0,35 Mt) was injected and an additional 6,51 · 10^3 m^3 of oil and 574,14 · 10^3 m^3 of gas were produced through the project (Novosel et al., 2018).

CO_2 source for CO_2-EOR is at Molve Natural Gas Processing Plant (NGPP, operated by INA), where high quality (purity) CO_2 is available because of high CO_2 content in adjacent natural gas fields The pipeline Molve-Ivanić is 88 km long (30 bar).

3.2. Geothermal projects

In most geothermal prospects in Croatia, there is a high CO_2 content in the geothermal water. Velika Ciglena is commercial 15 MW geothermal power plant near the city of Bjelovar. It produces around 10 000 m^3 of geothermal (175°C) water per day with gas to water ratio GWR = 25 m^3/m^3. There is no information about details of degasification facilities and where separated CO_2 is put, but in the future, it will likely have to be recorded and publicly available. Technology for CO_2 injection in this case is not complicated but will cause additional capital investments and operational costs (and energy for CO_2 compression and injection).

For geothermal project Draškovec it is planned to build the hybrid geothermal system facility that will utilize the energy potential of hot brines with dissolved natural gases to deliver combined heat and power. The pilot plant is expected to supply approximately 17 - 18 MWe of power from geothermal plant and natural gas power plant. CO_2 separation, capture and injection capacity is projected at around 0,05 Mt per annum. Technical data about reservoir is not available, and the project is so far presented only as a concept, without technical details on operational parameters. The project is decided officially as *Strategic investment project of the Republic of Croatia* (OG 72/2019).

3.3. Biorefinery project

Bio-Refinery plant (bio-Ethanol production) on the Sisak Refinery location (Sisak-Moslavina County, Sisak 60 km from Zagreb). A new pipeline 16 km long will be built on the existing pipeline route to transport CO_2 to the storage site, which will be able to absorb 60 kt of CO_2 captured in the biorefinery., plus potential 300-400 kt of biogenic CO_2 from CHP. The project is an effort towards transition of INA (oil company) to low-emission technologies, as the plant is some sort of replacement for the oil refinery in Sisak (*part of the compensation measures following the announcement of the closure of the basic refinery at the Sisak location*).

3.4. iCORD project

Industrial CO_2 Capture is planned at several locations (fertilizer plant, power plant, natural gas processing station and/or fractioning facility in central Croatia, cement factory in eastern Croatia and oil refinery in coastal Croatia) for CO_2 storage planned at oil fields in the Croatian section of the Pannonia Basin as the part of new INA CO_2-EOR projects (Figure 1.8.). The project is at study-level and indicates that INA is initiating networking with subjects that can provide CO_2 for further use, as the CO_2-EOR projects in Ivanić and Žutica showed good commercial results. The project seems to be another transition effort of INA.

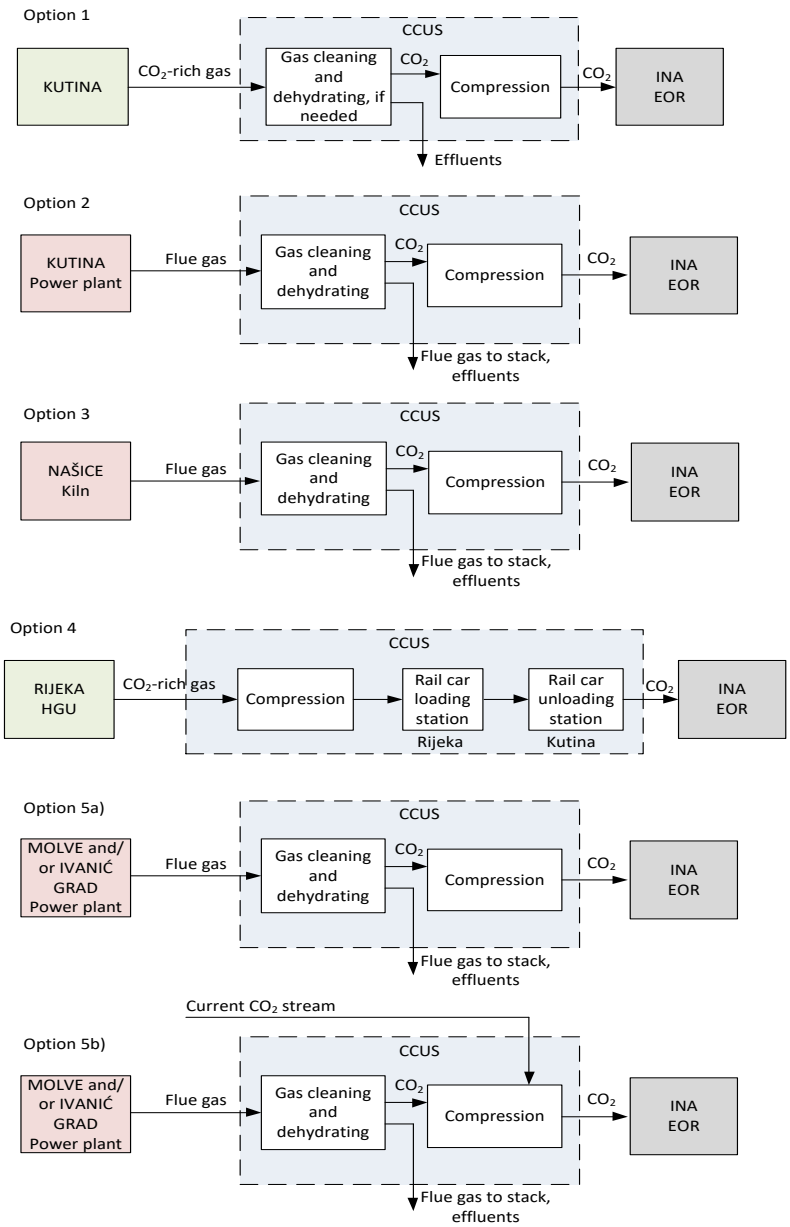

FIGURE 1.8. SCHEME OF THE PROCESSES IN ICORD PROJECT (TENDER, 2020)

4. Legislation and regulation relevant for CCS deployment

Existing legislation and regulation documents relevant for CCS deployment are listed in Tables 1.7 and 1.8. They mainly align the Croatian legislative framework with existing EU Directives related to capture and geological storage of carbon, in the similar manner as those related to renewable energy development and use.

TABLE 1.7 LEGISLATION DOCUMENTS WHICH DIRECTLY REFER TO CCS (MAINLY CO_2 STORAGE)

	Croatian title	Translated title	Year	Code	Type
1.	Pravilnik o trajnom zbrinjavanju ugljikova dioksida u geološkim strukturama (Pravilnik o trajnom zbrinjavanju plinova u geološkim strukturama)	Ordinance on permanent carbon dioxide storage in geological formations (Ordinance on permanent storage of gases in geological structures)	2018 (2013)	OG 95/2018, OG 106/2013	Ministry of Environmental Protection and Energy /Ordinance (Ministry of Economy/Ordinance)
2.	Zakon o istraživanju i eksploataciji ugljikovodika	Law on hydrocarbon exploration and exploitation	2018	OG 52/2018, OG 52/2019, OG 30/2021	Croatian Parliament/Law
3.	Uredba o graničnim vrijednostima emisija onečišćujućih tvari u zrak iz nepokretnih izvora	Regulation on limit values for emissions of air pollutants from stationary sources	2021	OG 42/2021	Government of the Republic of Croatia/Regulation
4.	Uredba o naknadi za koncesiju za eksploataciju mineralnih sirovina	Regulation on the concession fee for the exploitation of mineral resources	2014	OG 31/2014, OG 57/2020	Government of the Republic of Croatia/ Regulation
5.	Pravilnik o istraživanju i eksploataciji mineralnih sirovina	Ordinance on exploration and exploitation of mineral resources	2013	OG 142/2013	Ministry of Economy/Ordinance
6.	Zakon o Rudarstvu	Mining law	2013	OG 56/2013, OG 14/2014, OG 98/2019	Croatian Parliament/Law
7.	Uredba o naknadi za istraživanje i eksploataciju ugljikovodika	Regulation on the fee for exploration and exploitation of hydrocarbons	2020	OG 25/2020	Government of the Republic of Croatia/Regulation

Croatian title	Translated title	Year	Code	Type
8. Pravilnik o stručnoj osposobljenosti za obavljanje određenih poslova u naftnom rudarstvu	Ordinance on professional qualification for performance of specific duties in petroleum engineering	2018	OG 95/2018	Ministry of Environ-mental Protection and Energy /Ordinance
9. Zakon o klimatskim promjenama i zaštiti ozonskog sloja	Law on Climate Change and Ozone Layer Protection	2019	OG 127/2019	Croatian Parliament / Law
10. Pravilnik o rezervama	Ordinance on reserves	2018	OG 95/2018	Ministry of Environmental Protection and Energy /Ordinance
11. Pravilnik o građenju naftno-rudarskih objekata i postrojenja	Ordinance on construction of petroleum engineered facilities and plants	2018	OG 95/2018	Ministry of Environmental Protection and Energy /Ordinance
12. Pravilnik o naftno-rudarskim projektima i postupku provjere naftno-rudarskih projekata	Ordinance on petroleum engineering projects and procedure of petroleum engineering projects verification	2018	OG 95/2018	Ministry of Environmental Protection and Energy /Ordinance

TABLE 1.8. OTHER REGULATIONS AND LAW THAT POSSIBLY CAN AFFECT THE CCS/CCU DEVELOPMENT

Croatian title	Translated title	Year	Code	Type
1. Zakon o energetskoj učinkovitosti	Law on Energy Efficiency	2021	OG 41/2021	Croatian Parliament/Law
2. Zakon o Fondu za zaštitu okoliša i energetsku učinkovitost	Law on the Environmental Protection and Energy Efficiency Fund	2012	OG 107/2003, OG 144/2012	Croatian Parliament / Law
3. Odluka o donošenju Plana korištenja financijskih sredstava dobivenih od prodaje emisijskih jedinica ptem dražbi u Republici Hrvatskoj do 2020. godine	Decision on the adoption of the Plan for the use of financial resources obtained from the sale of emission allowances through auctions in the Republic of Croatia until 2020	2018	OG 19/2018, OG 84/2019	Croatian Government /Decision

4.1. Relevant legislation documents

For better understanding, all legislative documents in Table 1.7 are described in this chapter. It is worth mentioning that the criteria for CCS relevant legislation documents was the explicit mentioning of CO_2 storage in the legal texts.

4.1.1. ORDINANCE ON PERMANENT CARBON DIOXIDE STORAGE IN GEOLOGICAL FORMATIONS (ORDINANCE ON PERMANENT STORAGE OF GASES IN GEOLOGICAL STRUCTURES)

With this Ordinance, the Ordinance on Permanent Storage of Gases in Geological Structures (OG106/2013) ceased to be valid.

Previous legal framework (OG 106/2013)

With this outdated Ordinance, regulatory framework for permanent storage in geological structures on the territory of the Republic of Croatia in economic zones and the continental shelf within the meaning of the United Nations Convention on the Law of the Sea was established (together with the Mining Law and Hydrocarbon Exploration and Exploitation Law). By this ordinance, the following is defined: guidelines for choosing storage space (capacity estimation, geological trap quality, etc.), conditions to obtain exploration permit, storage permit and concession. The obligations of the concessionaire of the storage site expire by transferring the responsibility to the state body (Ministry, Croatian Hydrocarbon Agency). Transfer of responsibility includes covering the minimum projected costs for surveillance for the period of 30 years.

Part of the regulation about CO_2 purity is vague since it is stated that "Composition of the gas should be predominantly CO_2, while the concentrations of other components need to be below the levels which could have a negative impact on the integrity of underground storage, or which represent the risks that could have a significant impact on the environment". The responsibility of ensuring equal accessing rights to the storage is also inadequately defined; it is stated that the access should be allowed if the buyer is willing to pay or if it is economically justified for storage operator, and in that case, improvement of this ordinance is possible by the means of fiscal system on which this regulation can then be applied to.is possible by the means of fiscal system on which this regulation can then be applied to.

Procedures during exploration, data collecting, developing static and dynamic models, hazard detection and surveillance are mainly taken from the Directive 2009/31/EC Of The European Parliament And Of The Council of 23 April 2009 on the geological storage of carbon dioxide and amending Council Directive 85/337/EEC, European Parliament and Council Directives 2000/60/EC, 2001/80/EC, 2004/35/EC, 2006/12/EC, 2008/1/EC and Regulation (EC) No 1013/2006. Finally, this Ordinance, together with the Law on hydrocarbon exploration and exploitation (OG 52/2018, OG 52/2019, OG 30/2021) represents the transposition of the Directive 2009/31/EC.

Current legal framework (OG 95/2018)

By this ordinance, conduction of procedures and testing which purpose is to determine the possibility of permanent storage of CO_2 within geological formations is established. Also, conditions under which CO_2 can be permanently stored in the geological structures are defined. Purity of CO_2 is now mentioned in the Article 12 of this regulation, however without any improvement in terms of accuracy of description. Numerous parameters which need to be analyzed and estimated before CO_2 storage are defined within three stages:

1. Data collection,
2. Development of a three-dimensional static geological model,
3. Characterization of storage dynamic behavior, characterization of sensitivity and risks estimation.

Even though stages are detailly defined by the means of analyses and procedures which need to be conducted, solely details on the quality evaluation of these analyses can be interpreted in many ways. Also, authors of this report find that there is significant difference in quality and quantity of the available data between depleted hydrocarbon fields (for which data was collected for decades) and deep saline aquifers (data from wells nearby is commonly non-existent what makes the interpolation of the data to 3D space demanding, and the estimates burdened with uncertainty).

Moreover, interactions between permanent CO_2 storage in geological structures and other activities are defined (e.g. exploration, exploitation and underground storage of hydrocarbons, geothermal utilization of aquifers and underground water reserves utilization), which could be interpreted as a "good-will" indication for CO_2 utilization, while storing it simultaneously. However, for that purpose the regulation is not sufficiently defined (the ordinance should contain elaborated details of CO_2 monitoring of the storage complex throughout the process, the overall energy balance of the injection complex and the natural gas or energy storage complex or the geothermal energy system, etc.).

The conditions for obtaining concessions, exploration and storage permits are not defined by this regulation, but with Hydrocarbon Exploration and Exploitation Law instead.

4.1.2. LAW ON HYDROCARBON EXPLORATION AND EXPLOITATION (OG 52/2018, OG 52/2019, OG 30/2021)

The Law on Exploration and Exploitation of Hydrocarbons prescribes every part of the process of exploration and exploitation of hydrocarbons and geothermal waters, storage of natural gas, permanent storage of carbon dioxide, as well as harmonization of Croatian legislation with EU directives. It defines the Energy Development Strategy of the Republic of Croatia as the basic act of planning the above-mentioned processes, and the same strategy should contain the basis for directing and harmonizing economic, technical, scientific, educational and organizational measures. This Law, together with the Ordinance on permanent carbon dioxide storage in geological formations, represents the transposition of the Directive 2009/31/EC.

Role of the Croatian Hydrocarbon Agency

According to this law, the Hydrocarbon Agency prepares and organizes presentations for the public and potential investors, maintains and organizes a database of geological and geophysical data, as well as data from deep wells in order to acquaint potential investors with hydrocarbon, geothermal and geological potential for natural gas storage and storage of carbon dioxide.

The law states that the Agency prepares reports on the fulfillment of investors' obligations on the basis of issued permits for exploration and exploitation of hydrocarbons or geothermal waters or for storage of natural gas, but not for storage of CO_2 (permits for CO_2 storage are issued by the Ministry of Economics and Sustainable Development. Also, the agency is not involved in the right to request data and information from CO_2 storage operators/investors.

Within the law, the content of the documentation on the determination of reserves is defined, but in the case of CO_2 storage it is determined only by the volume of geological structures and not by the volume of CO_2 that can be stored (although it is defined in the permitting procedure in the same law) and it is not in alignment with the procedures defined by the Ordinance on the Permanent Storage of Carbon Dioxide in Geological Structures (OG 95/2018).

The conditions for issuing a CO_2 storage permit are defined in Chapter 5 of this Law - Permanent storage of carbon dioxide. It is not clear why the minimum period for which a permit for permanent storage of carbon dioxide is issued equals 20, and the maximum is 40 years. Regular inspections of the injection and monitoring facility shall be carried out at least once a year during the three-year period after closure and once every five years until the responsibility is transferred to the Hydrocarbon Agency (after 20-40 years). This is somewhat inconsistent with the Ordinance on the Permanent Storage of Carbon Dioxide in Geological Structures (OG95/2018) where the liability of the concessionaire ceases after the expiry of the concession, after which the funds for monitoring and surveillance of the location for the next 30 years need to be ensured. Hence, alignment of the two aforementioned legal acts with regards to the concessionaire's liability is needed. Finally, misdemeanor provisions set maximum fines of 1 000 000 HRK (less than 150 000 €). As these are investments worth hundreds of millions HRK, such fines do not seem purposeful.

In the amendment to the Law from March 2021 (OG 30/2021), a new point 79 was added which is relevant for CCS and which defines a "development society". It should represent a subject (i.e. a company) registered for exploration and exploitation of geothermal waters and permanent storage of carbon dioxide, and its establishment is proposed by the Hydrocarbon Agency to encourage and develop potential in exploration and exploitation of geothermal waters and permanent storage of carbon dioxide. The development

society (which does not yet exist) will be established by the Government of the Republic of Croatia, with the prior consent of the Ministry (at this moment it is the Ministry of Economics and Sustainable Development).

Authors of this report believe that such a system, where governmental bodies decide about the outcome of the tenders and issue the permits for exploitation of geothermal fields or CO_2 storage, and at the same time can propose a "development society" is not favorable for the development of a market competitive system of CO_2 capture, transport and storage. Also, three years has passed after the role of the Agency was set to prepare and organize presentations to meet potential investors, and as far as is known, in this regard the Agency was inactive. Since the Ministry and the Government of the Republic of Croatia confirm, i.e., establish such a company, and the Law states that the "development society" can do all research, exploration and exploitation activities, by withdrawing funds from European Union funds that encourage the development and use of renewable energy sources, such company has a potential advantage over other stakeholders who will, with respect to the competitive market economy rules, also try to obtain funding from the same funds.

4.1.3. REGULATION ON LIMIT VALUES FOR EMISSIONS OF AIR POLLUTANTS FROM STATIONARY SOURCES (OG 42/2021)

Operators of large combustion plants and gas turbines with an output of at least 300 MW, which were put into operation on or after 13 May 2009, are required to assess whether the conditions for technically and economically feasible modernization in terms of implementing CO_2 capture facilities are met. There are no power plants in Croatia that exceed this number at present.

4.1.4. REGULATION ON THE CONCESSION FEE FOR THE EXPLOITATION OF MINERAL RESOURCES (OG 31/2014, OG 57/2020)

It determines the concession fees and the system of distribution of funds to local and regional self-government units. As a rule, the amounts of concessions refer to the area of the land plot on which the facility for exploitation was built. In the case of the inclusion of underground CO_2 storage, different models should be considered, especially when it comes to storage in deep saline aquifers.

Additionally, within the latest legislative updates, hydrocarbons, geothermal water and permanent underground CO_2 storage fall under the jurisdiction of the Law on hydrocarbon exploration and exploitation in which permits for exploration/exploitation/underground storage are introduced (instead of concessions). At the moment, there are no new fields which are regulated by the new regulations.

4.1.5. ORDINANCE ON THE EXPLORATION AND EXPLOITATION OF MINERAL RESOURCES. (OG 142/2013)

This Ordinance determines the content of the proposal for the selection of the most favorable bidder for the exploration of mineral resources for the purpose of granting a concession for exploitation, the appointment of a responsible manager of mining works in the exploration area, guarantees for the costs of rehabilitation of the exploration area, reports on mining works in the exploration area, exploitation area and non-fulfillment of obligations under the concession agreement, etc.

The Ordinance directly relates to CO_2 storage by defining the content of the final report after exploration operations for the purpose of permanent underground gas storage are finished. However, since it is an ordinance that also applies to exploitation, and the Ordinance on Permanent Storage of Carbon Dioxide (OG 95/2018) mentions exploitation, it will probably be necessary to further harmonize these two regulations.

4.1.6. MINING LAW (OG 56/2013, OG 14/2014, OG 98/2019)

The Mining Law's regulations are in alignment with Directive 2009/31/EC and they (among other) refer to:

- Exploration and exploitation of mineral resources underground,
- Issuing concession for exploitation,

- Building and using the mining objects and facilities,
- Performing mining measurements,
- Concession fees,
- Indemnities,
- Caution measures,
- Safety and security,
- Qualifications for performing all mining activities,
- Inspections,
- Misdemeanor provisions.

It is important that there is a connection with the Regulation on Exploration and Exploitation of Mineral Raw Materials (OG142/2013), i.e., that exploration for the permanent storage of gases in geological structures is considered as exploration of mineral resources. Article 11 also states that the exploitation of mineral resources covers the storage of hydrocarbons and the permanent (geological) storage of gases in geological structures. It is defined here that within 48 months of finishing exploration operations it is necessary to prepare a Study on geological structures suitable for hydrocarbon storage and permanent gas storage, which is confirmed by the Decision on the determined structure, shape, size and volume of geological structures suitable for gas storage. It should be noted that "permanent gas storage" or "geological gas storage" terms are used instead of geological CO_2 storage. Perhaps there was an intention to leave some room for storage of CO_2 of different purities. It is also defined that a concession can be granted for the purpose of permanent storage of gases. Unlike mineral raw materials, a concession can be granted in any area where there are no obstacles, and not only in previously planned areas. Obligations to submit data and documentation on the structure, shape and size of geological structures suitable for hydrocarbon storage and permanent gas storage are specifically defined, and documentation can be prepared by legal entities that meet the conditions for performing the activity of preparing documentation on mineral reserves. The concessionaire for storage of hydrocarbons or permanent storage of gases in geological structures is obliged to keep annual records on the injected and/or obtained quantities of gases from geological structures. The concession contains the smallest and the largest specified amount of injected and extracted gases. The commission for determining reserves/capacities, according to this law, is the same as the commission for evaluating the study on hydrocarbon reserves.

In this document, there is room for improvement, especially in the form of deadlines related to the development of mining projects, studies, issuance of decisions and the like.

