Part C: CCUS clusters and hubs: Carbon Neutral Scenario for the Baltic States

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Carbon Neutral Scenario for the Baltic States
Shogenova et al, 2023 (in press)

Introduction

- Today, CCUS projects around the world store about 45 million tons of CO_2/per year.
- To reach climate neutrality we need to increase CO_2 storage from millions into billion tons/year.
- CCUS clusters and hubs are one of the options to accelerate this needed scale-up.
- We revealed at least 10 advantages of using CCUS clusters and hubs (read lecture made on BCF 2022):
- 1) faster scale-up
- 2) decrease the unit cost
- 3) reduce the risk of investment
- 4) reduce cross-chain risk
- 5) governmental support
- 6) new jobs
- 7) CO_2 use revenues
- 8) synergy with renewables
- 9) synergy with CO2-negative technologies and
- 10) increased public awareness and improved perception.
- This study aims to propose cross-border CCUS clusters and hubs that could help Baltic States become carbon-neutral, or even negative in situations of geological and regulatory limitations and uneven distribution of the produced large CO_2 emissions in three countries.

Data and methods

- CO_2 emissions produced in 2021 and reported in EU ETS (2022) were used for the CCUS scenario.
- Additionally, bio-CO_2 emissions were assessed from national reports for Estonia and data on bio-CO_2 for Lithuania were added from data from CaptureMap provided by Endrava used in the mapping of CO_2 emissions sources in the CCUS ZEN project.
- Minimum, maximum, and average capacities were estimated using minimum, maximum, and average porosities for optimistic and conservative cases for all structures in our previous research (Shogenov 2013a, 2013b; Simmer, 2018).
- Data on CO_2 storage sites and CO_2 emission sources collected by the CCUS ZEN project in the Q-GIS system was used and updated to propose Baltic onshore and offshore CCUS clusters.
- We applied 95% as an average CO_2 capture rate, considering 90, 95 and 99% capture rates for various advanced capture technologies (IEAGHG, 2019).

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CO_2 emission sources

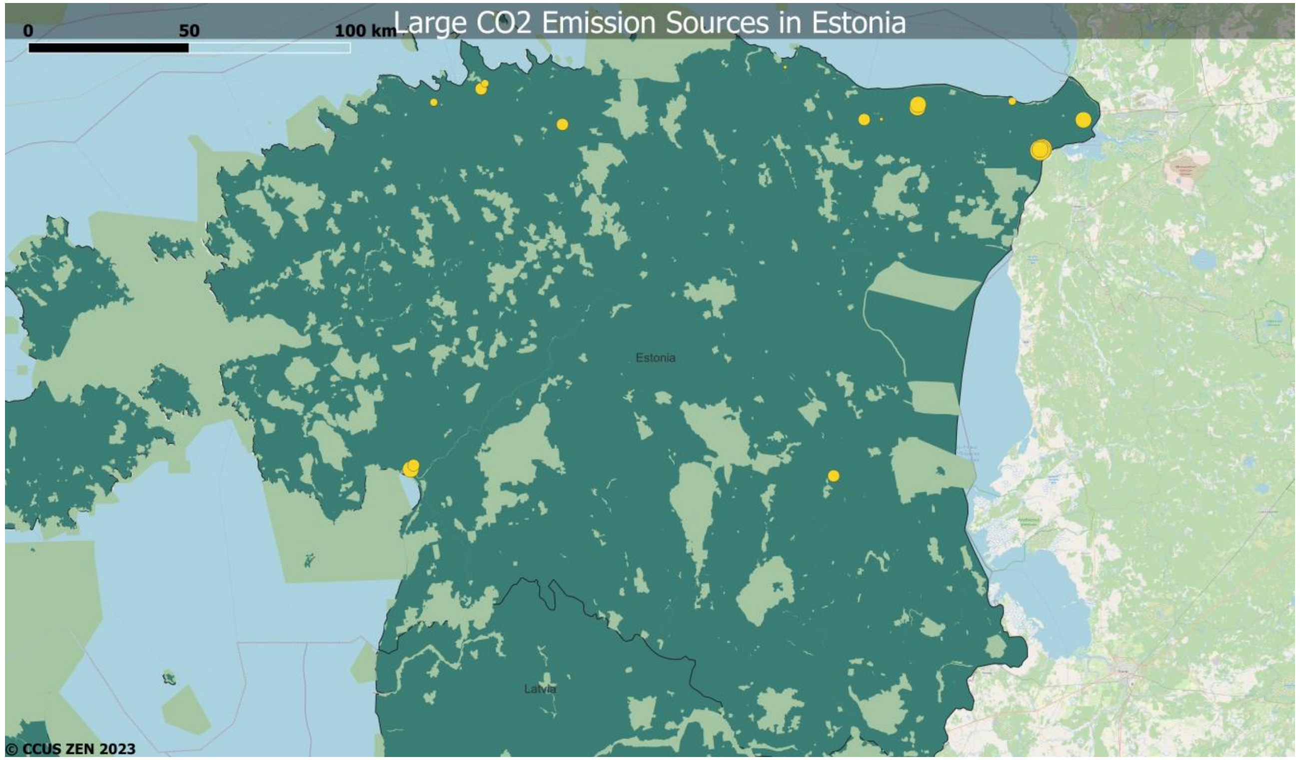

Table 1: Large CO_2 emissions produced in Estonia in 2021

N	Plant Name	Region	Sector	CO_2 produced in 2021, kt: Fossil CO_2	CO_2 produced in 2021, kt: Bio- CO_2	Total CO_2, kt
1	Eesti PP	Auvere	Power	2,607,958	16,000	2,623,958
2	Auvere PP	Auvere	Power	885,666	409,944	1,295,610
3	Auvere SOP	Auvere	SOP	788,760	-	788,760
4	Balti PP	Narva	Power	645,847	187,767	833,614
5	VKG SOP	NEE	SOP	697,209	-	697,209
6	VKG Energia North TP	NEE	Power	593,857	-	593,857
7	Kiviõli Chemical Plant	NEE	SOP	159,357		
8	Horizon Paper Factory	Kehra	Paper	12,888	239,481	252,369
9	Utilitas Tallinn PP	Tallinn	Power	9,796	259,000	268,796
10	Fortum Cogeneration	Pärnu	Power		268,000	268,000
	Plant	Tartu	Power		244,450	244,450
11	Anne Cogeneration Plant	Iru	WtE		138,483	138,483
12	Iru Waste to Energy Plant					
	Total CO_2 produced			6,401,338	1,763,125	8,164,463

- The largest fossil CO_2 emission sources in Estonia are represented by four power plants (PP) and three shale oil plants (SOP) (Table 1).
- All these plants, located in the North-East of Estonia, use Estonian oil shales for energy and oil production. Among them, Eesti Energia (Enefit) PPs also produce bio-emissions during the co-combustion of wood waste together with oil shale.
- Additionally, several Estonian plants produce bio-emissions, including paper and pulp production (Horizon Paper Factory), energy co-generation plants (Fortum plant in Pärnu and Anne plant in Tartu) and one waste-to-energy plant (WtE) located in Iru near Tallinn.
- In total about 8.2 Mt CO_2 was produced in 2021, including 6.4 Mt from fossil fuels and 1.76 Mt of bio- CO_2.