4.1.7. REGULATION ON THE FEE FOR THE EXPLORATION AND EXPLOITATION OF HYDROCARBONS (OG 25/2020)

This regulation establishes the fees for the exploration and exploitation of hydrocarbons, geothermal waters, natural gas storage facilities and structures for the permanent storage of CO_2.

The fee for the area of the approved exploration area for permanent storage of carbon dioxide in geological structures is HRK 500 000 / km2 per year, and for the exploitation field HRK 2 000 000 / km^2 per year (over € 250 000), which is far more than for any other type of field (for example, the production geothermal field has a fee of HRK 30 000 / km^2, and underground gas storage HRK 200 000 / km2 and production oil fields HRK 4 000 / km^2, probably because of much longer exploitation time, but still not many orders of magnitude longer). The ratio of area fees is given in Table 1.9.

TABLE 1.9. AREA BASED FEES

Facility (field) type	Fee (HRK/km²)	Fee (EUR/km²)	Fee magnitude factor
Exploration hydrocarbon field	400	52	0.0008
Production hydrocarbon field	4 000	520	0.002
Exploration geothermal field	no fee	-	-
Production geothermal field (t > 100°C)	30 000	3 900	0.015
Production geothermal field (t < 100°C)	1 000	130	0.0005

Facility (field) type	Fee (HRK/km²)	Fee (EUR/km²)	Fee magnitude factor
Exploration underground natural gas storage	50 000	6 500	0.1
Exploitation underground natural gas storage	200 000	26 00	0.1
Exploration geological CO_2 storage	500 000	65 000	1
Exploitation geological CO_2 storage	2 000 000	260 000	1

The amount of fees for the injected volumes of carbon dioxide in geological structures shall be governed by the contract between the investor and the Croatian government on the basis of the issued license.

4.1.8. REGULATION ON PROFESSIONAL QUALIFICATIONS FOR PERFORMING CERTAIN TASKS IN PETROLEUM ENGINEERING (OG 95/2018)

This Regulation prescribes the following:

- the program, conditions and manner of taking the professional exam in the field of petroleum engineering,
- the structure and manner of work of the examination committee for taking professional exams in the field of petroleum engineering,
- the conditions that must be met for taking the professional exam in the field of petroleum engineering and
- other issues related to professional qualifications, proficiency testing and professional training related to certain activities of petroleum engineering and mining works.

Permanent storage of carbon dioxide has just been added to this regulation, posing a potential risk that studies and permits will be approved by hydrocarbon experts rather than experts on geological CO_2 storage technologies.

4.1.9. LAW ON CLIMATE CHANGE AND OZONE LAYER PROTECTION (OG 127/2019)

The Act generally refers to jurisdiction and responsibility for climate change mitigation, adaptation and ozone layer protection, climate change and ozone layer protection documents, greenhouse gas emissions monitoring and reporting, the greenhouse gas emissions trading system, aviation, sectors outside the greenhouse gas emissions trading system, Union Register, ozone-depleting substances and fluorinated greenhouse gases, climate change mitigation financing, adaptation to climate change and ozone layer protection, climate change and ozone protection information system, administrative and inspection supervision.

The law describes the harmonization with EU regulations, decisions and directives, and regarding the mechanisms and the way of implementation of monitoring and reporting of emissions, allocation of emission credits, establishment and regulation of the emissions trading system.

Basic documents on climate change and the protection of the ozone layer have also been defined (bolded represent documents which mention CCS):

1. Low-carbon development strategy of the Republic of Croatia (with a duration of at least 30 years, updated every five years if necessary, with targets in accordance with Article 15 of Regulation (EU) No. 2018/1999).

2. Climate change adaptation strategy in the Republic of Croatia.
3. Action plan for the implementation of the Low carbon development strategy of the Republic of Croatia.
4. Action plan for the implementation of Climate Change Adaptation Strategy in the Republic of Croatia
5. Integrated energy and climate plan of the Republic of Croatia
6. Program for mitigation of climate change, adaptation to climate change and protection of the ozone layer.

The regulation on the allocation of emission allowances, Article 35, states that no free emission allowances may be allocated to the operator of electricity generating installations, including new electricity generating installations, installations for the capture, transport or storage of carbon dioxide.

The regulation on financing climate change mitigation, climate change adaptation and ozone protection (Article 104) defines the possible use of the Innovation Fund to support innovation in low-carbon technologies and processes, including carbon capture and use, and to support the construction and operation of environmentally safe carbon capture and geological storage projects, and to support innovative renewable energy technologies and storage.

4.1.10. ORDINANCE ON RESERVES (OG 95/2018)

This Regulation prescribes the content of requirements for the determination of reserves, i.e., for the determination of data on the structure, shape, size and volume of geological structures suitable for the storage of natural gas or the permanent storage of carbon dioxide.

The balance of hydrocarbon reserves, geothermal water for energy purposes, i.e., the data on the structure, shape, size and volume of geological structures suitable for natural gas storage or permanent storage of carbon dioxide should be published on the Ministry's website.

The content of the ordinance on identified reserves does not include annual injection capacity or CO_2 storage capacity in general, but it is stated that 19 articles of the same regulation are 'appropriately' applied to the categorization of geological storage data, applicable to CO_2 storage.

4.1.11. REGULATION ON THE CONSTRUCTION OF PETROLEUM AND MINING INSTALLATIONS AND FACILITIES (OG 95/2018)

The Regulation prescribes the education, professional exam and professional experience of all designers, auditors, supervisory engineers and other prescribed experts/engineers for the construction of petroleum and mining facilities and plants. The content of the trial exploitation program and the report on the performed trial exploitation have been defined, and the geological storage of CO_2 has only been added so that it does not include all the engineering specifics of this technology.

4.1.12. ORDINANCE ON RESERVOIR ENGINEERING PROJECTS AND PROCEDURE OF RESERVOIR ENGINEERING PROJECTS VERIFICATION (OG 95/2018)

This Ordinance prescribes: the content of mining projects (needed for wells) and the work of the commission for the verification of oil and mining projects, etc. Permanent storage of carbon dioxide has been simply added to the Ordinance but has not been considered in detail.

4.2 Other regulations and law that possibly can affect the CCS/CCU development

4.2.1. LAW ON THE FUND FOR ENVIRONMENTAL PROTECTION AND ENERGY EFFICIENCY (OG 107/2003, OG 144/2012)

This Act established the Fund for Environmental Protection and Energy Efficiency (2003), which regulates the purpose and manner of use of funds, and in 2012 amendments were made to include Directive 2009/29/EC which amends Directive 2003/87/EC with a purpose to improve and expand the EU ETS (OJ L 140, 5.6.2009). The law determines fees and payers/emitters for emissions into the environment (which includes CO_2). The Fund supports scientific projects focused on CO_2 mitigation, and on CCS, such as CCS/CCUS project (ESCOM, http://escom.rgn.hr/about).

4.2.2. DECISION ON THE ADOPTION OF THE PLAN FOR THE USE OF FINANCIAL RESOURCES OBTAINED FROM THE SALE OF EMISSION ALLOWANCES THROUGH AUCTIONS IN THE REPUBLIC OF CROATIA UNTIL 2020 (OG 19/2018, OG 84/2019)

The Fund for Environmental Protection and Energy Efficiency can, by this decree, finance several measures/activities from the funds obtained by selling the EUAs on auctions (Tables 1.10. and 1.11.). The category including only CCS and CCU does not provide useful information as CCS is interrelated with ENU, ESIF and IR (Table 1.10). The comparison of the planned funding measures shows the general tendency of the authorities to achieve the 2050 targets. The government is currently discussing a new plan for using financial resources from the EUA auctions for both scientific and industrial projects (which include CCS projects).

TABLE 1.10. DISTRIBUTION OF MEASURE FUNDING BY PRIORITY MEASURES

Measure label	Total cumulative funding until 2020 [HRK]	Total cumulative funding until 2020 [EUR]	Proposed percentage distribution [%]
OI	165 000 000	21 450 000	10,93%
ENU	435 000 000	56 550 000	28,81%
ENS	40 000 000	5 200 000	2,65%
PR	116 000 000	15 080 000	7,68%
NES/OT	119 000 000	15 470 000	7,88%
ESIF	190 000 000	24 700 000	12,58%
IR	70 000 000	9 100 000	4,63%
TZ	20 000 000	2 600 000	1,32%
CGO	355 000 000	46 150 000	23,52%
	1 510 000 000	196 300 000	100%

TABLE 1.11. MEASURES FUNDED

Measure label	Definition
OI	Total renewable energy sources
ENU	Total energy efficiency (without transportation sector)
ENS	Total energy poverty
PR	Total transportation sector
NES/OT	Total non-energy sector (including waste management sector)
ESIF	Total European Structural and Investment Funds (ESIF) projects and priority measures for climate change adaptation
IR	Total research and development and expert support
TZ	Total projects with third countries
CGO	Centers for waste management

4.2.3. LAW ON ENERGY EFFICIENCY (OG 127/2014, OG 41/2021)

This law is not directly related to CCS technologies, but contains a definition of the executive public body responsible for the implementation and monitoring of taxation in the field of energy or carbon emissions, financial plans and instruments, fiscal incentives, standards and norms, training and education, etc. The law on energy efficiency is already connected with operating strategy of oil operator(s), especially in the midstream sector (preparation, processing and transportation from hydrocarbon fields to processing plants and then to refineries). Since they are important emitters, the parts of this law affect oil and gas companies' (strategic) decisions about storage possibilities and feasibility. It is linked to oil company operations and CO_2 injection decisions because oil companies are likely the only ones with knowledge of similar technologies to CCS.

4.3. Strategic documents regarding CCS/CCU in Croatia

Strategic documents which are or can be relevant for CCS/CCU deployment in Croatia are presented in Table 1.12.

TABLE 1.12. RELEVANT STRATEGIC DOCUMENTS

Croatian title	Translated title	Year of publishing	Authors
1. Integrirani nacionalni energetski i klimatski plan za Republiku Hrvatsku za razdoblje od 2021. do 2030. godine	Integrated National Energy and Climate Plan for the Republic of Croatia for the Period of 2021-2030 (NECP)	2020	Ministry of Economy and Sustainable development / Croatian Parliament
2. Strategija energetskog razvoja Republike Hrvatske do 2030. s pogledom na 2050. godinu	Strategy of Energy Development of the Republic of Croatia until 2030 with a View on 2050 (EDS)	2020	Ministry of Economy and Sustainable development / Croatian Parliament
3. Nulti scenarij za energetski sektor (nacrt za javnu raspravu)	Zero Scenario for Energy Sector (draft for public discussion)	2020	Ministry of Economy and Sustainable development / Energy Institute "Hrvoje Požar"
4. Strategija niskougljičnog razvoja Republike Hrvatske do 2030. s pogledom na 2050. godinu	Strategy of Low-carbon Development of the Republic of Croatia until 2030 with a View on 2050 (LCS)	2021	Ministry of Economy and Sustainable development / Croatian Parliament

In Strategy of Energy Development of the Republic of Croatia until 2030 with a View on 2050 (EDS), it is stated that, in the long-term, new technologies of hydrogen, methane and liquid fuels (jet and diesel fuels) production from RES will have a significant role in energy transition. These are "power to liquids (PtL)" and "power to gas (P2G)" technologies (Figure 1.9.). The mentioned gaseous and liquid fuels will represent an indispensable form of energy in those sectors in which usage of electricity is limited: aviation, maritime and road freight transport along with some industry sectors. Currently, these technologies are deployed on a pilot and demonstration scale, but it can be expected that they will play an important role in the future, primarily in the gas use segment.

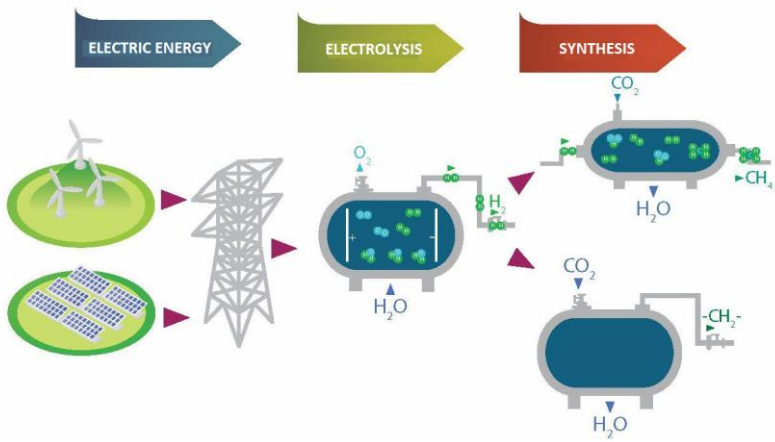

FIGURE 1.9. POWER TO GAS AND POWER TO LIQUID TECHNOLOGIES SCHEME (FROM STRATEGY OF ENERGY DEVELOPMENT OF THE REPUBLIC OF CROATIA UNTIL 2030 WITH A VIEW TO 2050)

As stated in EDS, on the path to zero-emission energy, hydrogen should be considered as an important fuel of the future. CCS technology can also play a significant role in enabling zero-emission energy. It is also stated in EDS: "Despite previous, unsatisfactory results in research using CCS technology, it is realistic to expect that the increase in emission prices will encourage a new stage of research and result in the safety and commercially satisfactory results, further opening space for long-term development of sustainable hydrogen-based global energy."

According to NECP, it is particularly important to emphasize the need to collaborate in new and still underexplored areas and to encourage joint scientific and research work. In this context, the Republic of Croatia singled out issues such as hydrogen, battery development, and CO_2 capture and storage as particularly important, with the willingness to extend cooperation to other areas in the future. The establishment of regional cooperation within the framework of the initiative "Clean Energy for the EU Islands", primarily with the Republic of Italy and other Mediterranean EU Member States, is also expected.

It is also accented in NECP that CCS/CCU projects can apply for funding from the Innovation Fund. Additionally, systems for CO_2 capture, transport, use and storage are identified as one of the areas with the most significant capacities for both industry and scientific community.

In order to mitigate climate changes and to achieve climate goals, Croatia has developed two measures which consider CCS/CCU and they are mentioned both in the NECP and Strategy of Low-carbon Development of the Republic of Croatia until 2030 with a View on 2050 (LCS):

1. Establishing a platform for the collection, use and storage of CO_2 (dimension decarbonization)

2. Decarbonization of transport through production of advanced biofuels from agricultural production residues and energy crops with integrated carbon capture, use and storage.

Additionally, it is mentioned in LCS that Croatia has technical and natural conditions fulfilled for using the technology of carbon capture and storage. CCS is considered as a transitional solution, which should, in the coming 3-4 decades, enable the continued use of fossil fuels with a share in total electricity production, while gradually reducing greenhouse gases emissions, until the technological and organizational conditions for low-carbon development are achieved. The scenario of moderate energy transition is achievable without CCS, while the scenario of accelerated energy transition implies CCS implementation in natural gas fired power plants and cement industry after 2040. In addition to the cement industry, it is also stated that refining and fertilizers production industries should analyze the feasibility of CCS implementation after 2040 in order to achieve the set climate goals. Finally, Innovation Fund and European Energy Program for Recovery (EEPR) are listed as funding sources for CCS projects.

Another important strategic document which needs to pass the public discussion is Zero Scenario for Energy Sector. This scenario is developed for achieving more ambitious emissions reduction until 2030 and climate neutrality by 2050 of the energy sector. It is stated that many emissions related to the industrial processes will be hard to annulate, but CO_2 capture, storage or utilization (by producing other products) represents one of the possible solutions.

Zero Scenario also envisages lower costs of CCS and wider commercial deployment as the technology advances. Great contribution to the technology development is represented by knowledge transfer from the oil and gas exploitation sector, accompanied by clear and stable regulatory framework.

It is also stated that CO_2 removal should be considered not only through geological storage, but through its simultaneous utilization (CCUS), to enable economically viable choice for emissions reduction. Some of the currently most profitable utilizations are presented:

- EOR/EGR
- Supplementation for the plants in greenhouses
- Wine and non-alcoholic beverages production
- Certain industrial processes

Also, following utilizations are expected to be at significant level:

- Synthetic gases and fuels production
- Polymer production
- Fertilizer production
- Carbon fibers production
- Bioethanol production
- Methanol production
- Caustic soda production
- Acetic acid production

CCUS is also considered for geothermal reservoirs by the means of using CO_2 as working fluid in binary cycles. Moreover, CO_2 is considered as a working fluid for underground energy storage.

This Scenario also covers the definitions of each aspect of CCS and capture technologies, but what is most important, several implementation challenges are identified:

- Insufficiently defined and precise legislative framework, long duration of the procedures for license issuing.
- Spatial plans: locations of the CO_2 injection facilities are not provided by the existing documents.
- Need for additional exploration work to identify the exact locations of the CO_2 injection facilities (although it is possible to estimate significant capacities in the continental part of Croatia and in the northern part of Adriatic Sea).
- High investments in CO_2 capture facilities.
- Lack of transport infrastructure: for the transport of captured CO_2, pipeline construction is needed. Half of the emissions in Croatia from stationary sources is located near the coast and most of the reliable storage capacities are estimated to be in the mainland.
- CCS implies the price increase of the products and labor due to significant new capital and operating costs. Also, the cost projections vary significantly because of different transport distances and underground/reservoir conditions.
- Public resistance: in the mainland of Croatia, people are used to living next to oil/gas and mining plants and works, so it is necessary not to violate the acceptance of underground works by the public. The projects need to be well-prepared and respecting the highest safety standards. Nevertheless, public education and close cooperation with local government structures are necessary in implementing such projects.
- Seismicity: Underground CO_2 injection projects can sometimes cause smaller seismic events because of activating micro-fractures or faults due to reservoir/storage pressure increase, which may then alarm the public.
- CO_2 leakage: Although risk of CO_2 leakage from an underground storage is small, the atmosphere, water and nearby population need to be protected by conducting careful storage management and systematic monitoring.
- Monitoring: Risk of CO_2 migration towards groundwater and the surface needs to be minimized to an acceptable level.

Furthermore, the scenario implies significant yield of e-fuels (synthetic fuels) in energy demand for the period between 2040 and 2050. It is stated that e-fuels will be produced from green hydrogen and CO_2 which comes either from the atmosphere or from industry's flue gases. By exploiting e-fuels, significant CO_2 emissions reduction is achieved when compared to equivalent fossil fuels.

When compared to electric energy, e-fuels have higher energy density and are more suitable for storage. However, e-fuels vehicles have low efficiency (15 %). Additionally, production costs are relatively high (7 EUR/liter), but their decrease is expected to take place because when the production develops momentum, technology advances and electricity price from renewable energy sources drops. By 2050, production cost could decrease to the level which is one to three times higher than for fossil fuels production.

Moreover, establishment of industrial clusters is promoted which would connect industrial facilities (CO_2 emitters) with synthetic fuel production facilities. That would result in simultaneous economic efficiency enhancement of the synthetic fuels production facilities and partial decarbonization of the industry.

The contribution of e-fuels in the transport sector will be focused on aviation sector, maritime and freight road transport, what is also stated in the LCS.

Regarding the hydrogen production in the Zero Scenario, for the mid-term and long-term period, centralized production from fossil fuels with CCS can represent an acceptable technology.

4.3.1. ESTABLISHING A PLATFORM FOR THE COLLECTION, USE AND STORAGE OF CO_2

This is an analytical, research and financial measure which is planned to be implemented from 2021 until 2030.

Following objectives and descriptions of the measures are noted in strategic documents (LCS and NECP):

The carbon capture and storage technology for large emission sources is not yet commercially available. According to Directive 2009/31/EC on geological storage of carbon dioxide and Article 36 of the Industrial Emissions Directive 2010/75/EU, for power plants of more than 300 MW which have been granted a construction permit after the entry into force of Directive 2009/31/EC on geological storage of carbon dioxide, it is necessary to evaluate whether the following conditions are met:

a) availability of a suitable location for storage,

b) transport facilities are technically and economically feasible and

c) upgrade of facilities for CO_2 capture is technically and economically feasible.

If these conditions are met, the competent authority shall ensure at the site of the facility the appropriate space for equipment for CO_2 capture and compression. This is regulated by the Hydrocarbon Exploration and Exploitation Act (OG 52/18, 52/19, 30/21), which enables CO_2 storage on the territory of the Republic of Croatia. This method should be further developed and the potential and possibilities for this technology should be considered at the national level. In view of this, there are plans for the development of a storage capacity evaluation study, as well as the National feasibility study with the action plan for preparatory activities for carbon capture and storage projects. This study will cover the capture stages on emission sources, transport, injection and storage of CO_2, and the interconnection of the CO_2 transport system with other EU countries. There are also plans to inform the public about CCS technology.

Planned activities are as follows:

- Conducting research into the potential for geological storage of CO_2 in the Republic of Croatia
- Developing/amending the evaluation study of storage capacities available in the territory of the Republic of Croatia
- Implementation of CO_2 geological storage projects in the Republic of Croatia in accordance with estimated potential
- Informing the interested public about CCS technologies

One million HRK (approximately 133 000 €) is planned for funding the study and action plan, while funds for the implementation of projects will be determined after the analysis of the potential. Sources of financing will be Croatian Hydrocarbon Agency, Universities and EU funds. The Ministry of Economics and Sustainable Development and Croatian Hydrocarbon Agency represent executive and supervisory bodies.

4.3.2. DECARBONIZATION OF TRANSPORT THROUGH PRODUCTION OF ADVANCED BIOFUELS FROM AGRICULTURAL PRODUCTION RESIDUES AND ENERGY CROPS WITH INTEGRATED CARBON CAPTURE, USE AND STORAGE

This is a financial measure which will be implemented from 2021 until 2026. Following objectives and descriptions of the measures is noted in LCS:

Objective is to create a long-term sustainable biomass supply chain and produce bioethanol with negative net greenhouse gas emissions. An industrial complex for production of advanced bioethanol will be built on the basis of Axens' (France) patented innovative FUTUROL™ technology with the integration of BIO-CCUS. The plant will have a capacity of 55,000 tons per year of advanced bioethanol to be distributed on the market through commercial channels of INA and MOL Group. About 52,000 t/y of biogenic carbon dioxide will be captured and stored in oil fields using BIO-CCUS technology. The production of advanced bioethanol will use a combination of agricultural residues, mainly cereal and maize straw, and the energy plant Miscanthus x giganteus, in accordance with Part A of Annex IX to Directive 2018/2001 on the promotion of the use of energy from renewable sources, which lists the raw materials acceptable for production of advanced biofuels. The industrial complex will consist of a plant for production of advanced bioethanol, for production of biogas and a high-efficiency cogeneration plant.