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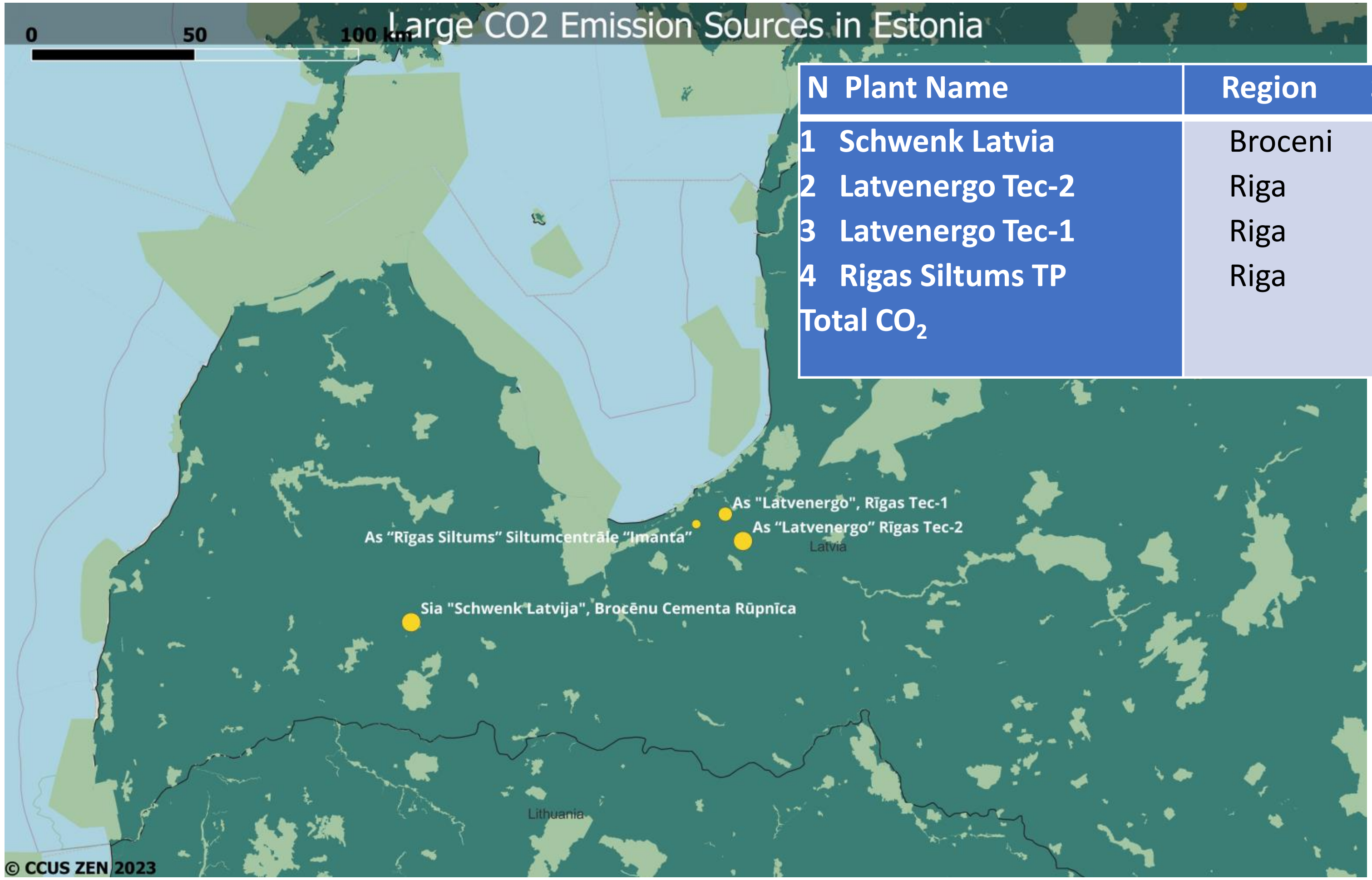
CO_2 emission sources

Table 2: Large CO2 emissions produced in Latvia in 2021

N	Plant Name	Region	Sector	CO_2 produced, kt
1	Schwenk Latvia	Broceni	Cement	752,118
2	Latvenergo Tec-2	Riga	Power	675,287
3	Latvenergo Tec-1	Riga	Power	227,341
4	Rigas Siltums TP	Riga	Power	99,743
Total CO_2				**1,754,489**



- The largest CO_2 emissions in Latvia are produced by four plants including Schwenk Latvia cement plant in Broceni and three PPs located near Riga (two Latvenergo PPs and one Rigas Siltums thermal plant).
- Together they produced 1.75 Mt CO_2 in 2021 (Table 2).
- Bio-emissions were not reported by emitters to national authorities in Latvia.

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CO_2 emission sources

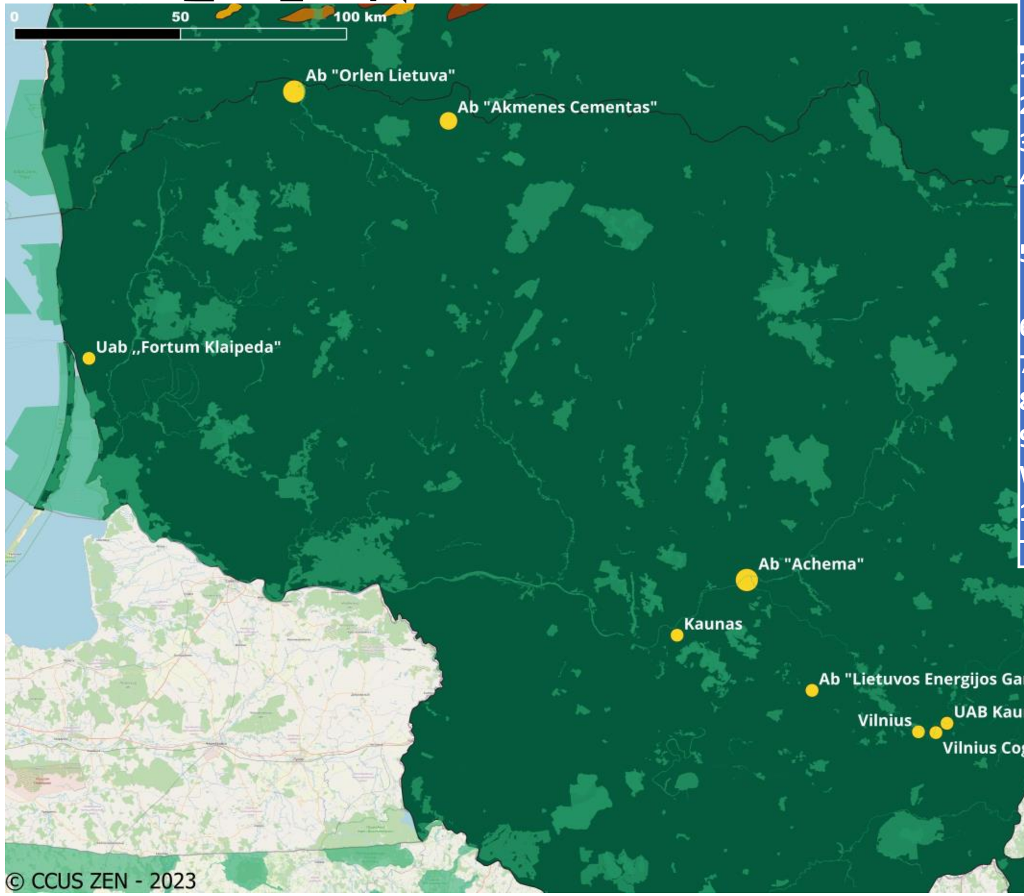

Table 2: Large CO2 emissions produced in Lithuania in 2021

N Plant Name	Region	Sector	CO_2 produced in 2021, kt: Fossil CO_2	CO_2 produced in 2021, kt: Bio-CO_2	Total CO_2, kt
1 Achema	Kaunas	Chemicals	2,208,916		
2 Orlen Lietuva	Telšiai	Refineries	1,501,524		
3 Akmenės Cement	Šiauliai	Cement	997,056		
4 Lietuvos Energijos Gamyba, PP	Vilnius	Power	304,646		
5 Vilniaus Šilumos Tinklai PP N2	Vilnius	Power	293,090		
6 Kaunas WtEP	Kaunas	WtE		198,000	
7 Vilnius WtEP	Vilnius	WtE		169,000	
8 Fortum Klaipeda WtEP	Klaipeda	WtE	126,007		
9 UAB "Toksika" hazardous WtEP	Šiauliai	WtE		79,000	
10 UAB Kauno WtEP	Vilnius	WtE	112,704		
Total CO_2			**5,543,943**	**446,000**	**5,989,943**

- The largest CO_2 emissions in Lithuania are produced by five plants including Achema, Orlen refineries, Akmenes Cement and two power plants in Vilnius.
- Together with two WtE cogeneration plants 5.54 Mt CO_2 were produced in Lithuania and reported in EU ETS in 2021.
- Another three waste-to-energy plants produced together 0.45 Mt bio-CO_2.
- About 6 Mt of CO_2 emissions were produced in Lithuania by large emitters in 2021 (Table 3).