2.96 billion HRK (approximately 350 mil. €) is needed to implement the measure and funding sources will be Innovation Fund, Modernization Fund, Recovery and Resilience Fund and private investment (from INA). Executive body is INA while the implementation of the measure will be supervised by the Ministry of Economics and Sustainable Development.

4.4. Summary of legislative and regulatory framework

To summarize, Croatia has established a legislative framework for underground CO_2 storage primarily by implementing the Directive 2009/31/EC through the Law on hydrocarbon exploration and exploitation and the Ordinance on permanent carbon dioxide storage in geological formations. Mentioned Law and Ordinance are supported to some extent by other legal acts from Chapter 4.1. The existing legislative framework defines everything what is needed in order to deploy an operational storage site, meaning that there are no legal obstacles at the moment for geological CO_2 storage. However, the missing link between the existing legislative framework and full CCS chain development is the regulation of other aspects than pure storage. Finally, the existing legal framework in Croatia is conducive to underground CO_2 storage, but CO_2 capture, transport and utilization remain unaffected by present legal acts. Additionally, by regulating CO_2 transport, purity and monitoring, a legal framework for CCU would be created, which is important since new CO_2 utilization technologies are emerging, and TRLs of the existing ones are increasing.

Concerning the strategic documents of the Republic of Croatia, plans for CCS deployment are observed in the Fast transition scenario (after 2040 for natural gas power plants and cement plants). Main two measures which will assist in achieving Croatia's climate goals and which are described in NECP and LCS are: establishing a platform for the collection, use and storage of CO_2 (dimension decarbonization) and decarbonization of transport through production of advanced biofuels from agricultural production residues and energy crops with integrated carbon capture, use and storage (BIO-CCUS). Besides natural gas power plants and cement industry, it is stated in LCS that the refining and fertilizer production industries should analyze the feasibility of CCS implementation after 2040. Furthermore, Zero-emission scenario (needs to pass public discussion) envisages wider utilization of captured CO_2 (EOR/EGR, CCUS in geothermal reservoirs, synthetic gases and fuels production, polymer production, fertilizer production, methanol production, etc.) but the utilization technologies are just mentioned without any quantitative assessment. Moreover, it is stated in EDS that CCS could comply with developing sustainable hydrogen-based global energy, as the simultaneous use of CO_2 and hydrogen is observed in several PtL and P2G technologies.

To conclude, possibilities of deploying both, CCS and CCU technologies are mentioned in Croatia's strategic documents to some extent. However, what is more important than the strategic documents themselves, are the adjacent action plans for their implementation. Mentioned plans yet need to be enacted and hence, the exact extent of long-term deployment of CCS/CCU in Croatia remains to be unpredictable.

Chapter 2. Croatia's outlook for CCS and CCU

1. Summary of stakeholder engagement

In the Republic of Croatia (referred to as "Croatia" in further text), 18 relevant actors/stakeholders from four different sectors:

1. Institutions
2. Private Sector
3. Academic Sector
4. Other Sector (Non-governmental organizations and associations)

The distribution of the stakeholders throughout the sectors is shown in Figure 2.1.

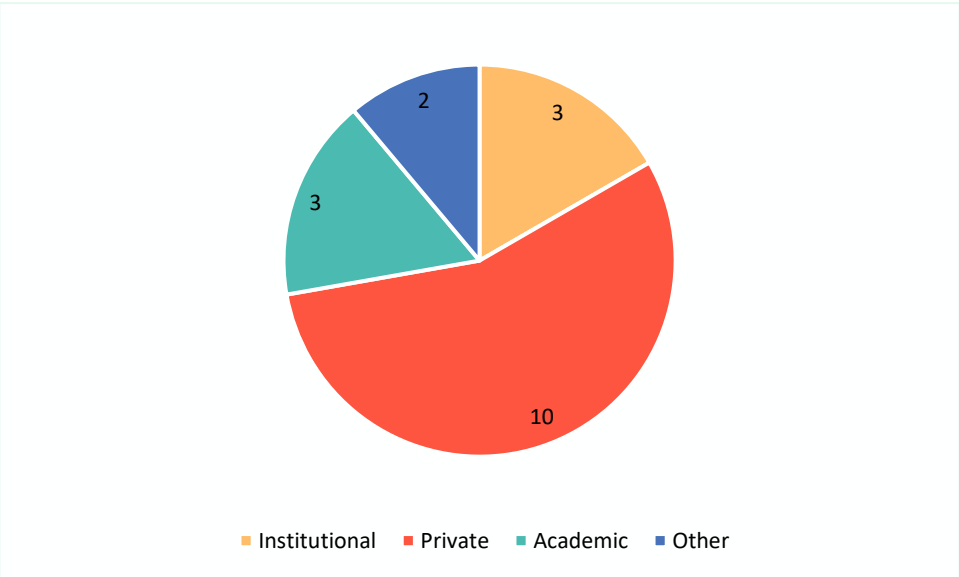

FIGURE 2.1. NUMBER OF STAKEHOLDERS IN EACH SECTOR

The majority of the stakeholders who contributed to the workshop and interviews came from the private sector. For the purposes of this report, this is considered optimal, since the implementation and deployment of CCS/CCU technologies will occur in the private sector and private sector organizations are fully exposed to the market and its associated risks. Additionally, the high number of representatives can be explained by wide spectrum of carbon-intensive industries in Croatia. However, the private sector is not more important than any other sector in this report, as clustering and inter-sectoral cooperation is inevitable for full-scale application of CCS/CCU technologies and projects. The remaining sectors (institutional, academic and others) are relatively balanced in terms of representation.

It is worth mentioning that institutions are of outmost importance, as members of this sector are either the policy makers, regulators, or competent authorities (or combination of the aforementioned) of the CCS/CCU technologies and projects. Therefore, they directly

affect the creation of regulatory and financial frameworks in Croatia, which in turn determine the potential for and the dynamics of CCS/CCU implementation.

The academic sector can contribute significantly to CCS/CCU projects, through the development and deployment of technologies and regulatory framework, but also through raising public awareness and a positive perception of particular CCS/CCU concepts, for example:

- Advising the authorities about required changes in regulatory framework.
- Supporting the investors and operators with scientific research and professional expertise needed for the project to be in alignment with regulations.
- Educating experts through undergraduate and graduate study, but also through specialist studies tailored to different CO_2 mitigation concepts.

Regarding the non-governmental organizations (NGOs) and associations of alternative energy sources, in Croatia they contribute to the CCS/CCU scene by pointing out the need for amending the existing regulations and contribute to developing relevant strategic documents, promote their field of expertise or even organize protests to indicate an urge for changes regarding the relevant topic (mainly environmental NGOs). They are seen in two roles, primarily as a corrective and controlling factor, as enablers of the public debate, which is the only way to elevate the public interest and consequently the perception of CCS/CCU technology. The majority of NGO's has not enough knowledge to be objective about technologies that involve CO_2 injection underground.

Regardless of the sectoral affiliation of relevant stakeholders, through their activities, directly or indirectly, all of them affect the public opinion and form a general landscape for CCS/CCU in Croatia.

Institutions:

1. Croatian Energy Regulatory Agency (HERA)

HERA is an autonomous and non-profit public institution which regulates energy activities in the Republic of Croatia. Their obligations, authorities and responsibilities are based on the Act on the Regulation of Energy Activities, the Energy Act and other legislation regulating specific energy activities. Therefore, HERA's contribution in CCS/CCU is best observed in regulation of the activities which can exhibit characteristics of a natural monopoly, i.e. CO_2 transport and storage. Their representative has relevant knowledge on the subject matter and was involved through the means of an interview and participation in the workshop. The regulation of specific CCS/CCU activities is mentioned, but expert insights about other CCS/CCU aspects are provided.

2. Croatian Hydrocarbons Agency (CHA)

The main role of Croatian Hydrocarbon Agency is monitoring investors in terms of fulfillment of their contractual obligations, in compliance with the highest technological and environmental standards, as well as exerting strict control over exploration and exploitation of hydrocarbons in the Republic of Croatia. The Agency is responsible for defining exploration activities, determining rules and conditions for exploration and exploitation of hydrocarbons and providing operational support to competent bodies during licensing rounds. Their main responsibilities, as stated on their official website, are: "the supervision of all aspects of exploration and exploitation of hydrocarbons, encouraging competitiveness and optimal hydrocarbons management and ensuring balance between energy and environmental policies of the Republic of Croatia." The Agency is also the competent authority for geological sequestration of CO_2 and has the same jurisdiction as outlined above for hydrocarbons.

3. Ministry of Economy and Sustainable Development (MINGOR)

The Ministry of Economy and Sustainable Development is the central state body responsible for economic affairs in the Republic of Croatia, including investment processes, as well as for environmental protection. The Ministry also deals with issues related to the competitiveness of the Croatian economy, instruments and measures of economic and industrial policies and policies associated with

innovation and new technologies, as well as activities stemming from general and sectoral environmental policies, biodiversity and geodiversity conservation, sustainable use of natural resources and nature conservation.

Since the Ministry is the authority (competent body) and policy maker in terms of CCS/CCU, whose legislation proposals must be confirmed by the Croatian Parliament, they are of high importance in this report. Their specific position on CCU/CCS, as outlined in this projects' stakeholder engagement activities, can be summarized as follows:

- The topic of CCS/CCU is in the Ministry's focus for some time and is implemented within the "Proposal of the Strategy of Low-Carbon Development of the Republic of Croatia until 2030 with view on 2050" which has been adopted by the Government of the Republic of Croatia.
- A model of CO_2 development which would direct and enable transition from discussions and research to realization of the projects is expected in the upcoming period.
- Suggestions from relevant academic staff and experts regarding new technologies which could accelerate the accepted climate goals from the Strategy are welcome.
- From a practical perspective, the topic of CCS/CCU is under CHA's jurisdiction, and the CCS4CEE experts were therefore advised to continue our communication about the project with the CHA.

As CHA is responsible for operative handling of underground resources (including hydrocarbon, geothermal and CCS/CCU resources), the Ministry asked to exclude themselves from interviews, but participated in the workshop via their Head of Climate Policy.

Private Sector:

Regarding the private sector, several carbon-intensive branches of the industry are targeted as relevant stakeholders:

- Cement industry (4 stakeholders)
- Power generation (1 stakeholder)
- Oil and gas refining/processing (1 stakeholder)
- Fertilizer production (1 stakeholder)
- Glass industry (1 stakeholder)

Most private sector stakeholders come from the cement industry. Therefore, it is worth mentioning the existence of an association of Croatian cement factories (Croatia Cement). The association represents and promotes the common goals of the cement industry in Croatia, which include the sustainability of cement production and minimization of environmental impact across the value chain, in Croatia.

4. NEXE

Nexe d.d. is a cement company whose cement plant was the 4th largest emitter of CO_2 in Croatia (2019), which is the main reason for involving them in this study. The director of business strategy and development was engaged through the interview and workshop.

5. Holcim Hrvatska

Holcim Hrvatska d.o.o. is also a representative from the cement industry in Croatia. Their factory was the 7th largest emitter of CO_2 in Croatia (2019). Holcim's board president, director of the cement factory in Koromačno, and their finance and tax specialist were engaged through the means of interviews and participation in the workshop.

6. CEMEX

CEMEX Hrvatska d.d., another cement producer, own 2 cement factories which were the 6th and 12th largest emitters of CO_2 in Croatia (2019), respectively. Their representative is sustainability manager in CEMEX and leader of the working group for environmental

protection and sustainable development in Croatia Cement, and was engaged through an interview and participation in the workshop.

7. Calucem

Calucem d.o.o. is another cement producer. Their cement factory is also the smallest emitter of CO_2 among other cement producers (14th in 2019). Calucem's representative is a process engineer and member of the working group for environmental protection and sustainable development in Croatia Cement, and was engaged via an interview and participation in the workshop.

8. HEP Proizvodnja

HEP Proizvodnja d.o.o. is part of the HEP group (Croatian state-owned power-supply company) whose primary activity is electric power production, but also conducts distribution and supply of natural gas and heating energy . The production is ensured by utilizing several hydropower plants, renewable energy sources (PV cells, and bio-mass power plants) and fossil-fuel driven thermal power plants. The latter is of high relevance for CCS/CCU, since seven thermal power plants owned and operated by HEP emit CO_2. Five out of seven of those power plants fall under the category of major emitters (100 kt of CO_2 per year) and it was the main reason of the inclusion in the stakeholders' group. HEP representative is the director of the sector for thermal power plants, who was engaged through the interview.

9. INA

INA-Industrija nafte d.d., is a medium-sized European oil company. INA Group has a leading role in Croatian oil bussines and a strong position in the region in the oil and gas exploration and production, oil processing and oil and oil products distribution activities. Furthermore, they hold exploitation permits for the majority of oil and gas fields in Croatia, which means that they might have the more direct access to significant storage capacities. Also, INA has an active CO_2 injection Enhanced Oil Recovery (CO_2-EOR) project what places this stakeholder as a leader regarding the storage and utilization part of CCS/CCU in Croatia in terms of CO_2 injected. Moreover, two oil refineries (in Rijeka and Sisak) and two oil and gas processing facilities (near Ivanić Grad and Virje) are recognized as major emitters. Finally, INA plans to build and operate a biorefinery in Sisak (oil refinery in Sisak will be shut down) which will be complemented with Carbon Capture Utilization and Storage (CCUS) technology in order to mitigate the emissions from other facilities (by injection of by-produced CO_2 underground) and to diversify their business. INA representatives are engaged through the means of the interview and workshop.

10. Petrokemija

Petrokemija's d.d. core business is fertilizer production. Due to this activity, their facility was the 2nd largest emitter of CO_2 in 2019 in Croatia. In its production process, Petrokemija also has high yield of process emissions, meaning that even after they stop using fossil fuels as an energy source, certain part of emissions will remain and deployment of CCS/CCU technologies can impose as a possible solution. Contact persons from Petrokemija are as follows: director of production, assistant of director for production, and assistant of director for energetics. All the representatives were engaged either via interview or via workshop.

11. Vetropack Straža

Vetropack Straža is part of the Vetropack group and represents glass production industry in Croatia. Most of the CO_2 emissions from this industry come from burning of fossil fuels for heating, but there are also some process emissions. Vetropack Straža's glass factory was 16th emitter of CO_2 in 2019 in Croatia. Their representative is head of HSE department and was engaged through the workshop, but declined the interview on the grounds of feeling unprepared.

Besides the representatives from the carbon intensive branches of the industry, relevant stakeholders are also identified within the sector of hydrogen production and geothermal energy.

12. Active Solera

Active Solera is a Croatian based, hydrogen producing company which develops Solar Microwave Oven (SMO) technology. SMO technology uses only solar energy (in the means of pyrolysis) to convert waste and non-food biomass to hydrogen and carbonate byproducts for which a market exists (activated carbon, charcoal, and carbon powder) with, as they state, a negative carbon footprint since the lifetime of the byproducts is more than 100 years. Hydrogen produced in this manner is green hydrogen, since there are no adjacent CO_2 emissions. Due to the before mentioned facts, SMO technology applied by Active Solera has CCUS integrated in the core of the process itself and is, therefore, included in this study. Contact on Active Solera's behalf is its director, who participated through interview and workshop.

13. Calida Aqua

Calida Aqua represents a geothermal consulting company. Owner has an extensive knowledge about geothermal energy which he obtained while working at MB Geothermal, at geothermal power plant Velika Ciglena, but also from previous experience in INA oil company at reservoir engineering and simulation jobs and tasks connected with the abovementioned CO_2-EOR project from its inception. It is for these reasons that they were relevant and valuable stakeholder representative regarding CCS/CCU and as such engaged through the interview and workshop.

Academic sector

After searching the scientific project databases, three academic institutions were found as involved in relevant CCS/CCU research:

14. University of Zagreb - Faculty of Mining, Geology and Petroleum Engineering (UNIZG-RGNF)

Experts from the Faculty who are also the authors of this report are actively promoting CCS/CCU technologies as an efficient way of reaching greenhouse gases emission targets in the transitional period. This is accomplished through the scientific research which is best reflected in the published papers and involvement in scientific projects (either finished or ongoing) such as STRATEGY CCUS (H2020), ENOS (H2020) and Hystories (H2020), ECCO (FP7), CGS Europe (FP7), CO_2STOP (FP7), EU Geocapacity (FP6), ESCOM (Croatian Science Foundation), etc.
They also performed numerous studies related to natural gas storage, geothermal energy exploitation, injection of CO_2 and similar analyses that used holistic approaches to transition of hydrocarbon production and economy to greener technologies and systems.
Furthermore, many of the courses included in the petroleum engineering and geology study programs offer insights how student's future profession can be used to integrate CO_2 capture, CO_2 transport, CO_2 utilization and geological storage assessments of CO_2 with knowledge that is traditionally connected with petroleum engineers and geologists.
On the part of this institution there is a strong incentive to improve knowledge related to technologies for reducing CO_2 emissions, primarily CCS and CCUS, which is expressed through establishing Joint International Postgraduate Specialist Study (CO_2 Geological Storage International Master, hosted by the Rome university La Sapienza and University of Zagreb), and which covers all aspects of the geological storage of CO_2 so that the students can both understand the work of all specialists who will be involved in CCS projects (such as reservoir engineers, geologists, sedimentologists, stratigraphers, geophysicists, structural geologists, geochemical modelers, regulators, financial planners etc.)
Representatives are authors of this document, from Department of Petroleum and Gas Engineering and Energy and Department of Geology and Geological Engineering, both parts of the same faculty. Hence, the Faculty is recognized as a relevant academic stakeholder, but their representatives were not part of stakeholder engagement.

15. University of Zagreb - Faculty of Mechanical Engineering and Naval Architecture (UNIZG-FSB)

Faculty of Mechanical Engineering and Naval Architecture representatives have been recognized as relevant stakeholders based on their research on CO_2 mitigation through energy planning, renewable energy sources (RES) systems development, and energy transition which includes CCU. Several projects from the faculty regarding CCU are listed in Chapter 1 of this report. Therefore, several contacts from Department of Energy, Power and Environmental Engineering have been targeted and engaged, either via interview or via workshop.

16. Institute "Ruđer Bošković" (IRB)

IRB is regarded as Croatia's leading scientific institute in the natural and biomedical sciences as well as marine and environmental research. Their mission is to gain new knowledge that will contribute to the development of the Republic of Croatia in a knowledge-based society. With that said, one project regarding CCU should be accented: "Assessment of Adriatic Algae Potential in Cogeneration Production of 3rd Generation Biofuel", that was supported by cooperation with INA d.d. refinery. The project principal investigator was engaged in the interview and workshop.

Other Groups

17. Society for Sustainable Development Design (DOOR)

The Society for Sustainable Development Design is an association of experts dedicated to the promotion of sustainable development in the field of energy. They work in two strategic areas: climate change mitigation and combating energy poverty. They are included in this study with representatives who have been engaged via interview and workshop.

18. Zelena Akcija (ZA)

Zelena Akcija is a non-governmental, non-profit, non-partisan and voluntary association of citizens for environmental protection. They often organize public and panel discussions on climate change topics, but also organize protests against the usage of fossil fuels and energy/carbon intensive projects in general. Therefore, collecting the insights of such NGO would bring value to the whole report. However, very limited response was obtained from ZA.

2. Stakeholder positions on CCS and CCU

2.1. Position/influence/relevance

In this section, stakeholders' positions will be summarized regarding CCS/CCS by the following approach:

- Pace-setter (actively shaping, promoting and leading development)
- Foot-dragger (aiming to stop or at least contain development)
- Fence-sitter (more ambivalent position aiming at neither consistently promoting nor preventing development)

Institutional Sector:

All 3 stakeholders from this sector can be characterized as pace-setters of high influence and relevance on the subject matter.

HERA representative sees high potential for both CCS/CCU in Croatia since there is obviously high storage capacity, together with an opportunity to produce additional hydrocarbons (through EOR) in this transitional period while simultaneously storing CO_2 underground. He sees CCS/CCU technology as one of the pillars for cleaner Europe in the near future.

In CHA, CCS/CCU is observed as one of the novel options for achieving climate neutrality goals by 2050 which is determined by the EU Green Deal. Since permanent CO_2 disposal regulatory framework in Croatia is defined within the Law on Hydrocarbon Exploration and Exploitation, which is in alignment with EU CCS Directive (Directive 2009/31/EC of the European Parliament and of the Council), the interest for CCS/CCU deployment exists, but it should be further developed, firstly through the demonstration projects and afterwards scaled-up to complete commercial application.

The Ministry's position is defined primarily through mentioning CCS/CCU technologies in national planning documents (most importantly Strategy of Low-Carbon Development of the Republic of Croatia until 2030 with a view to 2050) which was described in more detail in Chapter 1 of this document. Ministry representative thinks that as the years of 2030 and 2050 approach, CCS/CCU will be more deployed due to the rise in European Union Allowances' (EUA) prices. The before mentioned EUA price rise can make CCS/CCU more attractive for investors.

Finally, all stakeholders are in favor CCS/CCU project development but delay of application of this technology (caused by financial risk and relatively high cost of implementation) shows there is a room for an improvement financial rules and regulatory framework in Croatia. It seems that at the EU level, development of the regulatory framework (including financial prerequisites) is faster.

Private Sector

Relevant stakeholders from the private sector are mainly recognized as pace-setters (6 out of 10). The criteria for determining pace-setters was:

- Ongoing CCS/CCU projects (INA)
- Feasibility/Pre-feasibility studies (NEXE, Petrokemija)
- Possible partners targeted and contacted (Holcim)
- Actively promoting and leading development (Active Solera, Calida Aqua)

All pace-setters have high influence and medium to high relevance with regards to the CCS/CCU scene in Croatia.

It is worth mentioning that no foot-draggers are present among the stakeholders in the private sector. This means that all the actors involved are not trying to stop or contain the development of CCS/CCU deployment in Croatia. However, the rest of the stakeholders are positioned as fence-sitters due to the one (or more) of the following:

- Their deployment of CCS/CCU depends only on the EUA price and other CO_2 related costs(i.e., carbon taxes, fines for unsurrendered EUAs)
- Amount of their CO_2 emissions along with its related costs are not critical and there is no trend of increasing the emissions. Hence, "business as usual" scenario is optimal for them.
- Are waiting for instructions from the company on the global level.

Among the fence-sitters, a generalization can be applied to their influence and relevance and set the values from low to moderate.

Academic Sector:

In academic sector, Faculty of Mining, Geology and Petroleum Engineering (RGNF) is recognized as a pace-setter due to the wide spectrum of projects and studies with regards to CCS and CCUS. Even though the faculty's representatives are the authors of this report, they were engaged as stakeholders, but their opinion is explicitly defined as authors' throughout the whole report. Besides each aspect of CCS/CCU technologies, the faculty analyzed aspects of CO_2-EOR, from reservoir behavior and consequently possible CO_2 storage during and after the CO_2-EOR process, to economics and technical or legal obstacles. It is proved as an important method of physical CO_2 utilization which can be used to securely store significant amounts of CO_2 underground while simultaneously produce oil with lower or even negative carbon footprint. Since Croatia has a long hydrocarbon exploration and exploitation tradition, and almost 50 years of CO_2 injection studies, there is a good case for exploiting this process in a more environmentally sustainable manner - with focus not on additional oil recovery, but on CO_2 retention during oil production as technologically ready the most economically feasible way of storing large amounts of CO_2.

Similarly, Faculty of Mechanical Engineering and Naval architecture is positioned as a fence-sitter based on their research in CCU. Their opinion is to use CCU only in the sectors which are hard to decarbonize, like the transportation sector: overseas ships, aviation sector and in part of high temperature processes which cannot switch to electricity usage and where hydrogen application is not practical. Concerning the CCS part of the technology, they are positioned as foot-draggers since, from their point of view, the technology does not have the perspective in decarbonization of the EU energy system (it prolongates the usage of the fossil fuels). In addition, stakeholders stated that EU taxonomy does not recognize CCUS, but CCS and some forms of CCU instead. Concerning CCU, it is defined by chemical conversion of the CO_2 into the other materials or fuels, which means that CO_2-EOR is not a form of CCU, in the stakeholder's opinion.

Institute "Ruđer Bošković" is mostly oriented to fundamental research in the field of natural sciences but is detected as "provisory" pace - setter. In order to be recognized as a “full” pace-setter, more projects and studies regarding CCS/CCU need to be conducted.

Others Sector:

Society for Sustainable Development (DOOR) is recognized as a fence-sitter. Despite of their relevance on the topic of sustainable development, their activity about CCS/CCU remains limited. An impression is made that they could get involved more with the topic after the technology gains momentum in Croatia and when its benefits are clearly presented by experts.

The interview with NGO Zelena Akcija (ZA), by this day, unfortunately, remains unconducted. Zelena Akcija organized a protest on the Strategy of Low-Carbon Development of the Republic of Croatia until 2030 with a view to 2050 due to their concern about, as they state, outdated energy models, which are based on the usage of fossil fuels until mid-century, and which can currently be found in the Strategy. Therefore, Zelena Akcija has a high relevance and influence on the subject matter due to their activity and large contribution to public opinion formation. Regarding the involvement into CCS and CCU, they are foot-draggers (based on publicly available data, NUS ZA, 2021).

2.2. Stakeholders’ justifications for CCS

There is no need to separate this section by type of stakeholder due to the high similarities between stakeholders’ opinions related to several aspects of CCS/CCU.

Climate related

Generally, majority of stakeholders find CCS/CCU technologies good for CO_2 emissions reduction. During the workshop, 70% targeted CCS/CCU as a necessity, 30% consider it as an option while none find it as a threat for emissions reduction. It is worth mentioning that 60 % of the cement industry’s CO_2 emissions are process emissions, coming from conversion of calcium carbonate by thermal decomposition to lime with CO_2 as a byproduct. Another industry targeted as a relevant actor in Croatia which has an appreciable amount of process emissions is glass industry and they are equal to 20%. Hence, a question remains: After fuel switching / fossil fuel abatement, by what means will process emissions be abated if not by deploying CCS/CCU technologies?

Economic

Majority of the stakeholders find CCS/CCU technologies from neutral to negative in terms of economic feasibility (Annex C, Workshop). The exception is INA, but that is not surprising since it is a vertically integrated oil company holding production licenses for most of hydrocarbon fields in Croatia and has an ongoing CO_2-EOR project, which they would like to promote as CCUS. Their positive estimation of the economic feasibility of capture, transport, utilization and storage elements of the technology can be explained by a foreseeable opportunity for creating additional revenue streams through the offering of their transport and storage capacities for other interested parties. Other stakeholders emphasize that an incentive system is needed to make the technology commercially viable. Finally, without incentives and the utilization of captured CO_2, pure CCS technology would reduce their overall business

efficiency (except if they owned storage capacities which is not a viable option since they are not primarily connected with business that implements technologies similar to CO_2 injection).

Social

An opinion arose from the academic sector which implies that the public awareness on CCS/CCU is not on the high enough level which would give the public an opportunity to rebel against this technology. However, after the projects take momentum, it is reasonable to expect that one part of the public will react and find CCS and/or CCU as unacceptable. Hence, a clear communication strategy is needed to prepare for the challenges which almost certainly await in the near future. Generally, the public might think positively of CCS/CCU as a set of technologies for greenhouse gases emissions reduction, but when it comes to the realization of the projects in their local environment, the opinion might be switched to negative (so called NIMBY effect).

On the other side two CO_2-EOR projects are ongoing, commercially, and without negative connotations in public. This can be attributed to the fact that oil has been produced in these areas for more than half a century, and that such activities have not come under the radar of public media, however from communication (before this analysis) with INA experts, we received information that there was some lack of understanding indication at local level, before the field pilot testing (in the early 2000s) and that they (engineers from INA) communicated with local communities and clarified the specifics and benefits of the CO_2-EOR process, some of which also reflected on the inflow of funds to local communities. This may serve as an example of good PR practice which uses bottom-up approach to ensure the public acceptance when new facilities are built in some areas.

Authors of this report present a more negative example: the construction of a liquefied natural gas (LNG) terminal in Omišalj, a coastal municipality in the north-west of the island of Krk in Croatia. The local population disapprobation caused a series of media debates and long-term uncertainty of the project, which immediately after the opening of the terminal proved to be in every sense positive and more successful than expected (it was also recognized by one institutional stakeholder). From these two examples, it can be assumed that it is extremely important to approach the local community as early as possible and inform them directly about all aspects of the technology that is intended to be applied near their homes, with clearly stated financial and environmental benefits and threats the environment in their area.

Finally, as already stated, there are no examples of public debates on CCS/CCU technology in Croatia. It is most reasonable to state that social aspect of CCS/CCU is neutral at this phase, without studies or discussions about the social cost of CO_2 emission reduction strategy.

Other

During the workshop, a survey was conducted with regards to the technological feasibility of each aspect of CCS/CCU technologies and the conclusions is that our stakeholders find the technology level of CCS/CCU to be satisfactory, meaning that it fulfills the expectations, but it is not outstanding or perfect. Additionally, all the stakeholders welcomed this kind of a project (CCS4CEE) since it enables all the relevant actors to share their perceptions and acquired knowledge with each other.

3. In-depth stakeholder perceptions of the CCU and CCS landscape

3.1. Overall prospects for CCU/CCS in target country

Overall prospects for CCS/CCU in Croatia are explained through the stakeholders' strategic rationales:

- Institutional stakeholders will, in the case of demonstrational or practical application, be intensively included in the procedure of issuing the Permits to permanently store CO_2 and at the same time will monitor the fulfilling of the investors' obligation along with the monitoring of the exploration/exploitation fields for geological storage of CO_2. Additionally, they will regulate the transport and storage of CO_2 if one of them gains the characteristics of natural monopoly.

- Private sector stakeholders can ensure long-term business sustainability through reduction of costs for CO_2 emissions, since captured, transported and stored emissions count as allowances which do not need to be surrendered (the assumption of lower costs is true only in the case of reduction of the numbers of allowances which can be allocated for free and sold in auctions accompanied by the increase in EUA prices)

- Development of demonstration and pilot projects with the aim of achieving techno-economical sustainability of the production of CO_2 neutral fuels.

- Due to its perceived role, deployment of CCS/CCU could lead to achieving climate goals for 2030 (55% reduction) and 2050 (net zero GHG emissions) respectively.

- Usage of CCS/CCU in hard to decarbonize sectors.

In general, all the engaged stakeholders perceive CCS/CCU technologies as positive and promising in Croatia. The main drivers for commercial deployment of CCS/CCU are represented by EUA prices and financial subsidies both from the state and EU. This means that financial aspects of CCS/CCU will be crucial for long-term deployment of the technologies. From the stakeholders' opinion, adequate regulatory framework and public acceptance is of outmost importance. The existing infrastructure in terms of pipelines, storage units and high well density is what characterizes overall CCS/CCU landscape in Croatia as promising.

Prospects can be described by the plans of the stakeholders regarding CCS/CCU:

- Green hydrogen production from waste by pyrolysis (Carbon capture and utilization is integrated within the production process). The waste is not limited to conventional waste, but can also be biomass, waste-water sludge, plastics, etc. In this way, activities like waste management and recycling, which are in the domain of public expenditures, can be transformed to activities that produce energy and high-value carbon byproducts (which was described by the stakeholder as having negative carbon footprint) for which a commercial market exists.

- In the case of geothermal energy in Croatia, produced associated CO_2 can be directly reinjected into the reservoir due to its high purity. However, by the means of carbon capture (if needed for geothermal application but also for CO_2-EOR operations), the application of membranes imposes as an optimal method due to its simplicity, affordability and longevity (if proper dehydration of the gas stream is applied before the capture). Additionally, some quantities of CO_2 can be injected into the geothermal reservoir which then adds energy (in form of pressure in a geothermal reservoir) to the system, but those quantities should be studied and estimated. Some preliminary reservoir simulations of CO_2 enhanced geothermal production were performed for commercially operating geothermal field Velika Ciglena (binary ORC power plant), but technological readiness level (TRL) for CO_2 heat mining is very low. Another option that seems to be attractive is hot dry rock geothermal system with CO_2 as a working fluid but the existence of adequate geological formations for such process in Croatia is questionable. It simply has not been explored.

- In Croatia, some of the stakeholders considered two options which are at a higher TRL: CO_2-EOR and synthetic fuels production, and provided the following reasons:
    - CO_2-EOR because it is a proven technology and considered by some stakeholders as environmentally beneficial, but also important, high purity CO_2 is available from natural gas processing plants (NGPP) because the most of natural gas reservoirs in Northern Croatia have high content of CO_2 (even up to around 50 % mole). Moreover, to extend the CO_2-EOR activity in Croatia, CO_2 availability is the problem, which opens space for clustering the oil producers with large CO_2 emitters.
    - Synthetic fuels, both gaseous and liquid, if produced with use of captured CO_2 and renewable hydrogen, can represent an optimal solution for energy consumption in this transitional period. This is due to the existing infrastructure (natural gas pipeline system for the industry and households and gas stations) which can support the synthetic fuels within the existing framework. For example, the process of the vehicle refueling and the vehicle technology itself can remain almost the same while using synthetic fuels as an energy source. Reduction in emissions can be achieved by the avoidance principle, or in other words: by using synthetic fuels, decrease in demand of the fossil fuel equivalent is achieved. Moreover, driving vehicles with diesel engines have an efficiency of around 40 %. The target is to reach a cogeneration (combined heat and energy production) efficiency of 80-90 %, but in some cases (like transport), lower efficiencies are acceptable.
- Possible amine capture at ammonia producing facility. Also, capacity of hydrogen production via methane reforming at the same facility can be increased significantly, meaning that there could be significant quantities of blue hydrogen available on the Croatian market. Furthermore, coproduction of methanol from CO_2 and blue hydrogen at the same location could represent an option for partial decarbonization of the ammonia production facility. Captured CO_2 will/can be used for CO_2-EOR in the near hydrocarbon fields.
- Possible implementation of carbon capture facility at a coal-fired power plant (and maybe other thermal power plants too) especially after 2040. Currently, options are also considered to build waste-to-energy plants in the area of existing power plants (implementation of carbon capture at these facilities is in the inception phase)
- In a cement factory, a capture system is planned to be deployed within the pre-calciner, with an investment estimated on 100 million €. However, it remains unclear which method of capture will be used. Captured CO_2 is planned to be transported by ships, and geologically stored within the Ravenna Hub CCS project in Italy.
- The last relevant prospect for CCS/CCU in Croatia is bioenergy with CCUS project (BIO-CCUS). It is planned to be built in Sisak and to produce advanced bioethanol and biogas from energy crops and agricultural residues. Steam will also be produced and used in a cogeneration facility. CO_2 from the process (52 000 tons per year) is planned to be captured and simultaneously used for CO_2-EOR and dedicated geological storage in the hydrocarbon fields nearby.

3.2. The role of CCU/CCS in sector integration

All the stakeholders realize that without cooperation/sector integration, deployment of CCS/CCU technologies would be either impossible or of too slow dynamics which is not desired since the transitional period is happening at the moment. Therefore, most of them stated that cooperation is needed between the emitters and storage operators (at least) but it will be further discussed in the section 4 of this chapter.

For the purposes of this section, potential contribution of CCS/CCU to the creation of a value-chain for decarbonized hydrogen is explained. Most stakeholders are familiar with the “color spectrum” of hydrogen production and hence, see an opportunity for the development of the hydrogen market in Croatia. Every one of those stakeholders think that blue hydrogen (“low carbon” hydrogen)

is the fastest solution which can contribute to the market formation due to its lower cost of production when compared to the green hydrogen and its environmental efficiency when compared to other fossil-fuel based hydrogen production methods. However, all relevant actors agree that blue hydrogen is a transitional option towards green hydrogen when its production becomes more cost efficient.

Additionally, private sector stakeholder thinks that a lot of industry sectors can at the moment switch to hydrogen as a purer energy source with relatively small investments.

Besides blue hydrogen, several other relevant actors recognized an opportunity to use captured CO_2 together with blue and/or green hydrogen either for methanol production or for synthetic fuel production. Regarding the synthetic fuels, one stakeholder thinks gaseous and liquid synthetic fuels should be used in this transition period in both, households and transport sector, while two others think that it could be used just in aviation sector due to the need for high energy density fuel.

There was also one opinion from the academic stakeholder who compared synthetic fuels to a plastic bag that was used several times but disposed at the end and not properly recycled. The same stakeholder pointed out that each usage of fossil fuels implies combustion accompanied by emissions of greenhouse gases.

As a authors' concluding remark, it should be accented that Institute "Ruđer Bošković" can contribute to technologies like green and blue hydrogen development in Croatia (due to their significant laboratory/research capacity), which can interact with transition and transformation of INA d.d. as the one of the most profitable companies in Croatia (around 10 000 employees) whose upstream hydrocarbon production does not satisfy domestic demand and production decline curve is steeper than the company needs for CO_2 emissions reduction.

3.3. Awareness of EU policy and financial instruments for CCU/CCS

All engaged stakeholders have recognized the relevant, existing EU policies regarding CCS/CCU (CCS Directive, EU ETS Directive). Regulatory landscape regarding CCS/CCU in Croatia is described in Chapter 1 of this report, while landscape on the EU level is detailly described in the report by Bellona[2].

Concerning the financial instruments, stakeholders are aware that EU has certain Funds for which they can apply to get their CCS/CCU project funded. However, most of them could mention only the Innovation Fund, which was not surprising since the Innovation Fund is the only in which it is explicitly mentioned that the financing is focused on the CCS/CCU technologies. Furthermore, one private sector stakeholder gave more in-depth opinion about available EU financial mechanisms for CCS/CCU:

- Innovation Fund- The fund will use revenues from selling 450 million EUAs (between 2020 and 2030) to ensure about 10 billion € of support for commercial demonstration of innovative low-carbon technologies. Both large and small projects will be supported, i.e., larger and less than 7,5 million €.

- Recovery and Resilient Facility- The forthcoming financing mechanism to compensate 672.5 billion € in loans and grants to support reforms and investments initiated by EU member states. The facility aims to mitigate the economic and social impact of the coronavirus pandemic and ensure the European economy and society are sustainable. Final negotiations are still ongoing before it enters into force, but the program has been approved for inclusion in the long-term EU budget 2021-2027.

[2] see "The current state of CCS technologies and the EU policy framework" by Bellona Europa

- InvestEU- The program will be implemented from 2021 to 2027 and builds on the investment model "Plan for Europe", i.e., Juncker's plan. It will provide at least 650 billion € in additional investment, boosting investment, innovation and job creation in Europe.

- Just Transition Fund

3.4. Perceived deployment barriers and risks

As mentioned in the workshop, relevant actors were asked to range the risks associated with CCS/CCU by relevance with their business and the results can be summarized:

1. Financial risk (70 %)
2. Social risk (35 %)
3. Technological risk (41%)
4. Environmental risks (41 %)

Majority of stakeholders agrees that financial risks are the most important. Investments in CCS/CCU are capital intensive investments and will in addition cause a significant increase in OPEX for most stakeholders. This could lead to the price increase of the final product, which would then cause a drop in stakeholders' competitiveness on the market. Stakeholders also worry about public acceptance, while they seem to trust the technology as an emission mitigating tool.

Main barriers which stakeholders noticed are:

- Large distance from other emitters,
- Large distance from storage units/locations,
- Inertia within companies/sectors regarding cooperation,
- Skepticism towards new investment (mainly perceived by the academic sector),
- The need of London Protocol ratification in order to enable offshore CO_2 storage between the countries,
- Differing anthropogenic from non-anthropogenic CO_2 by the means of EU ETS (regarding the production of CO_2 rich natural gas)

4. Stakeholder recommendations for CCU/CCS

4.1. Regulation

At the workshop, stakeholders rated the current regulatory framework of Croatia with an average grade of 2,5/6 in terms of how stimulating it is for developing CCS/CCU projects.

In general, stakeholders (excluding the ones from institutional sector) have the following suggestions for the alteration of the laws and regulations:

- CCS/CCU projects should be recognized as Projects of strategic relevance for the Republic of Croatian order to increase the funding rate.

- EU (therefore Croatia also) should define appropriate CCU Directive with adjacent clear methodology for Life Cycle Analysis
- Renewable energy sources' integration should be increased, so that the full potential of CCU technologies could be achieved
- Bioenergy with CCS should be somehow recognized withing the EU ETS.
- London Protocol should be ratified.

Since relevant actors from the institutional sector have high influence and relevance on the subject matter, their opinions should be collected separately:

Institutional representative confirmed that there is an opportunity for long-term deployment of CCS/CCU technologies because climate neutrality of the EU is described as a balance between the remaining emissions in 2050 and natural carbon sinks (oceans, forests/plants/vegetation cover, soil). The upcoming Climate Law will regulate afforestation for CO_2 removal, however the Parliament will limit the potential for natural carbon sinks. As such, CCS must be explored. Additionally, European Commission is considering if and in what manner can the transport and building sector be included in the EU ETS.

Another Institutional representative finds no obstacles for CCUS deployment in Croatia since the EU CCS Directive is fully implemented by transposition in the Law on hydrocarbon exploration and exploitation.

Last institutional representative thinks that so far, a great work has been accomplished by implementing the EU Directive into Croatia's domestic regulations.

4.2. Technology

The stakeholders were generally satisfied with the technological feasibility of CCS/CCU. However, since there is a wide spectrum of CCS/CCU technologies, it would be useful if some parts of it progressed to the stage of full deployment.

A technology was considered efficient if the stakeholders gave it a rating of at least 3 out of 5 (5 meaning very efficient). Hence, it can be stated that efficiency of all CCS/CCU technologies is on a sufficient level. More precisely, aspects of CCS/CCU can be ranked by efficiency:

1. Storage (83 %)
2. Transport (78%)
3. Utilization (73%)
4. Capture (72%)

What may seem unusual is the high stakeholder estimation of CO_2 utilization efficiency, but this may be due to classifying CO_2 EOR within the scope of utilization.

4.3. Infrastructure

Concerning one of the transportation options, a Trunkline option with regards to onshore pipeline transportation was presented to the stakeholders and it is thoroughly explained in Chapter 1 of this report.

This option was presented to the stakeholders either through the bilateral interviews or workshop and all relevant actors who were introduced to this approach accepted it as a good idea.

However, through the interviews, gathered opinions were mainly focused on dedicated pipelines between the CO_2 source and storage locations. That is understandable when considering the time and the degree of the development of Croatian CCS/CCU scene. But if CCS/CCU takes momentum and is deployed on a full-scale, dedicated pipeline system will not be economically viable option.

A common situation that has been recognized on a global scene regarding the state funded pipeline is the "chicken and egg" paradox: The state does not want to invest in the pipeline because it claims there are no users, while emitters will not invest in capture facility because there is no pipeline for the transport of the captured CO_2 to the storage site. Institutional stakeholder gave an analogy with LNG terminal in Croatia: at the beginning, the interest of the parties for terminal's capacities was low, but as project was developing, interest for capacities grew until all the available capacities for several years in front have been leased.

Offshore pipeline network exists in the Northern Adriatic and represent INA's pipeline for natural gas transport which is produced from the North Adriatic gas fields. Since production of natural gas from those fields drops significantly, pipeline capacity can be used in an opposite direction: for CO_2 injection into the geological formations in the Northern Adriatic.

Another alternative to offshore pipeline transport is transport by ships to the storage locations in the Adriatic Sea.

Regarding storage infrastructure, most of the stakeholders find that Croatia's storage potential and the existing infrastructure together with the level of knowledge is on a satisfactory level. However, there is one different opinion (from the institutional stakeholder) which outlines the level of knowledge concerning Croatia's storage potential:

- Geological potential for CO_2 storage is insufficiently explored and defined and by this moment, there are no studies which would point out the feasible geological structures for CO_2 storage in Croatia. Publicly available data, i.e., preliminary estimations of CO_2 storage capacities, are presented in terms of professional and scientific articles and publications, MSc and PhD theses (Even that way, whole area of Croatian part of Pannonian basin is not covered)

From affirmative opinions, several can be pointed out:

- Croatia has a network of several thousand of wells (which is an unreachable goal for many other countries) meaning that the geology is very well known and that geological risk is practically non-existent.