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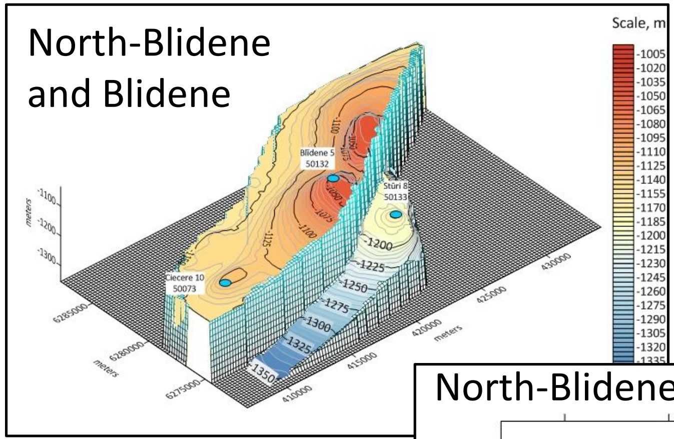
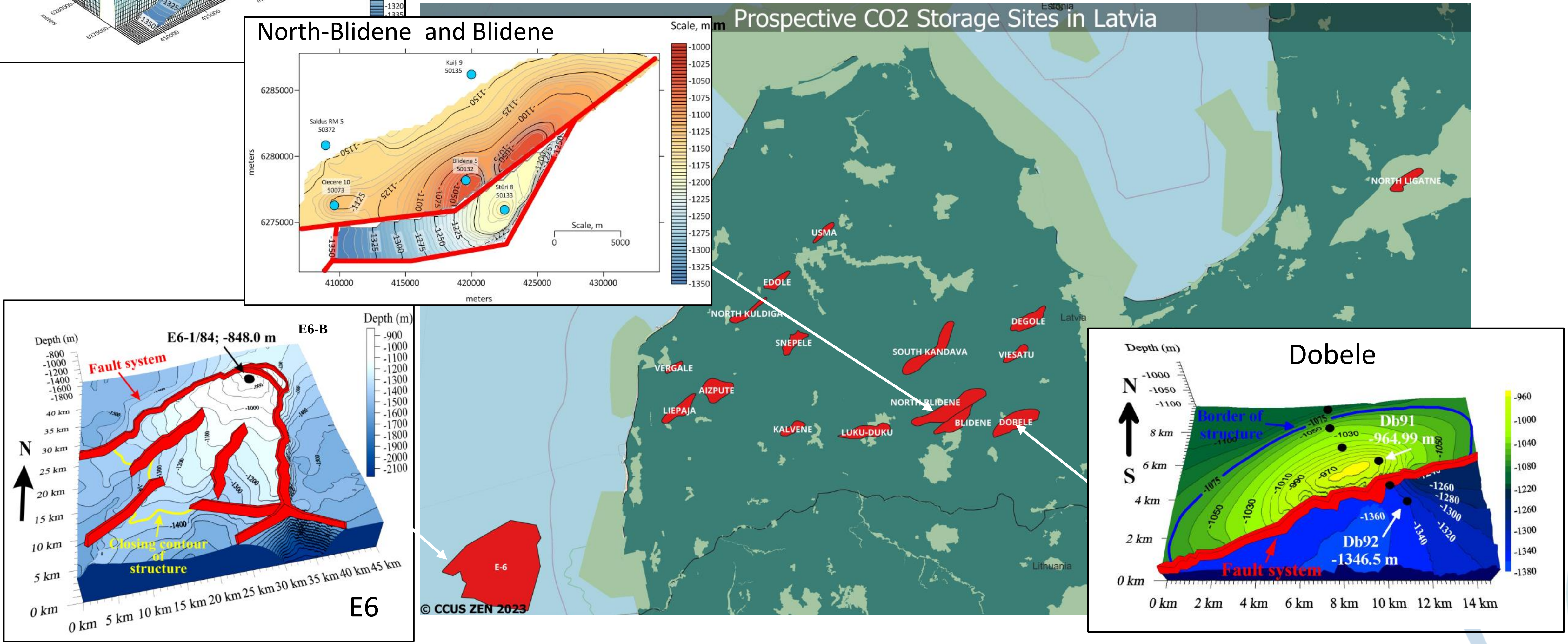
The most prospective storage sites in Latvia





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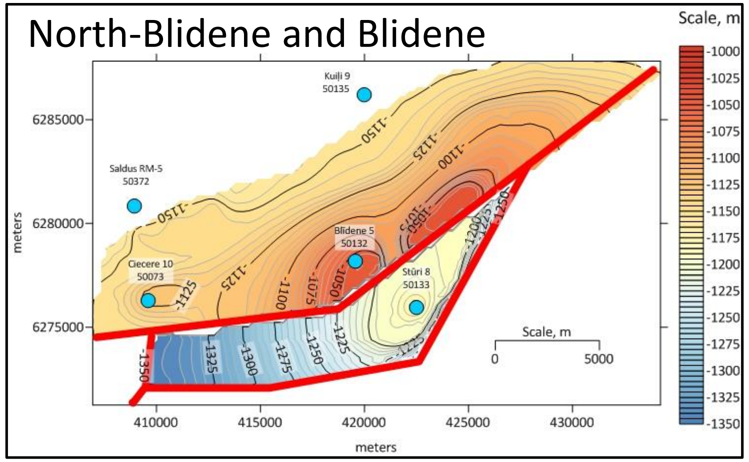
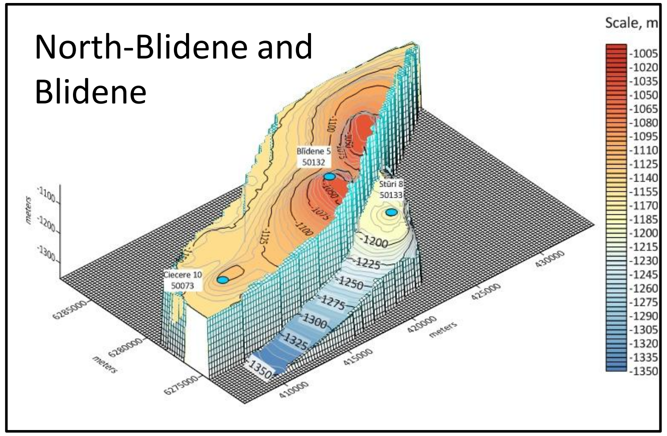
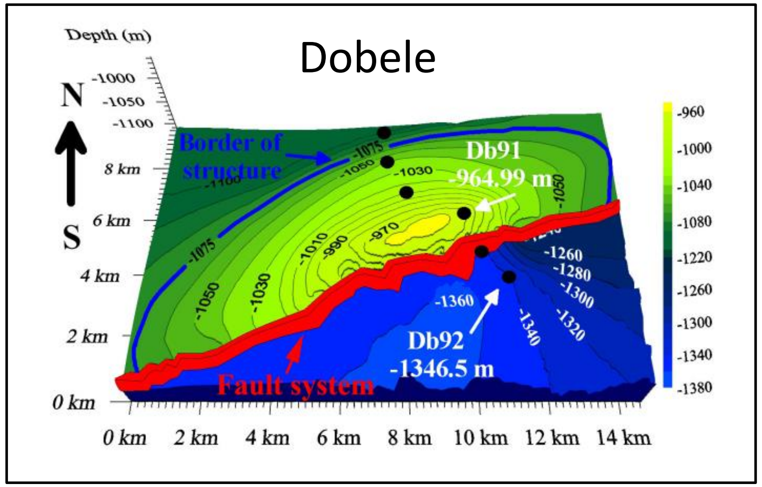
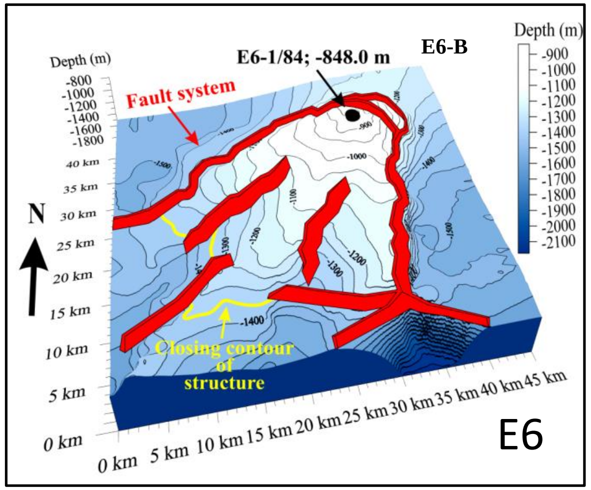
The most prospective storage sites in Latvia