- Storage capacities in Croatia are sufficient and there is no need for considering storage sites in other countries. Additionally, Croatia should use their storage capacities optimally and carefully when accounting for CO_2 coming from other countries since CCS/CCU will not be a relevant topic for several years, but it can be considered as a project for the whole century.

4.4. Market

Stakeholders do not have an elaborate vision of how the market should develop. Still, everyone agrees that both the state and the European Union must encourage such projects due to high capital costs and the fact that the operating costs of such a project may be higher than the current EUA price. They are also aware that for such projects, it is necessary to create additional value of the captured CO_2 through some type of utilization for the project itself to be profitable and sustainable in the long-term scenario.

Stakeholder statements related to this chapter are summarized:

- The price of the EUA should be high enough accompanied by its certain growth projections which will make the application of CCS / CCU more attractive than just buying the EUAs.
- With a high EUA price stakeholders will be "forced" to implement CCS / CCU because it is more profitable for them than buying allowances (plus they can trade with captured/utilized/stored allowances)

- after they have implemented CCS / CCU, they would like to see incentives from Croatia per ton (metric ton) of CO_2 captured as in 45Q from the USA in order to reduce operating costs (conclusion from the workshop). 45Q represents a performance-based tax credit (USD/ton of CO_2) to power plants and industrial facilities that capture and store CO_2 that would otherwise be emitted into the atmosphere. Stakeholders would like to receive the incentives in a direct-pay form rather than as a tax credit.
- They would also like to be informed by the government through the ministries and through the Croatian Chamber of Commerce about the available financial instruments of the European Union so that they can apply for them on time and receive more incentives.

Experts from RGNF (who are the authors of this report and coordinators of the related work package in Croatia, but also a CCS stakeholder from academia) would recommend the following:

- Authorities will shape the regulatory and financial framework for CCU / CCS market and economy. By observing the current state, it would be natural that regulations are proposed by ministries, permits and concessions are issued by CHA, and that there is a regulator (HERA) who will regulate the activities of transport and storage facilities if they develop monopolistic properties (by defining the size of tariffs paid to use the infrastructure and determining the methodologies for monitoring and surveillance of the CCU / CCS related activities).

- Emitters should form clusters with other industrial actors to cooperate the utilization and storage facilities. Also, emitters should connect with low-carbon, i.e. blue-hydrogen and green hydrogen producers. Almost certainly, because of well-established natural gas pipeline network (which is elaborated in published papers, like Grant et al., 2018), building the trunkline system along existing natural gas pipeline transport routes will be the most feasible option that will lead to reduction of CO_2 transport price).

Market should be established in a such way that all involved into CCS / CCU can find the economic feasibility, for example through trading of EUAs that are equal in amount to stored CO_2 and which would otherwise need to be surrendered.

4.5. Financial frameworks

Stakeholders' preferences regarding the financing tools are related to possibilities of external funding and investments in their (technology transition) projects:

- Non-refundable funds (from the state or the EU),
- Long-term loans with a low or none interest rate,
- EU funding in general (mentioned in section: "Awareness of EU policy and financial instruments for CCU/CCS")
- Co-financing of the operational costs

Regarding the public funding extent, most of the stakeholders find that the investors from the private sector would need to invest maximum 50 % of the estimated project value. More detailed opinions are depicted by the Table 2.1.

TABLE 2.1. STAKEHOLDERS RECOMMENDATIONS FOR PUBLIC FUNDING OF CCS/CCU PROJECTS

Opinion number	EU	STATE	INVESTOR
1.	Up to 50 %	Up to 50 %	The rest
2.	Up to 80 % with additional financing of OPEX	Up to 80 % with additional financing of OPEX	The rest
3.	60 %	10 %	30 %
4.	At least 50 %	At least 50 %	The rest

Moreover, the stakeholders were asked if the funding should be specific for each project, or a general support scheme should exist in order to enable CCS/CCU project. Stakeholders are divided about the issue of granting public subsidies: Half of them believes that there should be a general scheme, and minor part that the subsidy must be specific to each project while others don't have opinions on how public subsidies will be granted. A compromise is imposed as a solution: the majority of incentives will be determined through the (general) scheme on a per ton (of CO_2) basis, and there will be a variable part that will consider the specifics of each project, but only under the conditions of uniform monitoring and surveillance of CO_2 in the process (cradle-to-gate CO_2 life cycle assessment, LCA) that should be already classified as CO_2 utilization and/or storage.

Also, interesting pattern was observed:

- Stakeholders from the private sector lean toward project-based subsidies because they feel they can maximize the extent of public funding by that manner.
- Relevant actors from institutional sector find general support scheme more appropriate because the funding is more transparent and less complicated that way.

Finally, stakeholders were asked for their opinion on carbon contracts for difference (CCfD), type of contract where to parties agree on a fixed strike price over a carbon market price. For example (state-investor contract), if the market price is higher than the striking price, the investor pays the difference back to the state. On the contrary, if the market price is lower than the striking price, the state is obliged to make up for the difference to the investor. That way, CCfD have dual function:

- Reducing the long-term uncertainty associated to the carbon prices.
- Conveying a premium over expected carbon prices.

Majority of stakeholders are not familiar with CCfDs (Figure 4.2.) and those who are mainly approve (only one is against) the application in order to make the implementation of CCS/CCU more attractive. Several of the stakeholders' opinions can be accented:

- It is maybe better to firstly offer feed-in tariffs or other premium models for some time before introducing CCfDs because they are more attractive contracts for investors.
- A CCfD variation should be applied where a striking price will apply only for cases when the market price is lower than the striking price.

- These kinds of contracts will not stimulate investments in CCS/CCU. Contracts for difference as a way of trading are forbidden in the USA (not without reason).

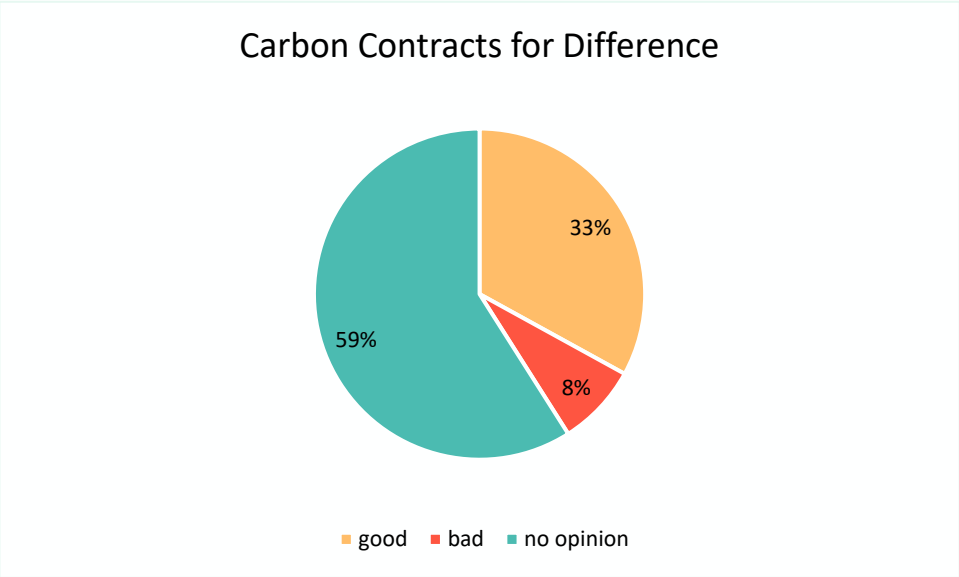

FIGURE 4.2. STAKEHOLDERS' OPINION ON THE CCFD

4.6. Inter-sectoral and regional collaboration

Intersectoral and regional collaboration should be organized through clustering of the relevant actors. Stakeholders mainly define clusters as geographically defined association of entities who have emissions, entities who have transport and storage capacities and entities who have the needed expertise and skills for supporting all activities. What all entities have in common is the interest in development and implementation of CCS/CCU projects. The following benefits can be achieved through mutual cooperation:

- Faster sharing of experience and knowledge
- Industrial process improvement
- Time savings
- Cost efficiency
- Creation of additional value (through utilization)

Stakeholders see possible cooperation between:

- Emitters to lower transportation costs,
- Emitters to utilize their CO_2 together for revenue maximization,
- Emitters and storage operators (Storage operators store emitters CO_2 and have an option to use it for EOR),
- Emitters, transportation system operator and storage operators.

4.7. Social aspects

Social aspects, together with public opinion are of high importance to all of stakeholders as social risks were recognized during the workshop as 2nd most important risk for their activities regarding CCS/CCU. Another conclusion from the workshop was that stakeholders appreciate public acceptance since it would make them more interested in deploying CCS/CCU technologies.

Throughout the interviews, majority of stakeholders stated that the public has developed consciousness for climate changes and for the need of CO_2 emissions reduction. In addition, it was unanimously agreed that the public's level of knowledge about CCS/CCU is not satisfactory which can be explained by absence of mainstream media' activity on the subject matter. In fact, it can be concluded that most of the public does not know what CCS/CCU technologies exactly are.

Main concerns of the public regarding CCS/CCU are identified by the stakeholders:

- Seismic activity during CO_2 injection in the reservoir (concern is due to the 2 major earthquakes which struck Croatia in March and December 2020)
- Possible CO_2 leakage to the surface
- Possible CO_2 negative impact on the drinking water aquifers
- Increase in the cost of energy due to CCS/CCU implementation

Despite of the public awareness about the need for CO_2 emissions reduction, the beforementioned concerns may cause a NIMBY (not in my backyard) effect.

Hence, a consensus of the stakeholders was reached about the optimal ways of further education of the public:

- Scientific based studies on the main concerns of the public
- Web site development for CCS/CCU promotion
- Flyers
- Educative Workshops
- Implementing a successful demonstration CCS/CCU project

Additionally, the most efficient means of further education indicated by the statements of the stakeholders are presented below:

- It can be achieved via organizing panel discussions and round tables to actively include both private and public sector and to increase the visibility of CCS/CCU projects in the media. The public should be sensitized in the context of natural riches that Croatia abounds in and by doing so, CCS/CCU projects would give an extra boost for the economy and environmental protection.
- CCS/CCU topics should be introduced to students during education.
- Best ways of sharing the information are workshops in which practical examples from the academia and the industry are presented.
- Further education is needed not only for the public, but for the experts (which can serve as some sort of knowledge update). Through constant communication and data sharing, the risk of rejection of the new technologies decreases. It is necessary to know what the advantages and risks are when implementing a new technology. The starting point should be local areas nearby potential CCS projects. The public reacts well to animations, schemes and graphical displays because they can simply demonstrate the rationale, usefulness, and security of the technology implementation. Finally, social media can also significantly affect the changing of the public's perception or even form it.

- It is necessary to hold lectures, develop a website and to print out flyers. The public should be educated in a simple and understandable way.
- One successful project could indicate the benefits of CCS/CCU, primarily through good PR campaign (appearances in the media).
- Further education of the public is needed in terms of presenting real facts and positive aspects of the CCS/CCU deployment. Also, it is desirable to explain what CCS/CCU technologies would not cause groundwater pollution. The education should be in terms of public discussions and presentations by the experts.
- The public should be informed about CCS/CCU through television shows, but only in the prime time.
- The education should be directed towards explaining to the public that companies within the energy sector cannot operate against the law. There are several surveillance systems like regular inspections, emissions monitoring, air quality stations throughout the city.

It is of outmost importance that the education of the public begins as soon as possible so that, when the real projects take place, all of the parties (stakeholders and local population) are aware of the benefits and opportunities that lie ahead.

Another interesting option would be (similar to organizations in Italy, France and Romania) the foundation of the Croatian "CO_2 Club" (or CO_2 Center of Excellence) which would include all the relevant stakeholders from this project and would include the creation of the platform to carry out the exchange of ideas, information as well as common projects, policy proposals or government actions in the field of CCS/CCU.

Chapter 3. CCS and CCU: Public acceptance in Croatia

1. Public survey

Within the scope of "Evaluation System for CO_2 Mitigation" project (ESCOM, https://escom.rgn.hr, (Vulin, 2019)) from 2017 until 2019, a survey was conducted with an aim of investigating the attitudes about activities in the field of climate change.

In order to achieve the stated goal of the research, the following contents are included in the research:

- research of knowledge and public understanding of CO_2 properties,
- perception of current activities in the field of climate change,
- perception of opportunities for oil and gas industry to reduce emissions,
- acceptance of technologies.

The survey was conducted by the online method of data collection:

- on members of the general public (643) and
- on respondents who have titles related to the field of geosciences (160).

For the purposes of this report, only the results from the general public are presented.

In the survey, examinees were mainly asked whether they agree with certain statements or not and for the purposes of this report, 17 statements/questions were separated. Statements directly related to CCS/CCUS are highlighted in bold.

1. **Are you familiar with CCS technology?**
2. **Are you familiar with CCUS technology?**
3. **CO_2 can be stored in depleted oil and/or gas reservoirs.**
4. **CO_2 must not be stored in deep saline aquifers, even if it is water that is not in contact with groundwater.**
5. **CO_2 is used for plastics production.**
6. **I approve the underground storage of CO_2, but not in the Republic of Croatia.**
7. **I approve underground CO_2 storage, but only offshore (in deep underground structures under the sea).**
8. **I approve underground CO_2 storage, but only onshore (in deep underground structures, but not under the sea).**

9. **CO_2 emitting companies can make profit on the CO_2 market by selling that same CO_2.**

10. **Select emission reduction measures that you consider effective.**

11. The impact of climate change will significantly change the quality of life in less than 30 years.

12. The exclusion of fossil fuels from use and the introduction of renewable energy sources is possible and feasible, but it is not applied due to the great influence of the oil and gas industry.

13. New technologies need to be applied to mitigate climate change.

14. Significant measures to reduce CO_2 emissions are needed.

15. Higher CO_2 taxes need to be introduced.

16. If it were to significantly affect global warming, I am willing to pay higher electricity bills.

The results of the survey directly related to CCS/CCUS are represented by the Figures 3.1 to 3.10.

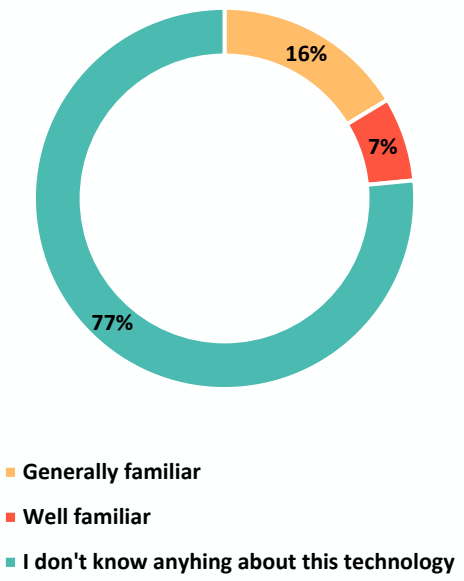

FIGURE 3.1. ANSWERS TO THE QUESTION "ARE YOU FAMILIAR WITH CCS TECHNOLOGY?"

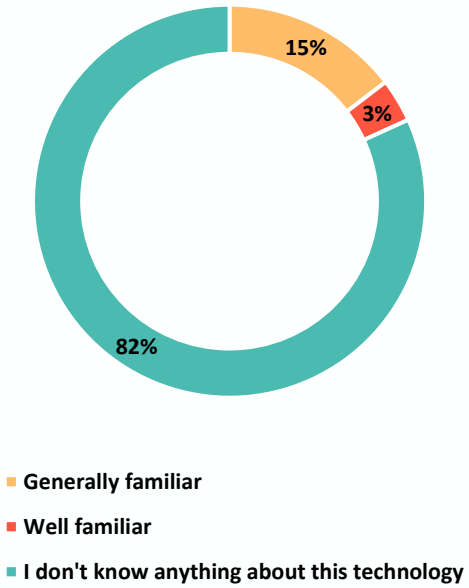

FIGURE 3.2. ANSWERS TO THE QUESTION "ARE YOU FAMILIAR WITH CCUS TECHNOLOGY?"

77 % of the public is not familiar with CCS technology, while 7 % from the remaining 23 % is well familiar. When asked about the level of familiarity with the CCUS technology, 79 % of the public was not familiar with it, while 18 % was generally familiar and only 3 % of the public was well familiar with the technology.

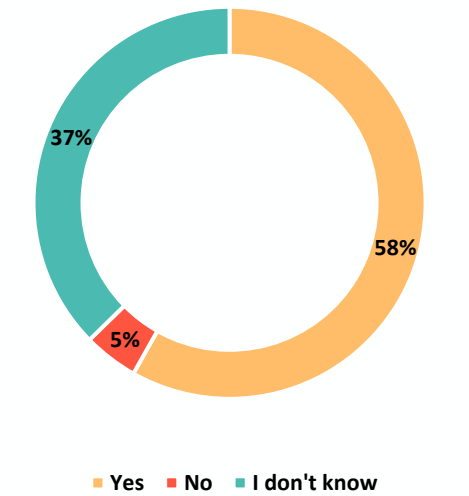

FIGURE 3.3. AGREEING WITH THE STATEMENT "CO_2 CAN BE STORED IN DEPLETED OIL AND/OR GAS RESERVOIRS."

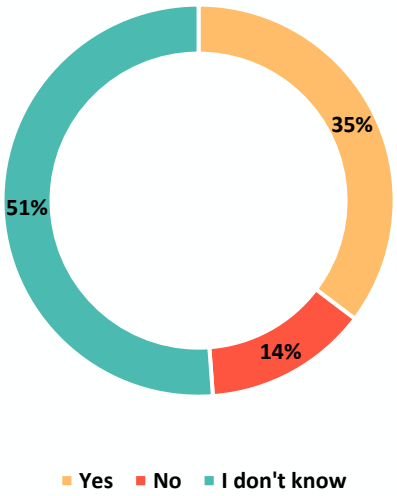

FIGURE 3.4. AGREEING WITH THE STATEMENT "CO_2 MUST NOT BE STORED IN DEEP SALINE AQUIFERS, EVEN IF IT IS WATER THAT IS NOT IN CONTACT WITH GROUNDWATER."

Unlike for CO_2 storage in depleted hydrocarbon fields, where only 5% of respondents disagreed with the concept, 35 % of the public agrees that CO_2 must not be stored in deep saline aquifers, even if it is water that is not in contact with groundwater. Additionally, 51 % of the public could not decide whether they agree or not with the statement.

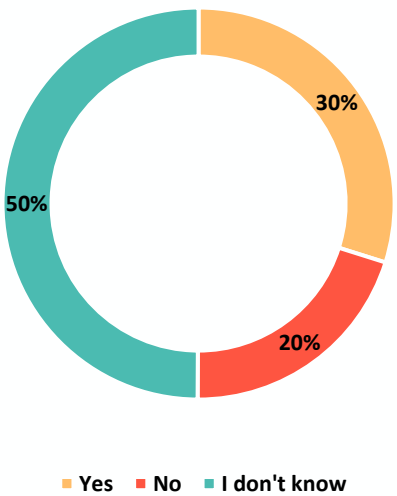

FIGURE 3.5. AGREEING WITH THE STATEMENT "CO_2 IS USED FOR PLASTICS PRODUCTION."

Regarding CCU (applied in plastics production), only 30 % of both groups think that CO_2 can be used for this particular purpose.

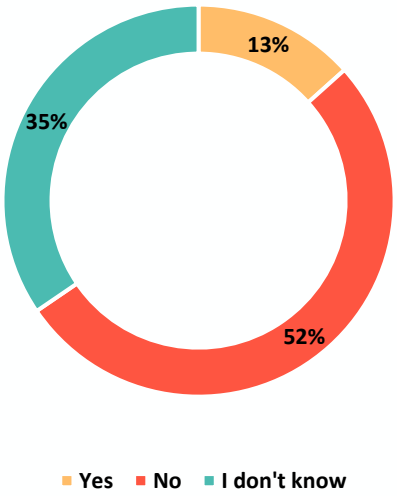

FIGURE 3.6. AGREEING WITH THE STATEMENT "I APPROVE THE UNDERGROUND STORAGE OF CO_2, BUT NOT IN THE REPUBLIC OF CROATIA."

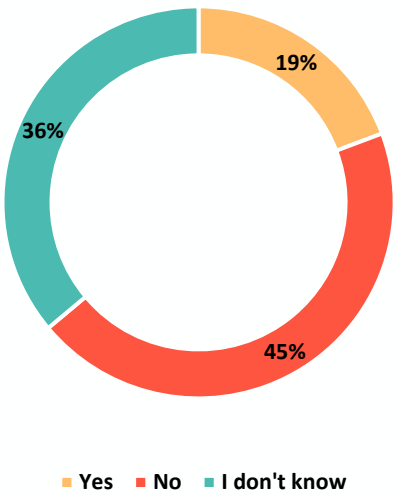

FIGURE 3.7. AGREEING WITH THE STATEMENT "I APPROVE UNDERGROUND CO_2 STORAGE, BUT ONLY OFFSHORE (IN DEEP UNDERGROUND STRUCTURES UNDER THE SEA)."

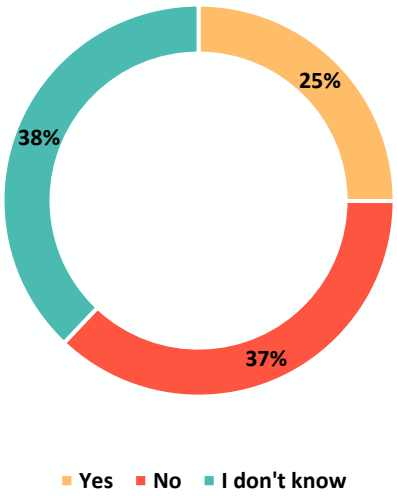

FIGURE 3.8. AGREEING WITH THE STATEMENT "I APPROVE UNDERGROUND CO_2 STORAGE, BUT ONLY ONSHORE (IN DEEP UNDERGROUND STRUCTURES, BUT NOT UNDER THE SEA)."

Concerning the approval of underground CO_2 storage, the percentages of approvals under various conditions should be accented:

- 13 % of the public (15 % of the geosciences group) approves it, but not in Croatia. This percentage represents the scale of "Not in My Backyard" effect (NIMBY) if CCS technology is to be commercially deployed across Croatia.
- 19 % of the public (26 % of the geosciences group) approves it, but only offshore.
- 25 % of the public (40 % of the geosciences group) approves it, but only onshore, meaning that the examinees are fonder of onshore CO_2 underground storage than offshore.

If respondents disagreed with the statements number 6, 7 and 8 (Approval of underground CO_2 storage but only under certain conditions), this could mean several things:

- They approve underground CO_2 storage, Croatia included.
- They approve underground CO_2 storage, both onshore and offshore.
- They don't approve underground CO_2 storage.

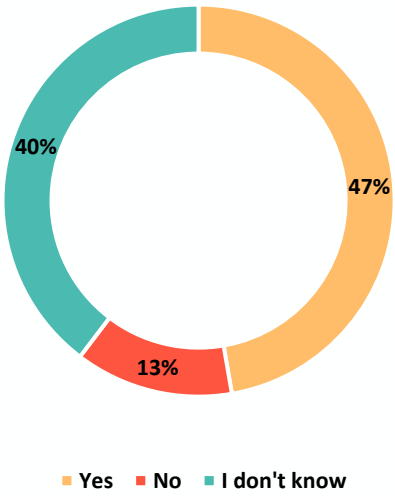

FIGURE 3.9. AGREEING WITH THE STATEMENT "CO_2 EMITTING COMPANIES CAN MAKE PROFIT ON THE CO_2 MARKET BY SELLING THAT SAME CO_2."

Regarding the possibilities of companies' profit making from selling CO_2 allowances (EUA), 47 % of the public agree that it is possible.

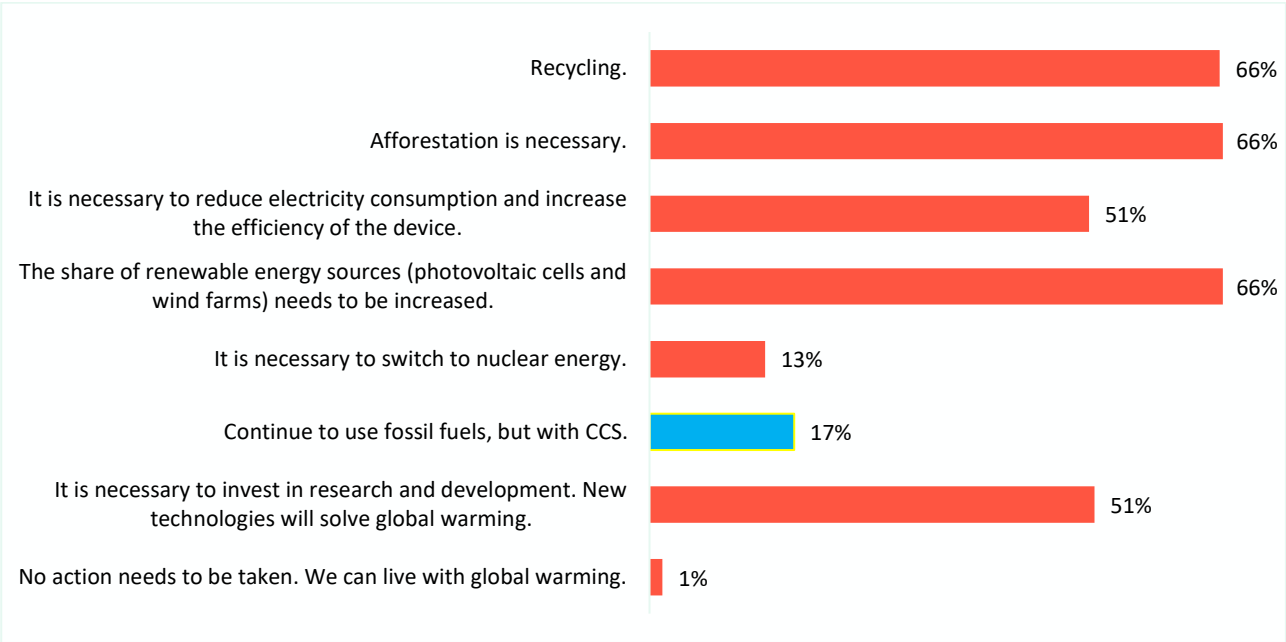

FIGURE 3.10. EXAMINEES SELECTION OF EMISSION REDUCTION MEASURES THAT THEY CONSIDER EFFECTIVE.

Top 3 emission reduction measures for the public are:

1. Increasing the share of renewable energy sources
2. Afforestation
3. Recycling

Only 17 % of the public group thinks that the use of fossil fuels can continue, but with CCS.

From the figures above can be concluded that the public agrees that (50 % criteria):

- The impact of climate change will significantly change the quality of life in less than 30 years.
- New technologies need to be applied to mitigate climate change.
- Significant measures to reduce CO_2 emissions are needed.
- Higher CO_2 taxes need to be introduced.
- They are willing to pay higher electricity bills if it were to affect global warming significantly.
- The exclusion of fossil fuels from use and the introduction of renewable energy sources is possible and feasible, but it is not applied due to the great influence of the oil and gas industry.

2. Stakeholders' expert insights

The public awareness and acceptance issues were also discussed with the relevant stakeholders, who are described in detail in Chapter 1 of this report. Their expert insights on public acceptance issues regarding CCS/CCU were obtained through bilateral interviews and workshop.

The stakeholders were asked about the public perception about the pre-eminence of climate change and the urgency of cutting down emissions of CO_2 in Croatia's economy (Figure 3.11.).

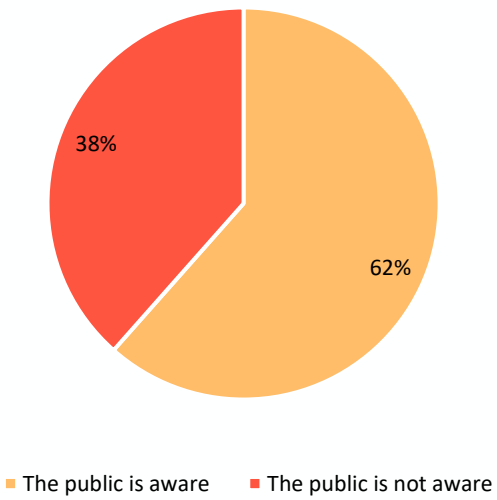

FIGURE 3.11. STAKEHOLDERS OPINION ON THE PUBLIC AWARENESS OF THE CLIMATE CHANGE AND OF THE URGENCY OF CUTTING DOWN CO_2 EMISSIONS IN CROATIA

Several statements of the stakeholders on the public opinion can be pointed out:

- The public is well familiar with the scope of climate change and with the necessity of CO_2 emissions reduction, but tendency towards activities for CO_2 emissions reduction is questionable when they include additional costs and changing of lifestyle.

- The public is not familiar enough with the importance of climate change and the necessity of CO_2 emissions reduction. Questionable statements appear in different spheres of society and simplified expert opinion should be presented to the public.
- The public in Croatia is probably more troubled by other concerns.
- The public is quite aware of the situation. But since the public in Croatia is dealing with other primary questions, it is not realistic to expect from it to act from self-initiative.
- At this point, the public is aware of the climate change and the need to curb CO_2 emissions. Especially now when the weather changes dramatically, everyone concludes that this is the climate change. However, the public is not worried enough to make personal sacrifices, that is, paying higher energy bills.
- In terms of climate change mitigation, the public probably expects more than can be done at the moment. People are willing to pay for the emissions reduction (through the bills). If the company deploys CCS/CCU, the consumers will maybe not rebel because of the higher bills. At the moment, nobody is making problems when the tariff for electricity from renewable energy sources (part of the electricity bill) increases their electricity price.

Next question for the stakeholders was about the public's level of knowledge about CCS/CCU projects and what would be their main concerns about CCS/CCU projects.

Consensus was reached among the stakeholders on public's level of knowledge about CCS/CCU project and it was characterized as insufficient/unsatisfactory.

Several possible main concerns of the public about CCS/CCU project can be accented:

- Safety risks associated with CO_2 leakage (groundwater pollution, air pollution, human safety),
- Products price/energy bills increase,
- Insufficient knowledge of the technology,
- NIMBY effect (meaning no relevant concerns exist, but the facility is undesirable for the local population),
- Possible earthquakes,
- Encouraging the continuation of fossil fuels usage.

Some stakeholders' answers can be listed:

- The public is very unfamiliar with CCS/CCU projects and with their potential advantages and disadvantages. Concern of the public is focused on environmental pollution through deployment of new technologies (e.g., CO_2 leakage).
- The public's level of familiarity with CCS/CCU projects is not satisfactory, it is still in its infancy. Due to the above, the main potential concerns cannot be identified and addressed.
- The public knows very little about CCS/CCU. There are no concerns now but if there were, it would be about earthquakes. That possible concern should not be ignored, so that someone does not say something is being hidden from the public. For that reason, scientific based estimation should be done in which it will be stated that the eventual magnitudes of these induced seismic activities would not be possible to feel.
  Additional concern would be on the exact location of injection where the public could be concerned about groundwater (drinking water) pollution or leakage risk. Hence, they should be informed that the injection would take place deep underground (for example at the depth of min. 3000 m).
  All the activities regarding CCS/CCU should be actively discussed publicly in order to give little space for pseudo-science which is developing on social media.
- Their knowledge is not on a satisfactory level. Main concern would be directed towards groundwater pollution and dangers from implementing CCS/CCU technologies since it is technically and technologically immature in Croatia.
- They are not familiar with CCS/CCU (less than 5% have even heard of it). Possible concern would be the NIMBY effect for CO_2 storage. It should be explained to the public that the budget of local governments would increase with the projects and that the whole process is harmless.

- One of the concerns would be that by deploying CCS/CCU, transition towards "greener" solutions is not encouraged, but a continuation of fossil fuel usage instead.

Furthermore, the stakeholders were asked whether they can identify the main narratives and memes related to CCS/CCU in Croatia, but only one relevant opinion arose (as expected since there is only one active large-scale project which utilizes CO_2: CO_2 EOR Project Croatia):

- Local population at the location of CO_2 injection (as a part of CO_2-EOR project) did not want CO_2 from another region in Croatia under their houses.

However, the situation was resolved by presenting several facts to the public:

- Injection data at the exact scale (depth of 3000 m),
- Employment of the local population and
- Cash flow of the local government budget with and without the project (regulatory framework in Croatia imposes that certain percent of fees which concessionaire pays to the Republic of Croatia belongs to the local government).

When asked to identify other industries with possible social experiences relevant to the CCS/CCU technology in the recent past, stakeholders were mentioning their own industrial sectors (cement, oil and gas, fertilizer, etc.), but due to the current number of operating CCS/CCU projects, it is clear that only one stakeholder from the private sector had social experience relevant to CCS/CCU. However, this number is expected to increase since CCS/CCU technology is planned to be deployed at several locations (described in Chapter 2 of this report).

Regardless of the lack of social experience related to CCS/CCU projects, there are some cases of public acceptance issues related to the power sector which were presented by the stakeholder:

- Plomin C, planned additional block of coal fired power plant with an installed capacity of 500 MW, was not realized. The project did not pass the public discussion even though CCS implementation was planned since EU legislation imposes CCS deployment on power plants of more than 300 MW if certain requirements are met (maybe the public was not aware of it). A lawsuit also occurred from one environmental non-government organization, and the subject of the suit was the existing power plant's environmental permit, but it did not pass in the court.
- Another example would be the reconstruction of one of the two power plant's towers in Zagreb. A signalization light was necessary on the tower since an airport is nearby. A lot of calls were received from citizens that they could not sleep, so the light was replaced with a weaker one, but still within the legally acceptable limits. Also important was the choice between flashing and constantly shining light.

Next question was related to the measure in which the public discourse on CCS/CCU is based on scientific evidence/facts (Figure 3.12.).

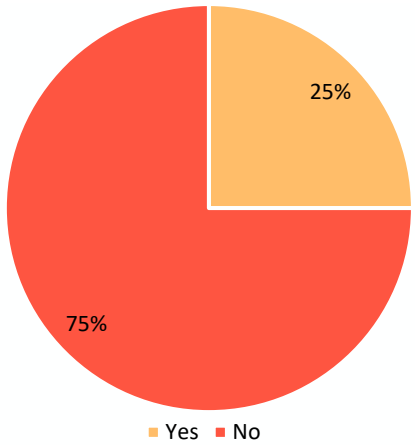

FIGURE 3.12. STAKEHOLDERS' OPINION ON WHETER THE PUBLIC DISCOURSE ON CCS/CCU IS MAINLY BASED ON SCIENTIFIC EVIDENCE/FACTS.

Most of the stakeholders find that public discourse on CCS/CCU is not based on scientific facts and several stakeholders' statements can be accented:

- Since publicly available information about CCS/CCU in Croatia is very limited, it can be assumed that public discourse is not based on scientific facts.
- It is not based on scientific facts, but it is important to have a good marketing and promotion.
- It is very little based on scientific facts since they are mostly incomprehensible for the public due to too high complexity of displaying the scientific results.
- The topic is not especially present in the public discourse. Since there is a lack of general information on the topic, lack of scientific facts in the discourse is also observed.
- It is generally based on scientific facts, but CCS/CCU technologies were not the topic of public discussions in Croatia. The public discourse depends on the education of the individual.
- The public trusts science and relies on it. However, their trust is not 100 %.
- One stakeholder believes that it is largely based on the scientific facts. "Maybe the public thinks that we have more time to act in terms of repairing the ecological situation than we really do."

By research of publications in Republic of Croatia related to CCS/CCU technologies, there are almost no scientific works that even mention that technology (except from authors from our institution - Faculty of Mining, Geology and Petroleum Engineering, University of Zagreb, but those publications are mostly related only to CO_2 storage technologies, CO_2 storage capacity and CO_2 injection studies). The only relevant work that can be mentioned is study by Ančić et al. (Ančić, Puđak, & Domazet, 2016), with English title "Do we see climate change in Croatia? Research of attitudes on some of the aspects of climate change in Croatian society" which (among others) contains the research of Croatian citizens' attitudes about climate change, their opinion about the effectiveness of EU and Croatian climate change policies and their influence on economic development. According to their findings, Croatian citizens accept climate change as global (not national) issue. The average score on awareness of climate change dangers is below European average – about 70 % recognize climate change as serious problem.

Interesting information can be extracted from another study (Firšt, 2019) where the top five (by visits) internet news portals in Croatia were analyzed for articles that are related to climate change. In around 200 published news, none of them mentioned CCS or CCU technology, and the closest search keywords were "climate change" (16,74 %) and "temperature increase (26,87 %). In conclusion, the author confirms that journalists are usually only translating global news from the world (around 18 % of news are at national level).

Implicit/explicit positions of stakeholders

Concerning the explicit positioning of the institutional stakeholders on CCS technology, the Ministry of Economy and Sustainable Development (together with the Government of the Republic of Croatia) accepts CCS as a technology for curbing the CO_2 emissions since they created legislative framework for underground CO_2 storage and listed CCS in the strategic documents as technology which will help to achieve set climate goals for 2030 and 2050, respectively. The Croatian Hydrocarbon Agency is positively positioning itself on CCS technology since the Agency represents an executive and supervisory body (together with the mentioned Ministry) for implementing the decarbonization measure of "Establishing a platform for the collection, use and storage of CO_2". The Croatian Energy Regulatory Agency representative implicitly approves CCS and it is expected that the Agency will take its explicit position on CCS technology if one of its aspects appears to have monopolistic attributes.

Regarding the private sector stakeholders, all of them implicitly approve CCS/CCU as an effective technologies to reduce CO_2 emissions, but only one stakeholder, national oil company INA, explicitly positions itself on CCS, primarily through deploying CO_2-EOR, but also through the plans for building a biorefinery with CO_2 capture facility.

The NGOs included in this report were not as active as expected and, hence, their explicit/implicit positioning on CCS/CCU was omitted. However, in one of the environmental NGO's report, CCS was referred to as an unproven and expensive technology. Finally, it is expected that the NGOs will position themselves explicitly on CCS/CCU if the number of deployed/planned projects increase.

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Annex A: EU ETS operators in Croatia

TABLE A.1. EU ETS OPERATORS IN CROATIA

Account Holder Name	Installation Name	Activity Type	City
Acciaierie Bertoli Safau Sisak d.o.o.	ABS Sisak d.o.o.	Production of pig iron or steel	Sisak
Adria Čelik d.o.o.	Adria Čelik d.o.o.	Production of pig iron or steel	Kaštel Sućurac
Badel d.o.o.	Badel d.o.o.	Combustion of fuels	Sesevete
Calucem d.o.o.	Calucem d.o.o.	Production of cement clinker	Pula
CEMEX Hrvatska d.d.	CEMEX Hrvatska d.d.	Production of cement clinker	Kaštel Sućurac
Ciglana Cerje Tužno d.o.o.	Ciglana Cerje Tužno d.o.o.	Manufacture of ceramics	Maruševec
Croatia Airlines hrvatska zrako-plovna tvrtka d.d.	12495	Aircraft operator	Zagreb
Dilj d.o.o.	Pogon Našice	Manufacture of ceramics	Vinkovci
Dilj d.o.o.	Pogon I	Manufacture of ceramics	Vinkovci
Dilj d.o.o.	Pogon Slavonka	Manufacture of ceramics	Vinkovci
DS Smith Belišće Croatia d.o.o.	DS Smith Belišće Croatia d.o.o.	Combustion of fuels	Belišće
Đuro Đaković Energetika i in-frastruktura d.o.o.	Đuro Đaković Energetika i infra-struktura d.o.o.	Combustion of fuels	Slavonski Brod
Eko Međimurje d.d.	Eko Međimurje d.d.	Manufacture of ceramics	Čakovec
Gavrilović d.o.o.	Gavrilović d.o.o.	Combustion of fuels	Petrinja
GIRK Kalun d.d.	GIRK Kalun d.d.	Production of lime, or calcination of dolomite/magnesite	Drniš
Gradska toplana d.o.o.	Toplana-Karlovac	Combustion of fuels	Karlovac
HARTMANN d.o.o.	HARTMANN HRVATSKA	Production of paper or cardboard	Koprivnica
HEINEKEN HRVATSKA d.o.o.	Kotlovnica ''Karlovačka pivovara''	Combustion of fuels	Karlovac
HEP-Proizvodnja d.o.o.	TE-TO Zagreb	Combustion of fuels	Zagreb
HEP-Proizvodnja d.o.o.	EL-TO Zagreb	Combustion of fuels	Zagreb
HEP-Proizvodnja d.o.o.	TE Rijeka	Combustion of fuels	Zagreb
HEP-Proizvodnja d.o.o.	TE Plomin 1	Combustion of fuels	Zagreb
HEP-Proizvodnja d.o.o.	TE Plomin 2	Combustion of fuels	Zagreb
HEP-Proizvodnja d.o.o.	TE Sisak	Combustion of fuels	Zagreb
HEP-Proizvodnja d.o.o.	TE-TO Osijek	Combustion of fuels	Zagreb
HEP-Proizvodnja d.o.o.	KTE Jertovec	Combustion of fuels	Zagreb
HEP-Toplinarstvo d.o.o.	Pogon Osijek	Combustion of fuels	Zagreb
Holcim (Hrvatska) d.o.o.	Holcim (Hrvatska) d.o.o.	Production of cement clinker	Koromačno
Hrvatska industrija šećera d.d.	HIŠ pogon Županja	Combustion of fuels	Zagreb
Hrvatska industrija šećera d.d.	HIŠ pogon Virovitica	Combustion of fuels	Zagreb

Account Holder Name	Installation Name	Activity Type	City
Hrvatska industrija šećera d.d.	Hrvatska industrija šećera - pogon Osijek	Combustion of fuels	Zagreb
Impol - TLM d.o.o.	Impol - TLM d.o.o.	Production of secondary aluminium	Šibenik
INA d.d.	INA- Industrija nafte d.d. Rafinerija nafte Rijeka	Refining of mineral oil	Zagreb
INA d.d.	INA d.d. Sektor rafinerije nafte Sisak	Refining of mineral oil	Zagreb
INA d.d.	Objekti frakcionacije Ivanić Grad	Combustion of fuels	Zagreb
INA d.d.	Objekti prerade plina Molve	Combustion of fuels	Zagreb
INA MAZIVA d.o.o.	INA MAZIVA d.o.o.	Combustion of fuels	Zagreb
Intercal Croatia d.o.o.	POGON I	Production of lime, or calcination of dolomite/magnesite	Sirač
Intercal Croatia d.o.o.	POGON II	Production of lime, or calcination of dolomite/magnesite	Sirač
Keramika Modus d.o.o.	Keramika Modus d.o.o. Tvornica Orahovica	Manufacture of ceramics	Orahovica
Knauf Insulation d.o.o.	Knauf Insulation d.o.o.	Manufacture of mineral wool	Novi Marof
Kronospan CRO d.o.o.	Kronospan CRO d.o.o	Combustion of fuels	Bjelovar
LEIER-LEITL d.o.o.	LEIER-LEITL d.o.o.	Manufacture of ceramics	Turčin
NEXE d.d.	Našicecement d.d.	Production of cement clinker	Našice
Opeka d.d. u stečaju	Proizvodni pogon Osijek	Manufacture of ceramics	Osijek
Opeka d.d. u stečaju	Proizvodni pogon Sarvaš	Manufacture of ceramics	Osijek
Petrokemija d.d. tvornica gnojiva	Petrokemija d.d. tvornica gnojiva	Production of ammonia	Kutina
Podravka d.d.	Podravka d.d. - lokacija Ante Starčevića 32 Kopr.	Combustion of fuels	Koprivnica
Podravka d.d.	Podravka d.d. - lokacija industrijska zona Danica	Combustion of fuels	Koprivnica
RAZVITAK d.d.	Proizvodni pogon Razvitak Ilok	Manufacture of ceramics	Ilok
Rockwool Adriatic d.o.o.	Rockwool Adriatic d.o.o.	Manufacture of mineral wool	Potpićan (općina Kršan)
Sojara d.o.o.	Sojara d.o.o.	Combustion of fuels	Zadar
Vetropack Straža tvornica stakla d.d.	Vetropack Straža tvornica stakla d.d. Hum na Sutli	Manufacture of glass	Hum na Sutli
Wienerberger d.o.o.	Pogon Karlovac	Manufacture of ceramics	Karlovac
Ferro-Preis d.o.o.	Ferro-Preis d.o.o.	Production of pig iron or steel	Čakovec
Finag d.d.	Finag d.d. Pogon Ciglana	Manufacture of ceramics	Garešnica
I.T.V. d.o.o.	I.T.V. d.o.o.	Production of lime, or calcination of dolomite/magnesite	Raša