Parameters	North Blidene	Blidene	Dobele	E6-A
Storage ID	S_LV10	S_LV2	S_LV4	S_LV5
Depth of reservoir top, m	1035-1150	1168-1357	965-1013	848-901
Reservoir thickness, m	48	66	52	53
Trap area, km^2	141	62	70	553
CO_2 density, kg/m^3	881	866	900	658
Net to gross ratio, %	75	80	85	90
Salinity, g/l	100-114	100-114	114	99
Permeability, mD	370-850	370-850	0.1-670/ 360	10-440 (170)
T, ºC	18	22.9	18	36
Storage eff. factor (Seff) Optimistic/Conservative (%)	30/4	5/3	20/4	10/4
Porosity (min-max/avg), %	12.5-25.6/20	13.5-26.6/21	10-26/19	14-33/21
Optimistic CO_2 storage capacity (min-max/avg), Mt	167-342/267	19-37.5/29.6	56-145/106	243-582/ 365
Conservative CO_2 storage capacity (min-max/avg), Mt	22.2-45.5/ 35.6	11.4-2.5/ 17.8	11-29/21	97-233/ 146

Carbon Neutral Scenario for the Baltic States

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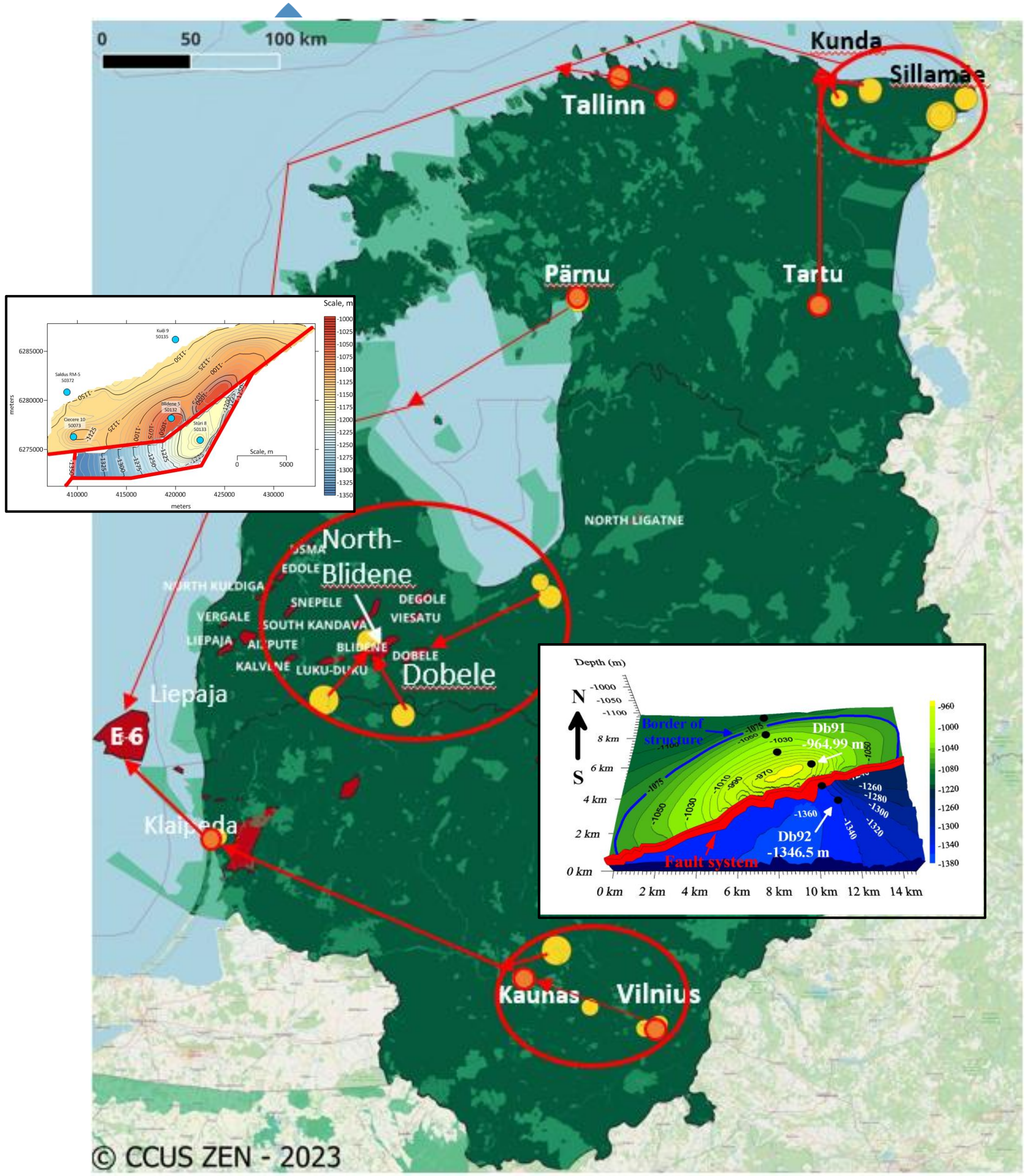
The Latvian-Lithuanian onshore value chain



Cluster name	Facility name	Company name	City	Industry sector	CO2 reported (ETS) (t/y)	Total CO2 emissions (t/y)
Baltic Lat-Lit-Onshore 1	Schwenk Latvija	Sia "Schwenk Latvija"	Broceni	Cement	752118	752118
Baltic Lat-Lit-Onshore 1	Orlen Lietuva	Ab "Orlen Lietuva"	Telšiai	Refinieries	1501524	1501524
Baltic Lat-Lit-Onshore 1	Akmenės Cement	Ab "Akmenės Cementas"	Šiauliai	Cement	997056	997056
Baltic Lat-Lit-Onshore 2	Latvenergo Tec-2	As “Latvenergo”	Riga	Power	675287	675287
Baltic Lat-Lit-Onshore 2	Latvenergo Tec-1	As "Latvenergo"	Riga	Power	227341	227341
Baltic Lat-Lit-Onshore 2	Rigas Siltums TP	As “Rīgas Siltums”	Riga	Power	99743	99743
Baltic Lat-Lit-Onshore					**Total for onshore cluster**	**4253069**

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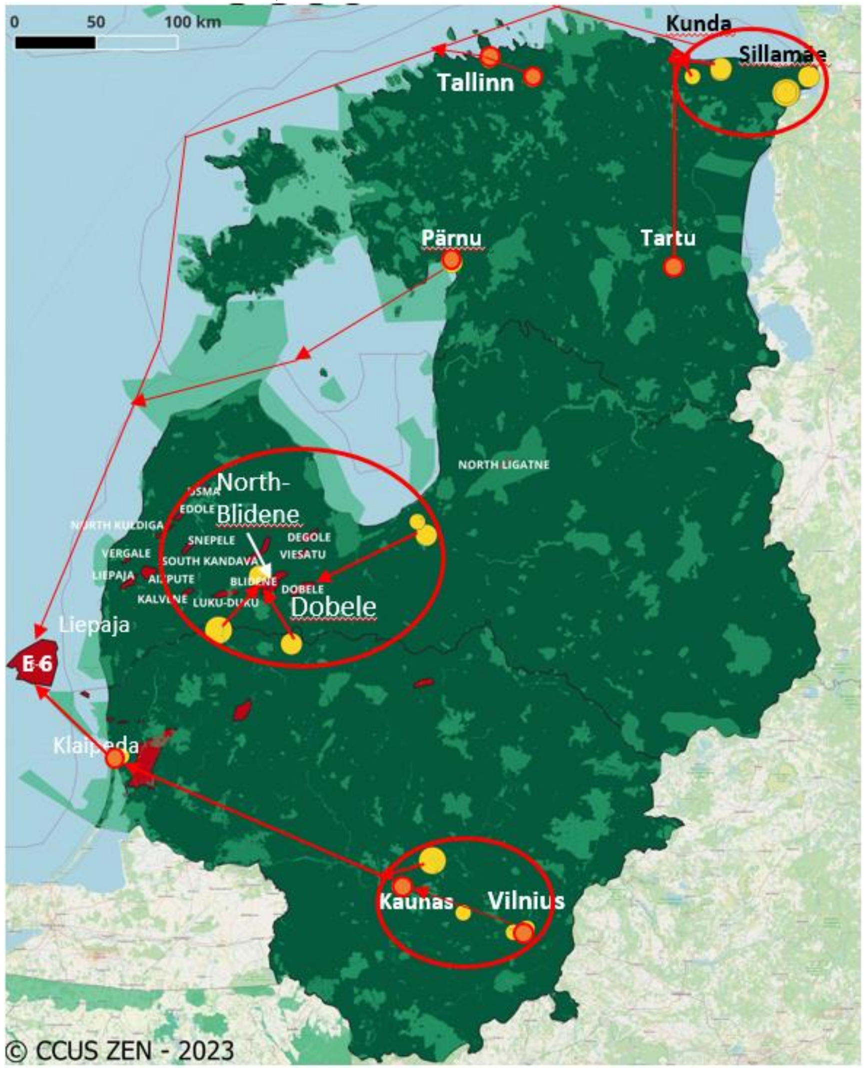
The Latvia-Lithuania onshore value chain



- The Baltic onshore cluster includes four of the largest Latvian CO_2 emitters and two Lithuanian plants located close to the Latvian-Lithuanian border (Orlen refinery and Akmenes cement plant, owned by Schwenk). This
- cluster will store annually 3.1 Mt CO_2 from three plants (Latvian and Lithuanian Schwenk-owned cement plants and Orlen Refinery) in the onshore North Blidene and Blidene structures.
- Latvian two Latvenergo PP and one Rigas Siltums TP located in the Riga region will transport about 0.95 Mt CO_2 in the Dobele storage site in western Latvia using up to 150 km CO_2 pipelines.

N	Cluster Name	Number of emitters	Fossil CO_2 Mt	Bio- CO_2 Mt	Total CO_2 Mt	Storage site	Capacity Opt/Cons. Mt	Trans-port	Distance km
1	Latvian Onshore	3	1.0		1.0	Dobele	106/21	Pipelines	150
2	Lat-Lit Onshore	3	3.25		3.25	North-Blidene & Blidene	267/35.6 29.6/17.8	Pipelines	15-185
3	Est-Lit Offshore E6	20	9.45	2.21	11.66	E6A	365/146	Pipelines Ship	30-140 80-645
	Total produced	26	13.7	2.21	15.91		767.6/220.4		
	Total stored	26	13.02	2.1	15.23				

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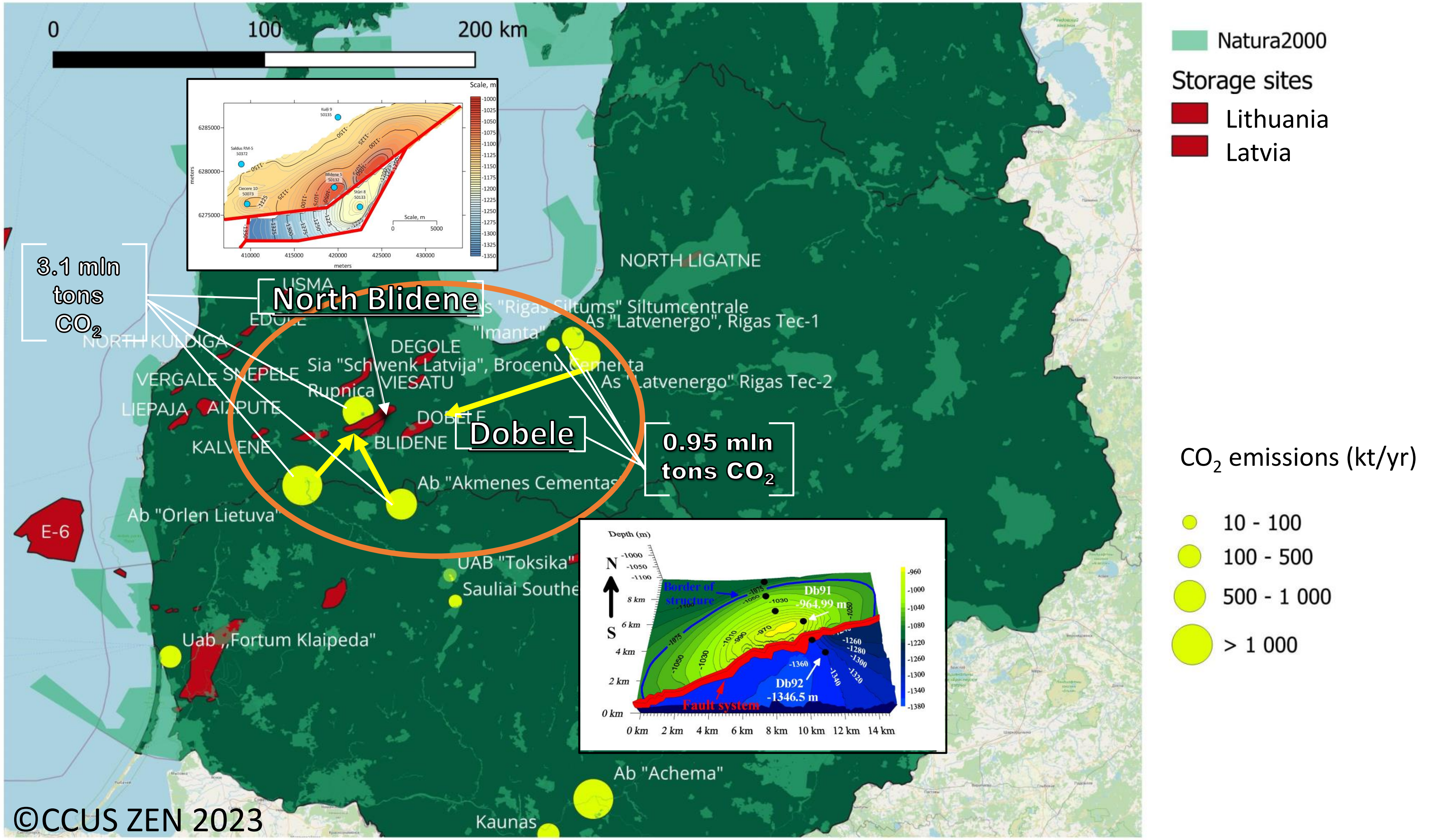
Latvian-Lithuanian onshore CCUS cluster