Account Holder Name	Installation Name	Activity Type	City
Intercal Croatia d.o.o.	POGON	Production of lime, or calcination of dolomite/magnesite	Sirač
Knauf d.o.o.	Knauf d.o.o.	Combustion of fuels	Knin
Metalska industrija Varaždin d.d.	MIV d.d.	Production of pig iron or steel	Varaždin
Opeka d.d. u stečaju	Proizvodni pogon Vladislavci	Manufacture of ceramics	Osijek
Plamen d.o.o.	Plamen d.o.o.	Production of pig iron or steel	Požega

Annex B: Croatia GDP structure

TABLE B.1. CROATIA GDP STRUCTURE PER ACTIVITY (SOURCE: CROATIAN BUREAU OF STATISTICS, 2021)

million EUR (1 EUR = 7,5 HRK)	Sector	2015	2016	2017	2018	2019	2020
Agriculture, forestry and fishing	Agricultural	1 329	1 420	1 401	1 501	1 527	1 576
Manufacturing, mining and quarrying and other industries	Industrial	7 600	7 826	7 992	8 051	8 167	7 803
Of which manufacturing industry	Industrial	5 714	5 970	6 179	6 257	6 275	5 903
Construction	Industrial	1 839	1 888	2 006	2 221	2 430	2 556
Wholesale and retail trade, transportation, storage, accommodation and food service activities	Service	8 235	8 513	9 119	9 750	10 252	8 059
Information and communication	Service	1 708	1 767	1 892	2 030	2 142	2 264
Financial and insurance activities	Service	2 337	2 397	2 491	2 461	2 531	2 440
Real estate activities	Service	3 616	3 657	3 718	3 754	3 844	3 881
Professional, scientific, technical, administrative and support service activities	Service	3 070	3 157	3 340	3 386	3 529	3 243
Public administration and defense, education, human health and social work activities	Service	5 585	5 810	6 025	6 425	6 767	7 050
Other service activities	Service	1 255	1 391	1 498	1 590	1 668	1 419
Gross value added (basic prices)	/	36 575	37 827	39 481	41 168	42 858	40 291
Taxes on products less subsidies on products	/	7 581	7 829	8 294	8 930	9 446	8 007
Gross domestic product (market prices)	/	44 156	45 656	47 775	50 099	52 303	48 297

Annex C: Workshop outcomes

Croatian Workshop within the CCS4CEE project was held on 5th of May 2021 and its structure was defined as follows:

1. Opening and presentation of the CCS4CEE project
2. Group discussion:
    - The technical and economic potential of CCS/CCU in Croatia
    - The regulatory and financial landscape surrounding CCS/CCU in Croatia
    - Barriers, opportunities and risks for the development of CCS/CCU in Croatia
    - What needs to happen to deploy CCS/CCU in Croatia
    - Potential synergies between actors and sectors for developing CCS/CCU in Croatia
    - Gaps in the sector and system which create challenges for actors and sectors to work together on developing CCS/CCU in Croatia.
3. Conclusions

It is worth mentioning that group discussion topics mainly coincide with the sections of Chapter 2 of this document (Croatia's outlook for CCS and CCU) and therefore, it was decided to integrate the resulting discussion along with the conclusions within the report in Chapter 2. However, in each topic of the discussion, stakeholders were asked several questions which represent an addition to the questions from the guidance document. The workshop questions were found to be of high significance for the report because a fruitful discussion occurred where the stakeholders presented their arguments for the answers on the subject matter. Therefore, questions from the discussion along with adjacent answers are presented in the text below.

For the purposes of this annex, following abbreviations are applied:

- IS- Institutional stakeholders
- PS-Private sector stakeholders
- AS-Academic stakeholders
- OS-Other stakeholders (primarily the NGOs), but they were not active in the discussion. Instead, their activity was represented by filling out the online forms during the workshop.

Before the discussion began, a relevant statement from institutional stakeholder was presented:

IS:" As we move towards 2030 and 2050, the requirements for emissions reduction are higher. Europe is moving towards climate neutrality, which is hard to achieve. This neutrality represents a balance between the emissions which will remain by 2050 and carbon sinks. CCS/CCU has been expensive and not widely deployed, but as the terms for emissions reduction are getting stricter (EUA prices), the technology will become more competitive. Emitters are faced with high EUA prices which are already higher than 45 € and that represents a problem for them since a lot of financial resources need to be spent for buying the EUAs instead of investing them in the facility. This year, the European Commission will deliver amendment proposals for EU ETS regulatory framework by which the number of allowances that are both, allocated for free and bought in auctions, will be reduced. That said, emissions related costs will rise which could lead to wider deployment of CCS/CCU technologies. Concerning the aforementioned, there are also methods which can reduce energy related emissions (fuel switching, integration of renewable energy sources), but still, process emissions will remain and CCS/CCU could impose as the only viable solution for removing the emissions.

1. The technical and economic potential of CCS/CCU in Croatia

First topic of group discussion was about technical and economic potential of CCS/CCU in Croatia. Stakeholders were immediately asked to fill out a form consisting out of two questions (Figures C.1. and C.2.):

- Please estimate the technological efficiency of CCS/CCU technologies in Croatia
- Please estimate the current economic feasibility of CCS/CCU technologies in Croatia

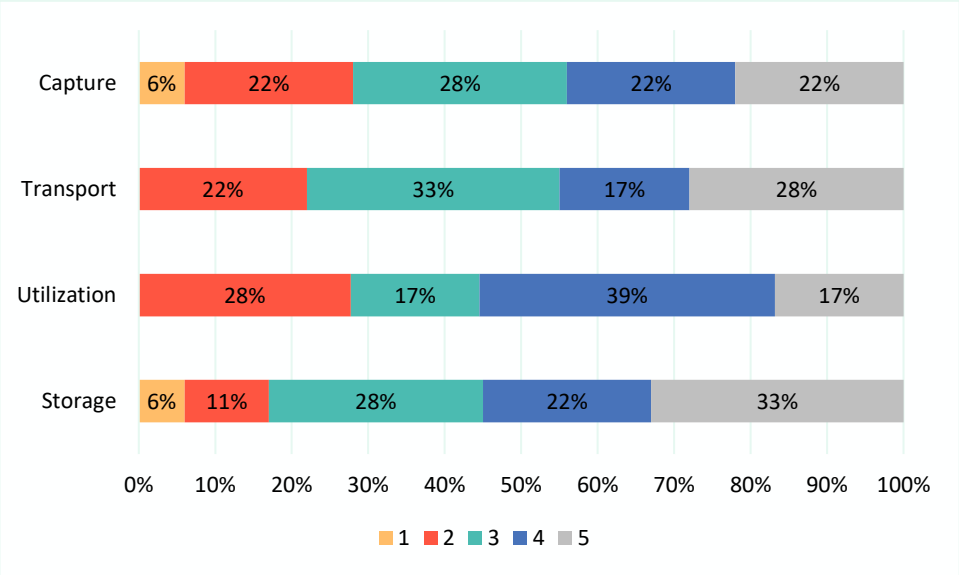

FIGURE C.1. STAKEHOLDERS' TECHNOLOGICAL EFFICIENCY ESTIMATION OF EACH PART OF CCS/CCU TECHNOLOGIES IN CROATIA (1-VERY INNEFICIENT, 5-VERY EFFICIENT)

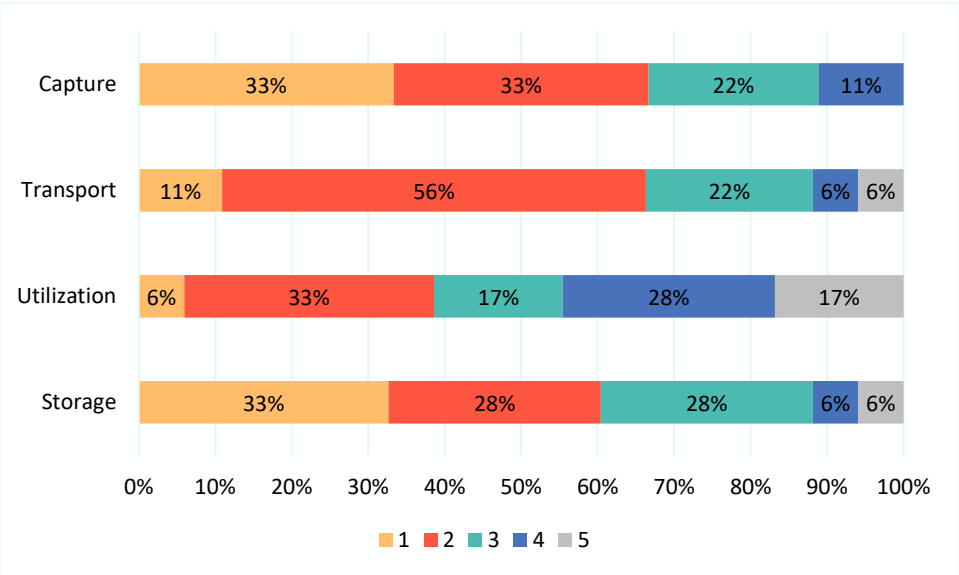

FIGURE C.2. STAKEHOLDERS' ECONOMICAL FEASIBILITY ESTIMATION OF EACH PART OF CCS/CCU TECHNOLOGIES IN CROATIA (1-HIGHLY UNFEASIBLE, 5-HIGHLY FEASIBLE)

PS1: "Since we are not near any of the potential storage sites it is questionable how our CO_2 could be transported and to where."

AS1: "It should be mentioned that the composition of the transported fluid is of hig importance. If there is any humidity in the transported fluid, CO_2 is then highly corrosive. For example, in Croatia, it was very efficient when the CO_2 was injected in the reservoirs through the so called "golden-casing" (alloys highly resistant to corrosion), but they are expensive. There are many options for CO_2 transport: by pipeline, ship, road or railroad.

AS2: "EU will raise its emissions reduction goals (from 40 % to 55 % by 2030). In the following 10 years, EU wants to test emission reducing projects on a full-scale which will be partially subsidized by public funds. One of these projects is Northern Lights, in which captured CO_2 from emitting facilities near the coast will be transported by ships to an onshore location from where it will be transported by pipeline and geologically stored in the reservoir on an offshore location. That is a project with diversified sources and one storage site. Other big projects in Europe are conceived so that there is one industrial cluster (with a wide spectrum of industry sectors) with high emissions and they jointly invest in local transport network which will transport all CO_2 to the storage site. Regarding the process emissions, project "Cleanker" is currently ongoing which is focused on the cement industry in Baltic countries and in Italy. In Croatia (but also in the region), if we want to realize CCS/CCU in its full potential, all of the relevant stakeholders would need to get together and decide about optimal networking so that the risks are equally distributed.

PS2: "One of the topics in our business strategy is usage of CO_2 as a feed-stock. There are some possibilities for utilization, but these quantities are marginal. Additionally, we don't see big opportunity for CCU since it is not our core business."

2. The regulatory and financial landscape surrounding CCS/CCU in Croatia

Moderator presented the current regulatory framework in Croatia which applies to CCS (there is none for CCU) together with some of the available EU financial instruments for CCS/CCU. Additionally, short description of EU ETS and 45Q in USA was presented to the stakeholders.

PS1: "How does the Mining law affect CCS? As far as I understand, the Mining law is not competent for any deep injection in the hydrocarbon reservoirs or aquifers."

IS1:" The mining law covers it, but on a minor level. The Law on hydrocarbon exploration and exploitation regulates permanent CO_2 storage since it mentions permit for exploration, permit for exploitation, permit for usage. By that Law and by Regulations on permanent carbon dioxide storage in geological formations, the government has implemented EU Directive on geological storage of CO_2. Besides that, the upcoming legislative changes in EU will not only cover climate legislation, but sectoral legislation (energy efficiency, transport sector) too, meaning that the changes will be comprehensive, all with the goal to achieve the set emissions reduction goals.

Additionally, European Parliament has given restrictions on using natural carbon sinks (like afforestation), which could mean that CCS/CCU technologies will get more on importance and necessity.

Finally, Low-Carbon Strategy is approved by the government and is sent to the parliament for adoption. In it, emissions reduction is increased by 2030 and CCS/CUU is listed as an important technology. The usage of CCS/CCU is observed from 2040. The Ministry of Economics and Sustainable Development has conducted a study on increasing the climate goals in Croatia and on achieving climate neutrality by 2050. Full legislative implementation of CCS/CCU could occur even before 2040 as it is stated now in the Low-Carbon Strategy."

Moderator adds that it is stated in the Low-Carbon-Strategy that in the case of the "fast transition" scenario, natural gas fired power plants and cement sector would need to apply CCS after 2040.

Stakeholders were once again asked to fill out the form consisting out of three questions (Figures C.3., C.4. and C.5.):

1. Does the current regulatory framework in Croatia encourage development of CCS/CCU projects?

2. Who should inform the investors about available financial/funding instruments for developing CCS/CCU projects?

3. Which system could encourage commercial development of CCS/CCU projects in EU and Croatia?

★★½☆☆☆ 2,5/6

FIGURE C.3. STAKEHOLDERS' RATING OF CURRENT REGULATORY FRAMEWORK IN CROATIA IN TERMS OF HOW ENCOURAGING IT IS FOR DEVELOPING CCS/CCU (1 STAR- VERY DISCOURAGING, 5 STARS- VERY ENCOURAGING)

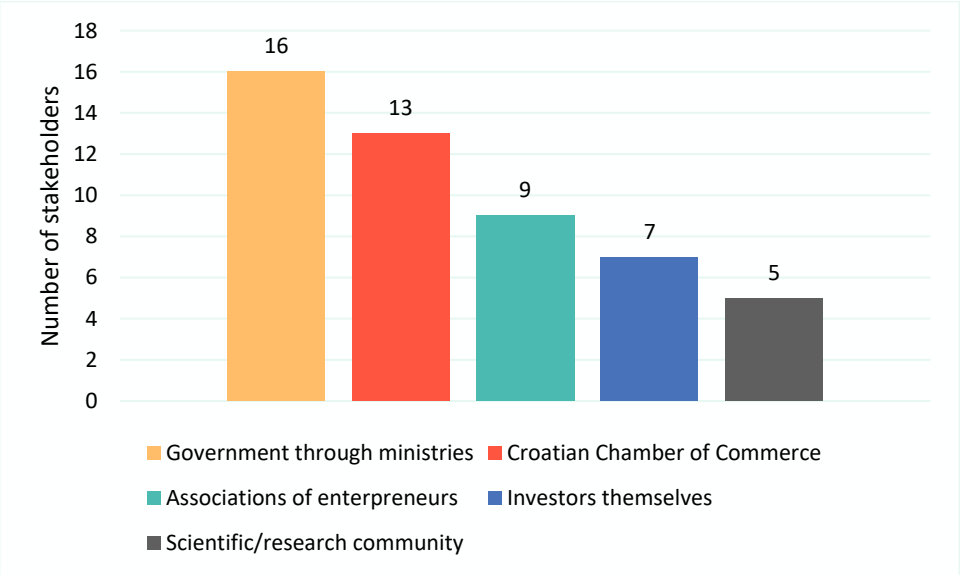

FIGURE C.4. STAKEHOLDER'S OPINION ON WHO SHOULD INFORM THE INVESTORS ABOUT AVAILABLE FINANCIAL/FUNDING INSTRUMENTS FOR DEVELOPING CCS/CCU

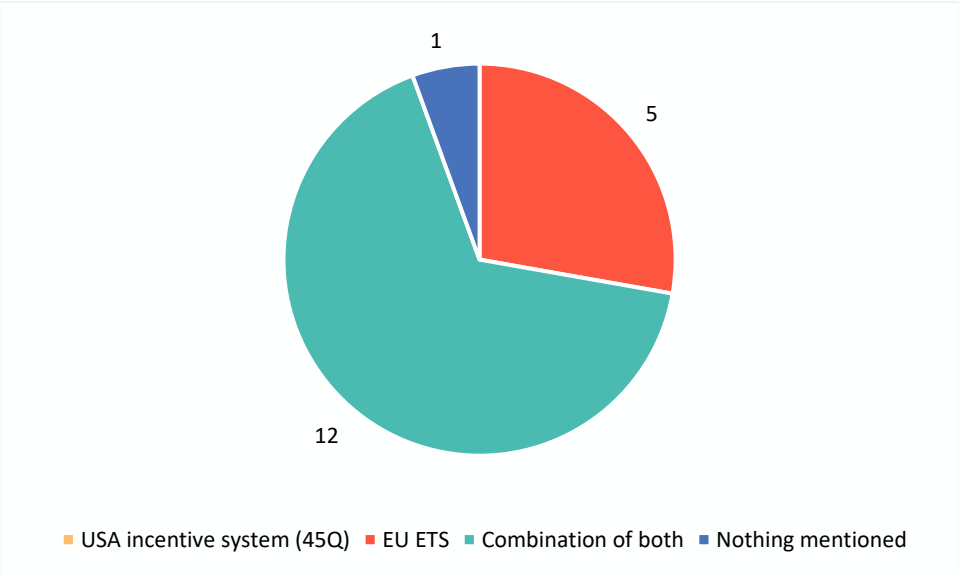

FIGURE C.5. STAKEHOLDERS OPINION ON WHICH SYSTEM COULD ENCOURAGE COMMERCIAL DEVELOPMENT OF CCS/CCU PROJECTS IN EU AND CROATIA (IN NUMBER OF STAKEHOLDERS)

AS1: "Is it realistic to consider Croatia having special incentive system outside of EU framework? If EU will just modify its existing cap-and-trade system, then we cannot have something else."

IS1: "EU will indeed develop something regarding the incentive system. Member States are allowed to develop additional mechanisms to encourage emissions reduction, however, best solution would be to have a harmonized system because working principles and conditions are same for all. Concerning the EU ETS, CCS is detailly regulated (geological storage of CO_2 is well regulated), but utilization is not. Also, EOR should belong to the trading system, but when you look through the whole documentation and guidelines, you cannot find any details about it. For example, how will the whole process of EOR be counted for (part of CO_2 is produced, part is permanently stored, some/all of the produced CO_2 can be recycled)? It will certainly be seen to encourage all this through the legislative framework and existing financial instruments."

PS1: "Each Member State has slightly different incentive system. It is not necessary to have a "copy-paste" solutions for emissions reduction."

IS2: "Concerning the statement of IS1, in Croatian Law on hydrocarbon exploration and exploitation, EOR is recognized, but only in the form of closed system (all of the produced CO_2 is recycled). If all of the produced CO_2 is recycled, then EOR is, in fact, a CCUS technology.

IS1: "It depends. For example, if you use CO_2 from the natural gas processing station in Croatia (naturally occurring CO_2 in natural gas reservoirs), you don't receive any compensation since that CO_2 is not included in the EU ETS."

PS2: "What happens in the case when CO_2 is not included in the EU ETS because it is biogenic?"

IS1: "It is not well defined nor clearly presented how it should be done on national and EU level."

PS1: "Regarding the natural gas processing station in Croatia, it is rather strange that nowadays, in times of a climate crisis, bureaucratic division of CO_2 on anthropogenic and non-anthropogenic exists".

IS1: "There are CO_2 emissions and natural carbon sinks. For example, ocean absorb large quantities of CO_2 and volcanos emit CO_2. This is a situation where human population is using fossil fuels in a very short timeframe when compared to the time needed for fossil fuel formation and because of that, climate changes are caused. We are focusing on human impact, which is crucial and from that comes this, as you state, "bureaucratic" division."

PS1: "High amount of CO_2 emissions is emitted from Croatian natural gas processing station which is not considered as anthropogenic because it does not come from fuel combustion. On the other hand, if humans did not exploit natural gas from the reservoir, there would be no CO_2 emissions. Of course, we cannot control the oceans and volcanos and they should not be taken into consideration."

IS1: "It should be noted that on a national level, CO_2 emissions from natural gas processing station are included in National Emissions Inventory, but it is not included in EU ETS, together with many others. Now the European Commission is considering whether to include transport and building sector in EU ETS."

3. Barriers, opportunities and risks for the development of CCS in Croatia

In this chapter of discussion, the stakeholders were asked to fill in a form consisting out of three questions (Figures C.6., C.7. and C.8.):

- In the near future, is CCS/CCU an option, a necessity or a threat for emissions reduction?
- Do you plan to utilize the captured CO_2, or you consider exclusive storage option?
- Range the risks (from highest to lowest) associated with CCS/ CCU by relevance to your business.