Latvian CO_2 emitters (4):

- Latvenergo PP (2 plants)
- Rigas Siltums Thermal Plant
- "Schwenk Latvia" SIA (Cement plant)

Lithuanian CO_2 emitters (2):

- Orlen refinery
- Akmenes cement plant



Baltic-1

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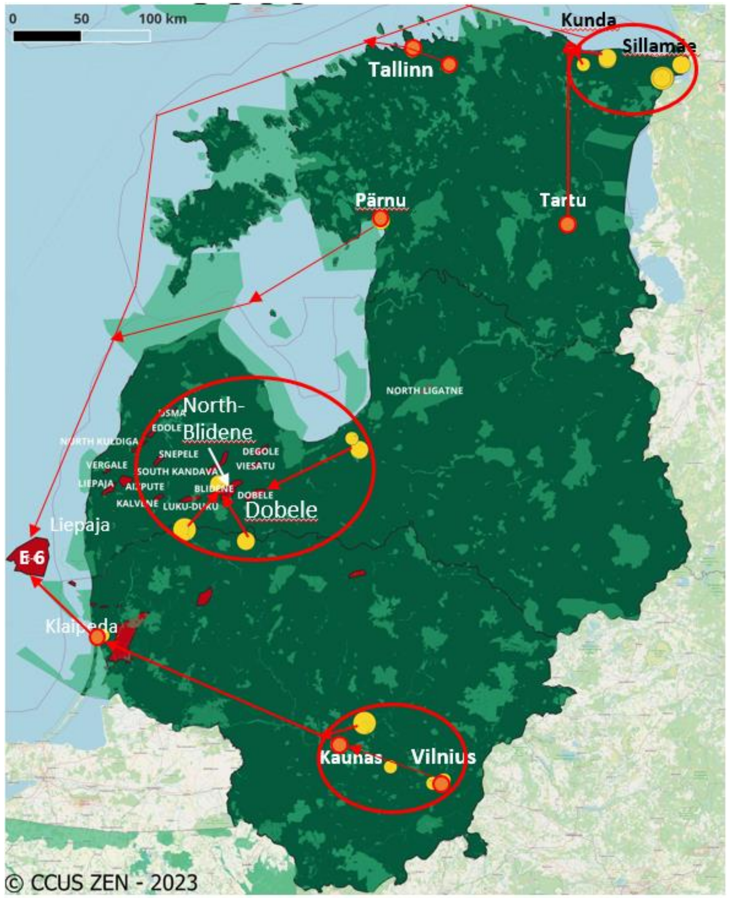
The Latvian-Lithuanian onshore value chain



- The Baltic onshore cluster includes four of the largest Latvian CO_2 emitters and two Lithuanian plants located close to the Latvian-Lithuanian border (Orlen refinery and Akmenes cement plant, owned by Schwenk). This
- cluster will store annually 3.1 Mt CO_2 from three plants (Latvian and Lithuanian Schwenk-owned cement plants and Orlen Refinery) in the onshore North Blidene and Blidene structures.
- Latvian two Latvenergo PP and one Rigas Siltums TP located in the Riga region will transport about 0.95 Mt CO_2 in the Dobele storage site in western Latvia using up to 150 km CO_2 pipelines.
- **Among possible use options:**
- CO_2 use for geothermal energy recovery in the Latvian central anomaly zone (not far from Dobele)
- CO2 use for production of sustainable carbon nanomaterials and graphite for the electric vehicle batteries (https://co2carbon.eu/) - international project coordinated by Estonian startup and RTU among participants.
- The Baltic countries are looking forward to produce hydrogen.
- It can be stored in the in the Blidene structure onshore (Figures 1-3).

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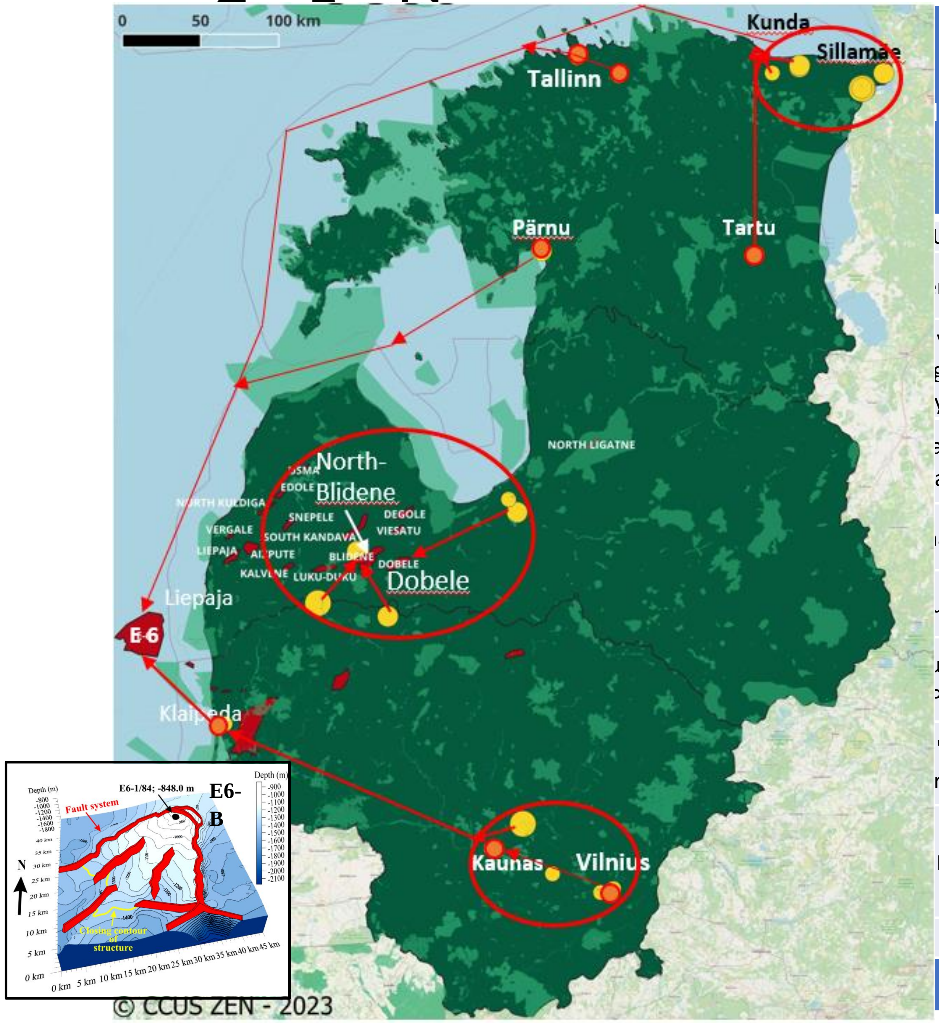
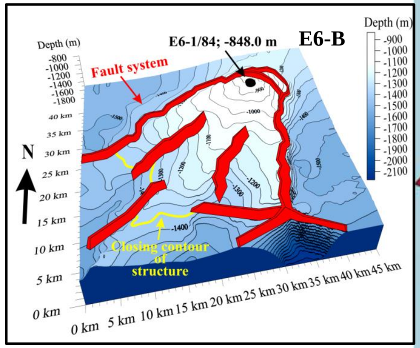
Baltic offshore scenario

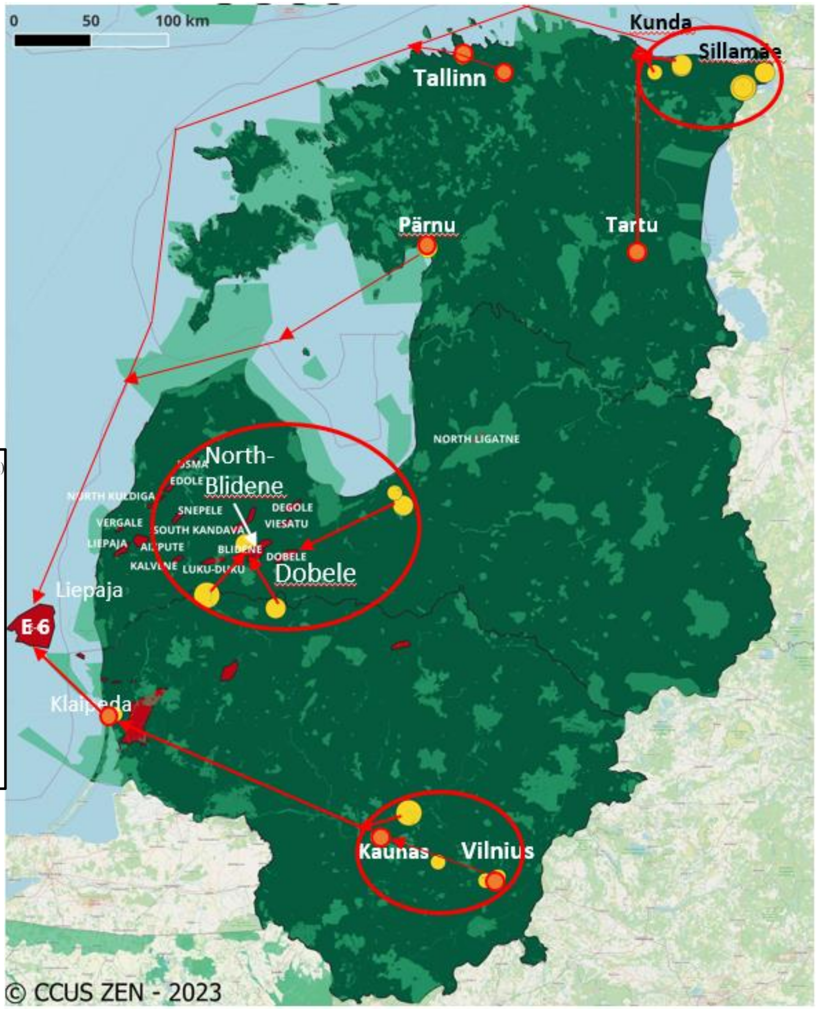


...ity name	Company name	City	Industry sector	CO2 reported (ETS) (t/y)	CO2 from Waste-to-energy (t/y)	Total CO2 emissions (t/y)
...UANIA						
...ma	Ab "Achema"	Kaunas	Chemical	2208916		2208916
...vos ...gijos ...yba, PP	Ab "Lietuvos Energijos Gamyba"	Vilnius	Power	304646		304646
...aus Šilumos ...ai PP N2	Ab "Vilniaus Šilumos Tinklai"	Vilnius	Power	293090		293090
...as WtEP		Kaunas	WtE		198000	198000
...us WtEP		Vilnius	WtE		169000	169000
...um Klaipeda ...P	Uab „Fortum Klaipėda“	Klaipeda	WtE		126007	126007
"Toksika" ...rdous WtEP	UAB "Toksika"	Šiauliai	Hazardous WtE		79000	79000
Kauno WtEP	UAB Kauno kogeneracine jegaine	Vilnius	WtE	112704	112704	112704
			Total for Lithuania			3491363
			Total for offshore clusters			11655826

Cluster name	Facility name	Company name	City	Industry sector	CO2 reported (ETS) (t/y)	CO2 from bioma ss (t/y)	CO2 from Waste-to-energy (t/y)	Total CO2 emissi... s (t/y)
	ESTONIA							
Baltic-Est-Lat-Lit-Offshore	Eesti Power Plant	Enefit Power As	Auvere	Power	2607958	16000		26239...
	Auvere Power Plant	Enefit Power As	Auvere	Power	885666	409944		12956...
	Auvere Shale Oil Plant	Enefit Power As	Auvere	Shale Oil Plant	788760			78876...
	Balti Power Plant	Enefit Power As	Narva	Power	645847	187767		83361...
	VKG Shale Oil Plant	VKG Oil As	Kohtla-Järve	Shale Oil Plant	697209			69720...
	VKG Energia North Thermal Power Plant	VKG Energia Oü	Kohtla-Järve	Power	593857			59385...
	Kiviõli Chemical Plant	Kiviõli Keemia-tööstuse OÜ	Kiviõli	Shale Oil Plant	159357			15935...
	Horizon Paper Factory	Horizon Tsellu-loosi ja Paberi AS	Kehra	Paper and pulp	12888	239481		25236...
	Utilitas Tallinn Power Plant	Utilitas Tallinna Elektrijaam Oü	Tallinn	Power	9796	259000		26879...
	Fortum Cogeneration Plant	Fortum Eesti As	Pärnu	Power		268000		26800...
	Anne Cogeneration Plant	Anne Soojus As	Tartu	Power		244450		24445...
	Iru Waste to Energy Plant	Enefit Power As	Iru	WtE			138483	13848...
					Total for Estonia:			81644...

Baltic offshore scenario





- The Baltic offshore cluster includes most of the large Estonian and Lithuanian fossil and bio-emission sources – one of which Klaipeda WtE Plant and other sources located in central and south-eastern Lithuania.
- The CO_2 is supposed to be transported from proximal emitters by pipelines, while the E6 structure is to be linked by pipelines and ships, located as far as 80 km from Klaipeda Port.
- Estonian north-east cluster, composed of seven emission sources (four plants produced only fossil emissions and three power co-generation plants using both oil shales and biomass for energy production) will us CO_2 pipeline or truck/train transport to Sillamäe and Kunda ports and then ship CO_2 to the E6 storage site in Latvia (615 km by ship from Sillamäe).
- This cluster will be able to capture and store annually 11.1 t CO_2, including 9 Mt of fossil and 2.1 Mt of bio-CO_2.

N	Cluster Name	Number of emitters	Fossil CO_2 Mt	Bio- CO_2 Mt	Total CO_2 Mt	Storage site	Capacity Opt/Cons. Mt	Trans-port	Distance km
1	Latvian Onshore	3	1.0		1.0	Dobele	106/21	Pipelines	150
2	Lat-Lit Onshore	3	3.25		3.25	North-Blidene & Blidene	267/35.6 29.6/17.8	Pipelines	15-185
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	Total produced	26	13.7	2.21	15.91		767.6/220.4		
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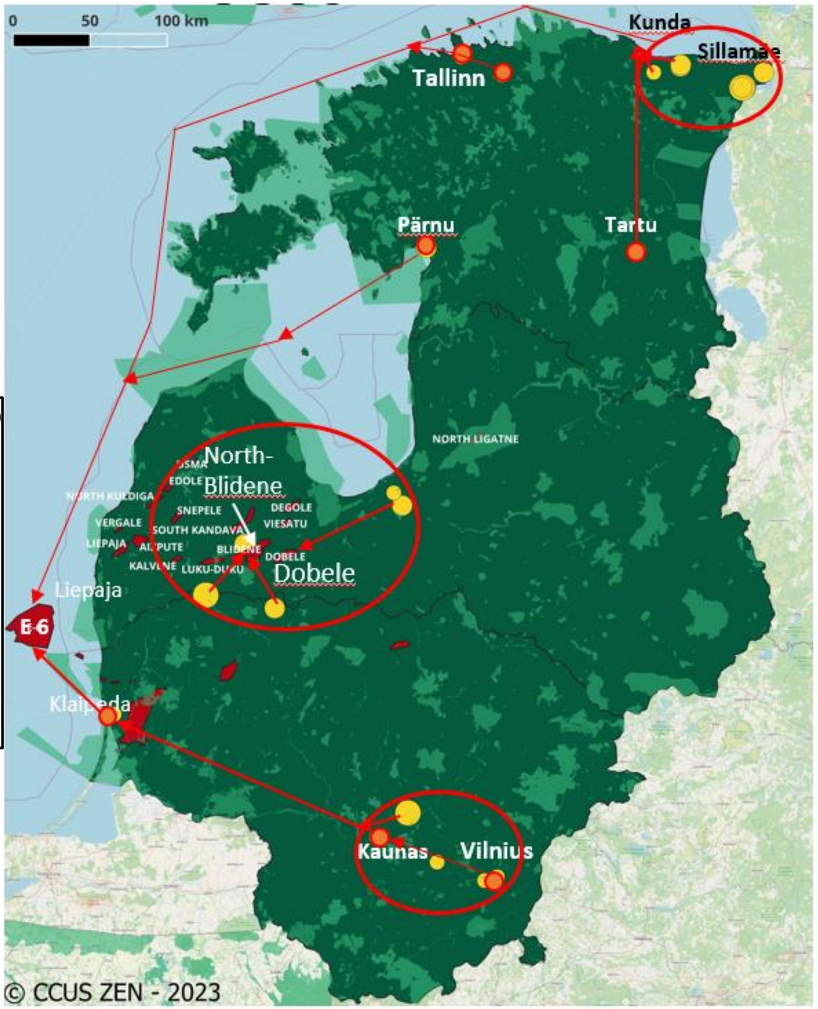