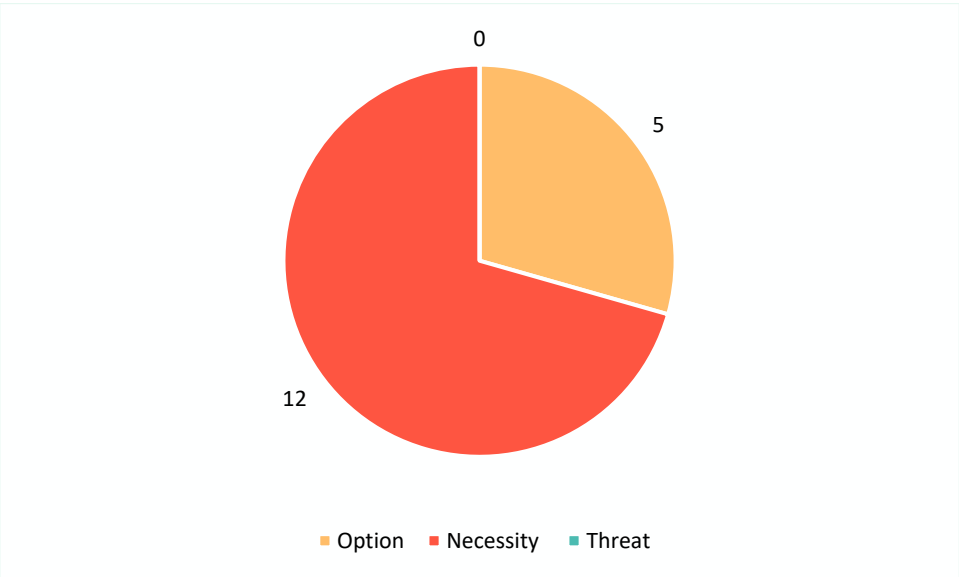

FIGURE C.6. STAKEHOLDERS' OPINION ON WHETER CCS/CCU IS AN OPTION, A NECESSITY OR A THREAT FOR EMISSIONS REDUCTION IN THE NEAR FUTURE

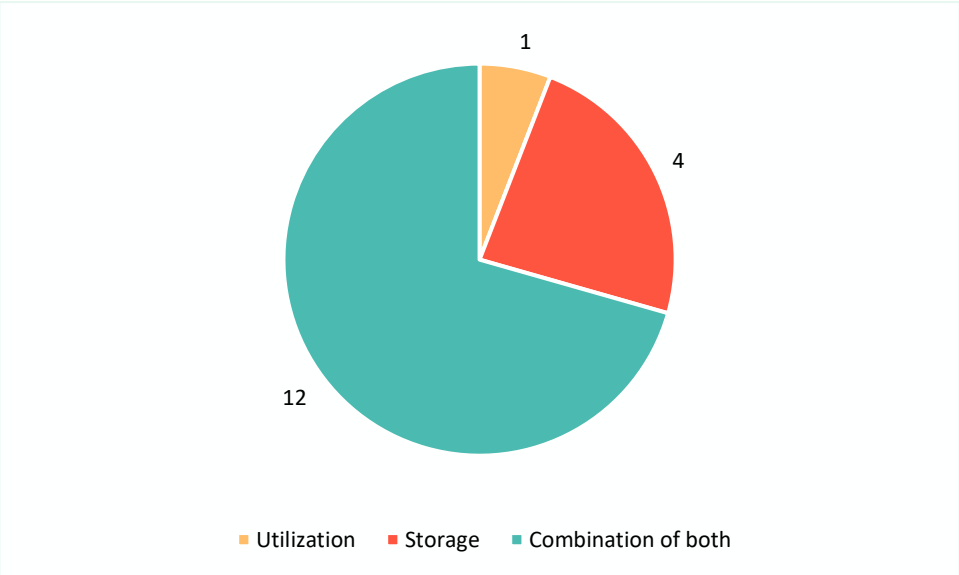

FIGURE C.7. STAKEHOLDERS' PLANS FOR CAPTURED CO_2 (STORAGE, UTILIZATION OR COMBINATION)

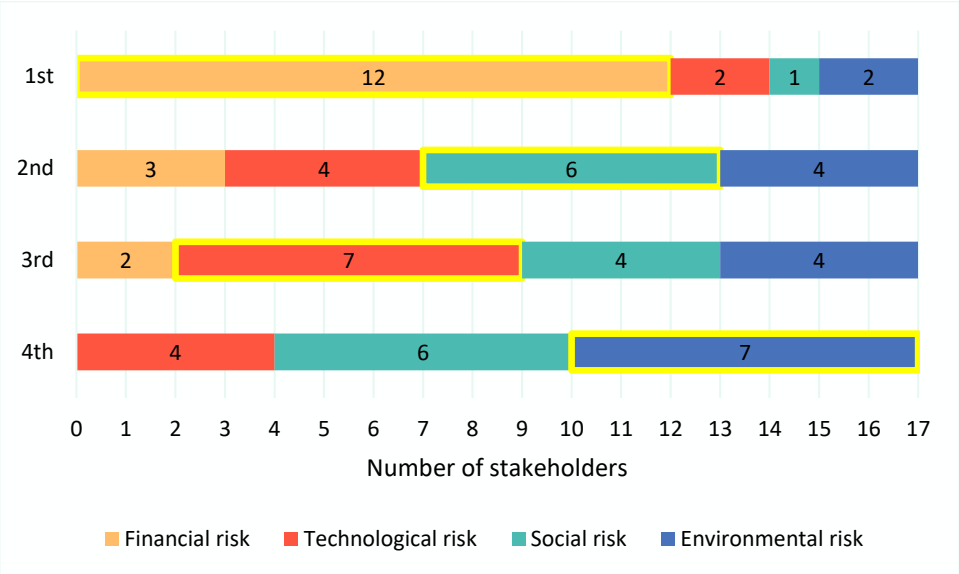

FIGURE C.8. STAKHOLDERS' RANKING OF RISKS ASSOCIATED WITH CCS/CCU BY RELEVANCE TO THEIR BUSINESS (1ST-HIGHEST RISK, 4TH-LOWEST RISK)

AS1: "Different analyses need to be conducted regarding the EUA and oil prices to observe the feasibility of CO_2-EOR. By doing so, CO_2-EOR gets a new dimension because the goal of reservoir management would not be to maximize oil recovery, but to find an optimum between additional oil recovery and stored CO_2. Considering the aforementioned, by exploiting oil via CO_2-EOR, significant free space underground is available for CO_2 storage which in most cases, could be enough to store more CO_2 than it can be emitted by burning the fossil fuels produced from oil. Hence, CO_2-EOR should be considered as an utilization option and not only those

technologies which convert CO_2 to another compound. The missing link is regulatory framework, system of precise CO_2 monitoring and defining penalties in the case of non-compliance.

IS1: "Economic feasibility is of outmost importance. Nowadays, we are based on the usage of fossil fuels and the situation will remain the same for several years. We should use fossil fuels even more but take proper care of adjacent carbon at the same time. Option of CO_2 utilization with storage is optimal. Other utilization methods should be considered except CO_2-EOR, like synthetic methane production. Any form of utilization is better than exclusive storage, because storage represents only a cost. It is very important to have benefits in cost-benefit analysis when utilizing the CO_2."

AS2: "It can be observed from the Figure C.8. that one problem was not discussed and it is decarbonization related costs sharing. Oil companies' core business was and still is fossil fuel production so they should invest in decarbonization. Also, others (other emitters) were and still are using available fossil fuel sources so now they need to invest even more in their processes. Question remains: How is financial burden going to be distributed for a greater cause that will happen in the future.

Regarding the statement from IS1, what will happen once you use the synthetic methane as a fuel? Main conclusion is that geological storage implies not only storage in geological formations, but in geological time to (it is permanently stored). Each CO_2 utilization is not equally good, but also there is no "good" or "bad" CO_2. Each CO_2 is the same and what matters is that it needs to be permanently stored in the geosphere."

IS1: "The infrastructure that we are currently relying on is made for fossil-based and similar fuels, we cannot change it immediately. The synthetic fuels are only a transitional solution. For example, synthetic methane is produced so that heating systems in households can remain unchanged. We are definitely going towards protecting the only planet that we have and synthetic fuels impose as a transitional solution.

AS2: "Synthetic fuels can be compared to a plastic bag which was used several times, but at the end disposed and not properly recycled. Each fossil fuel combustion implies emissions."

4. What needs to happen to deploy CCS in Croatia?

Moderator presented the decarbonization measure from the Low-Carbon Strategy of Croatia which implies the establishment of the platform for CO_2 capture, utilization and storage but no institutional stakeholder could provide additional information on the status of the measure.

Stakeholders were asked to fill in a form consisting of the following question (Figure C.9.):

- What would increase your interest in deploying CCS/CCU?

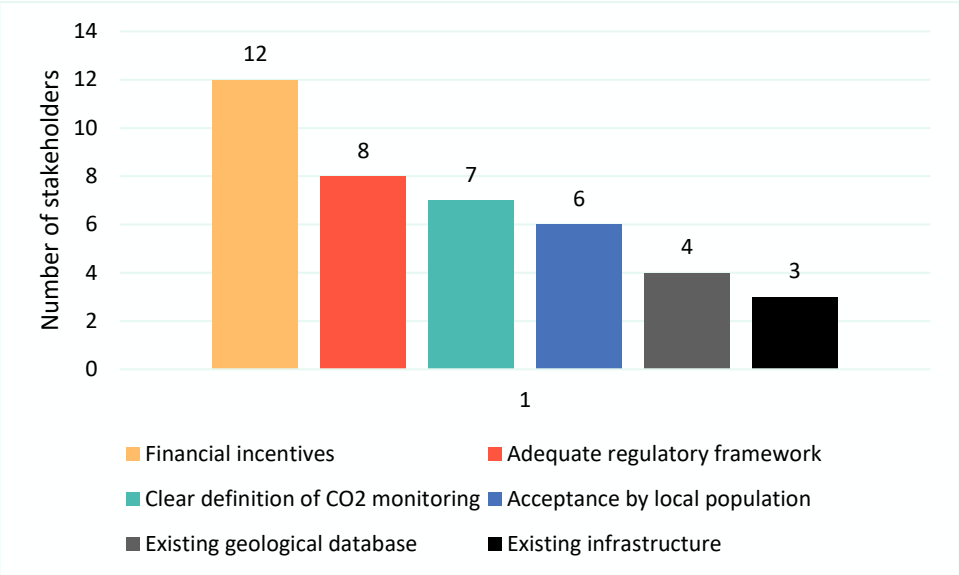

FIGURE C.9. STAKEHOLDERS' OPINION ON WHAT WOULD INCREASE THEIR INTEREST IN DEPLOYING CCS/CCU

AS1: "It is these results that show how financial aspect is interesting and how it could encourage CCS/CCU development. Funds which will be granted from EU funds could be initial impetus for launching CCS/CCU projects, not only pilot projects, but encouraging the industry in general to apply such technologies. It's not the same if you have to finance 100% of investment yourself or if you can get 30-45% from the funds. The financial aspect will be crucial.

5. Potential synergies between actors and sectors for developing CCS in Croatia

Stakeholders were asked with whom/which sector do they see potential collaboration in developing CCS/CCU projects, and gave the following answers.

- With emitters, ministry and oil companies.
- Considering the location of the company, none.
- With emitters and oil & gas sector.
- With all the relevant stakeholders
- With the industry.
- All of the emitters should see cooperation with the companies which can use or store CO_2. The state should ensure the development of the transportation infrastructure. Potential clustering is beneficial for all the parties, including the State.

PS1: "Our technology is based on green hydrogen production, i.e., the main product is hydrogen, while CO_2 is stored in the form of carbonated products. This hydrogen cannot be considered as "blue" hydrogen since it is not produced from fossil fuels. Considering EU climate goals, at the moment, blue hydrogen is currently more competitive in terms of price, but in the long run it cannot compete with green hydrogen, not only in price but also in the benefit that green hydrogen brings, which is CO_2-free production.

Certain technologies emit large quantities of CO_2 exactly because of using the fossil fuels. There is no time to use fossil fuels in technologies which are used by large emitters considering climate goals for 2030, i.e., 2050. Fuel switching on fuels which do not emit CO_2 (like hydrogen) could take place with little investment."

IS1: "Synthetic fuels represent a bridge towards complete deliberation from fossil fuels. It is demanding to switch from one system to another in a short period. We must continue using the existing technologies for some time. Achieving climate neutrality must take place under reasonable costs. Therefore, if changes will be needed for the whole infrastructure due to fuel switching, it is better to do it substantially. Fuel that is acceptable for all at the moment is electric energy. However, there are sectors which cannot accept electric energy as acceptable. Hence, synthetic fuels represent a form of transitional solution."

PS1: "Concerning the electric energy, hydrogen can serve as a clean source for electric and thermal energy production. Numerous industry sectors can start using hydrogen as much cleaner energy source with little investment."

AS1: "We deal with the assimilation of CO_2 with the cultivation of micro algae on wastewater. Utilization of waste CO_2, waste heat and wastewater were intended. Further processes like extraction, biofuel production and biomass usage were not considered. A potential for closing the economic circle exists, since the biomass can be well used for biogas and bio-diesel production. Then there is no CO_2 storage since it is emitted, but still, direct consumption of new fossil fuel is avoided.

IS1: "Synthetic fuels can be environmentally neutral. CO_2 is captured, transformed into a fuel, the fuel was used and CO_2 is emitted once again. That is much better than what we have today."

AS1: "With current vehicle technology, that is maybe the best we can do. Until now, conventional internal combustion engines are not adapted for more than 10% of biodiesel in the fuel mix. However, hydrogen represents the right direction for energy sector development."

6. **Gaps in the sector and system which create challenges for actors and sectors to work together on developing CCS in Croatia**

In the final chapter of discussion, stakeholders were asked what the main challenges for cooperation are (Figure C.10.).

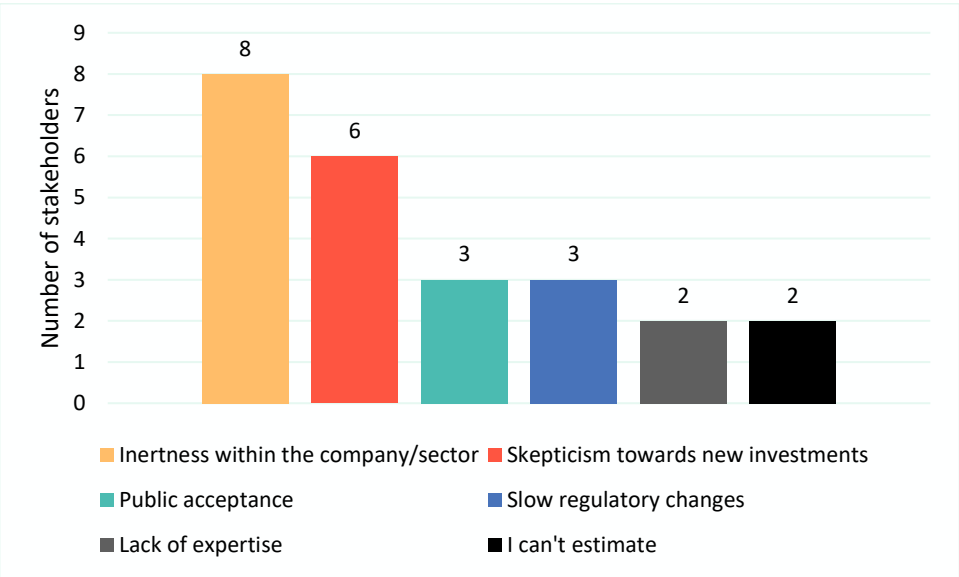

FIGURE C.10. STAKEHOLDERS' OPINION ON WHAT ARE THE MAIN CHALLENGES FOR COOPERATION IN CCS/CCU

AS1: "Public acceptance in Croatia, when compared to countries which work more intensively on deploying CCS/CCU, is underestimated because the stakeholders did not reach to the public enough for it to rebel. What will certainly happen and what stakeholders need to be prepared for is that the public will find the reasons why CCS/CCU is not acceptable for them (hence, clear communication strategy should exist. Until now, it has not been enough public topic.

Reporter: "Why do you think public opinion will be negative?"

AS1: "When large scale projects start on the field, then the local community has more influence on them. If there is a factory which employs local population, then the public supports it as opposed to the case of exclusive geological storage where public support is absent. That has already happened to the countries that have moved little further away from Croatia in R&D projects. However, this rule applies only to the on-shore storages and not to the off-shore storages.

Finally, what is important is that the benefits for all of us from deploying CCS/CCU are publicly communicated on time."

IS1: "In the Republic of Croatia, the public is very sensitized to all environmental issues and we know that there are very negative reactions to the construction of plants (especially related to waste management) and there could also be negative reactions to CCS/CCU plants. It is necessary to start public communication on time. The public needs to know what is being done with CO_2 underground. They could be worried that CO_2 is coming out through a crack near the house (possible NIMBYSM). Therefore, timely and valid communication by experts is needed."

PS1: "Cement company's roadmap documents fully support CCS/CCU. The biggest problem besides financial and regulatory framework is NIMBY effect. It should be accented that dialogue with the public is of outmost importance (political, social and media support is needed). Adequate communication campaign is needed. Without the public support, best projects are stopped (like waste management projects). Finally, after the discussion, reactions about the workshop from the stakeholders were obtained:

- A lot of useful information were presented.
- Thanks to the organizers and everyone for the interesting discussion.
- It is evident that the topic is very interesting and that a lot of people want to say something about the topic. Therefore, next workshop should be organized with a wider timeframe.
- The workshop was very useful and dynamical.
- We commend the workshop and would be glad to continue participating on these kinds of workshops.
- A "CO_2 club" should be formed in Croatia with these stakeholders.
- The expectations were exceeded.

Annex D: Authors' concluding remarks of the report

After communication with relevant actors and analysis of published professional and scientific papers, from the analysis of research topics of funded projects, texts in media, but also from previous experience several things can be summarized about obstacles in faster implementation of CO_2 injection technologies, such as permanent storage in depleted hydrocarbon fields, or CO_2-EOR as utilization technology and obstacles regarding characterization of deep saline aquifers that are good candidates for CO_2 storage.

Climate literacy- the process of public participation and involvement in practical solutions for climate change issues in everyday life- has not yet started in Croatia. Without this involvement, (people, NGO's, institutions, government, industry, the media, academia) successful significant CO_2 mitigation will not be achieved. Connecting and involving social forces, science, technology and economy as well, and encouraging through education about inclusion and not fragmentation of attitudes and knowledge will result in "climate literacy" and in an increasing the number of people which will feel the need to contribute to the process of CO_2 mitigation.

It seems like four defined groups (institutional sector, private sector, academic sector and non-governmental organizations) do not use the same "language" when discussing the deployment of CCS/CCU technologies.

For example, the institutional sector is grouped into different departments which, possibly, do not communicate much or do not share the same enthusiasm in searching for an optimum balance between market pull and technology push when proposing the rules, regulations or laws, but also when discussing with relevant actors from other groups, like NGOs or academia. The reason for that might be "traditional" education i.e., lack of planned and lifelong learning and training, lack of the working experience in industry, lack of communication with media etc.

Private sector stakeholders, probably because of some degree of self-containment mixed with narrow specialization and expertise, also have difficulties in accepting the change in technological process. Changes involve more work, and acquisition of new skills, which in larger companies (industries) can be hard to overcome. The result is that they usually rely on successful and to some degree similar examples, without detailed multidisciplinary research and development, even though interdisciplinary cooperation is encouraged through EU grants and funds. For a particular problem, they could use opportunity to act as greener industry at higher technological level, through cooperation with research institutions. Research institutions could help detect and articulate some problems, or they can help with public acceptance issues that might appear.

Research institutions in Republic of Croatia are, unfortunately (because of scientific metrics and system) not really encouraged to collaborate with other sectors. From experience at UNIZG-RGNF, which belongs to technical field of research, there is no motivation (or better to say, rewarding system) to initiate and perform research with social scientists or with (some) natural scientists. Some policy makers are neglecting the knowledge base and wider specialization of academic institutions, which usually leads to vagueness when exploration or exploitation of CO_2 storage sites is addressed in studies, regulations and laws. In most cases, CO_2 storage is just added to laws and regulations for hydrocarbon reservoirs, due to unilateral communication with contacts from industry.

Non-governmental organizations, in contrast to institutional or private actors, seem to be well informed from media. They approach and use the well-formed opinions that are sometimes not applicable to particular cases of companies or best technologies in Croatia. They accept a narrow focus of CO_2 mitigation technologies and usually are lacking adequate technical specialization for topics outside the technologies they are focused on. It was somewhat unexpected that during the CCS4CEE project workshop, which was really successful in terms of warm discussion, NGO representatives were not very active. The most successful discussion was established between the institutional and private representatives.

When CO_2 is considered, Republic of Croatia has several important features:

- large CO_2 point sources are only few in number and well dispersed, which means that a CCUS cluster could involve sources that are more than 200 km far from the storage site. In other words, large CO_2 sources which are not near any storage site can be included in

distant CCUS clusters because of their large emissions which reduce specific costs (transportation and storage costs per ton of CO_2) significantly.

- in all projections of fossil fuel demand, and the most optimistic projections of domestic natural gas and oil production decline, Croatia will import fossil fuels at least until 2050. As such, there is a danger of losing a large number of jobs in the oil sector. Needless to say, this import will significantly influence the national economy and independence in energy supply.

- hydrocarbon fields are almost all at a mature stage of production, and in northern parts of country these fields have high CO_2 content (often around 50 %). Reservoirs saturated with pure CO_2 were also discovered. Such natural occurrences of CO_2 should be used to increase public acceptance for CCS because the public has no knowledge of it.

- there is a long-time tradition of CO_2-EOR studies in Croatia (they started in mid 1970's) and there are two producing fields which use CO_2 from natural gas processing plant (and gas fields with high CO_2 content). Expensive CO_2 capture technologies are not needed in this case, because high-purity CO_2 is already available from the processing of natural gas. However, targeted research and exploration projects are needed to speed up CO_2-EOR research and development at other oil fields that are good candidates for storage. Because these developments are planned to happen in the areas with mature oil fields (in production for more than 50 years), there are no large public-acceptance issues, since the local population is used to the operations connected with exploration and exploitation of hydrocarbons which resemble the activities related to CO_2 injection to a large extent. Actually, they are bound to arise (see stance of NGO's) but can be alleviated with a timely and well-planned public communications strategy combined with financial incentives to local communities.

- regarding policies, there are several issues - natural gas processing plant (NGPP) is not included in EU ETS with all its emissions, with a negative impact on oil companies which use that CO_2 for injection (and most of that injected CO_2 stays stored). Major question has been put forward - Are there any possibilities to reduce or eliminate the difference between the anthropogenic CO_2 and the one that has been produced from oil and gas reservoirs by including the latter in EU ETS?

- regulations and laws are not providing the instructions on how to manage injected CO_2 and CO_2 that possibly might leak. There are no indications of CO_2 life cycle assessment, and in our opinion, it should be performed as "cradle-to-grave" assessment counting in combustion of additionally recovered oil, because it is proven that some CO_2-EOR are carbon-negative even if this is taken into account (Nuñez-Lopez et al., 2019, Hornafius and Hornafius, 2015, Sminchak et al., 2020, Godec et al., 2017).

- there is no clear definition of CO_2 utilization in EU, and some interest groups in Croatia are aggressive in supporting so called "chemical utilization", which requires change of chemical structure of CO_2 molecules. However, this could have huge economic impact, as CO_2-EOR will not be considered as utilization, even though the process is already cost-effective with current CO_2 prices (no income from CO_2 stored) and at least “gate-to-gate" (CO_2 at production well minus CO_2 injected) is shown to be CO_2-negative; “cradle-to-grave" is only preliminarily assessed to be carbon-negative (Valjak, 2020).

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Iceland Liechtenstein 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.

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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