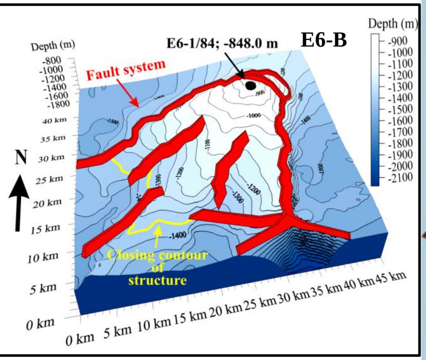

Among CO2 use options:

- The alternative CO_2 use option for Estonia is the application of CO_2 for mineral carbonation of Estonian burned oil shale (BOS) (Shogenova et al, 2021).
- Another option is the use of CO_2 for geothermal energy recovery in the E6 structure for the local energy needs of the drilling rig. More details you could see yesterday in our Poster presentation.
- All Baltic countries are looking forward to produce hydrogen.
- It can be stored in the smaller E6-B compartment of the E6 structure offshore (Figures 1-3).

N	Cluster Name	Number of emitters	Fossil CO_2 Mt	Bio- CO_2 Mt	Total CO_2 Mt	Storage site	Capacity Opt/Cons. Mt	Trans-port	Distance km
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Technical parameters of the Baltic CCUS clusters

- Total amount of 15.23 Mt of fossil and bio- CO_2 emissions could be captured, transported, used and stored, while only 13.7 Mt of fossil CO_2 gas was produced in 2021.
- The negative balance is calculated about 1.53 Mt CO_2.

Source: Alla Shogenova, Kazbulat Shogenov, Saulius Sliaupa and Rasa Sliaupiene. 2023. The Role of CCUS Clusters and Hubs in Reaching Carbon Neutrality: Case Study from the Baltic Sea Region. Chemical Engineering Transactions, in press.

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Conclusions

- The two largest onshore and one offshore storage sites in Latvia have the capacity to store all large Estonian, Latvian, and Lithuanian fossil and bio-CO_2 emissions.
- A total 15.1 Mt of fossil and bio- CO_2 could be captured, transported, used and stored, while only 13.7 Mt of fossil CO_2 produced annually. The negative balance is about 1.4 Mt CO_2.
- Additional revenues will come from geothermal energy recovery in Latvia for local heating and cooling needs, CO_2 mineral carbonation of BOS in Estonia and hydrogen production and storage in the Baltic CCUS clusters.
- The average optimistic storage capacity of the studied structures will be enough for more than 50 years, while conservative for 14.5 years.
- The CCUS cluster scenario represents the substantial volume to store the emitted CO_2 for the long transitional period.
- Additional structures in western Latvia occured near the largest ones could also be developed for CO_2 and H_2 storage.

Conclusions and integration of the learned lessons (Parts A, B, C)

- **Strategic: Lessons learned**
- - World climate strategies are working when supported by national strategies, policies, and financial instruments
- - CARBON PRICING – IS A NECESSARY BUT NOT SUFFICIENT POLICY
- It must FORM PART OF A SUPPORTIVE POLICY PACKAGE
- - Other policies are needed to drive research and development, unlock non-economic barriers to mitigation, and target emissions reductions with very high abatement costs
- **Political and Regulatory: Lessons learned**
- - Positive lessons: Ambitious political measures and initiatives of the European Union and support of research and innovation projects finally influenced the CCUS developments and much more CCUS projects and cluster projects are under development now in a number of European countries.
- - The increased activity of the oil and gas companies toward CO2 storage projects is caused by the recent implementation of the new CCS law in the USA
- - However, before Paris Climate Agreement in 2015, no significant activities took part.

Conclusions and integration of the learned lessons (Parts A, B, C)

Geological: Lessons learned

- Detailed geological knowledge is needed about storage sites before project implementation
- Requirements for CO2 storage site exploration before storage and monitoring during and after CO2 storage are described in annexes to EU CCS Directive and in the available guidances to the Directive.
- Geological modeling should be supported by exploration drilling and experimental work, including, geophysical, geochemical, etc.
- The available old infrastructure could be reused in some cases (positive), but could be a source of leakage (negative factor).
- Sometimes could be cheaper to drill new wells than to use very old wells and infrastructure (not corresponding to ISO requirements – International Standard Organisation)

Conclusions and integration of the learned lessons (Parts A, B, C)

Geological: Lessons learned from CO2-EOR

- Challenges in Depleted Oil reservoirs:
- Decreased Pressure
- Possible problems with wells integrity
- Decreased Temperature (negative for CO2-geothermal)
- Advantages:
- We have geological data and technical knowledge and experience
- CO2 injection will fill pores and return the original pressure
- Safe storage, if seal rocks are available

Conclusions and integration of the learned lessons (Parts A, B, C)

Economic: Lessons Learned

- The prices of CO_2 capture will decrease after wide industrial implementation according to economic laws (the same happened with computers, and other new technologies) and already have decreased in the USA.
- However, an ongoing energy crisis can negatively influence CO_2 capture and CO_2 compression costs.
- The CO_2 storage technology is mature owing to the available experience in CO_2-EOR (mainly in USA and Canada).
- CO_2 avoided is always lower than CO_2 captured
- CCUS clusters and hubs will decrease CCUS costs by sharing infrastructure and monitoring costs

Conclusions and integration of the learned lessons (Parts A, B, C)

- **In addition :**
- The overall cost of technology is decreasing with wide industrial implementation
- CO_2 acting underground as predicted with no leaks, no major seismic events, and no effects on groundwater are all great learning to build trust with stakeholders
- -Stakeholders' engagement is critical - sharing information with Stakeholders regarding CO_2 monitoring post-injection is important to build trust and acceptance
- CO_2 storage technology is mature and expertise is available from CO_2-EOR
- Education and increased public awareness can support CCS-wide implementation and avoid many mistakes made before
- Strategic, political, regulatory, economic, and public awareness and outreach issues and lessons should be considered together

Factors of success

- Climate strategies, international regulations, and international CO_2 tax are implemented (like EU ETS CO_2 tax)
- National policies and strategies include CCUS
- National CCS regulations permitting industrial scale CO_2 storage
- National CO_2 tax is implemented
- Governments, industry, and research Agencies are supporting financially CCUS
- Geological conditions are suitable for CO_2 storage, or neighboring countries are ready to host your national emissions
- CO_2 storage monitoring starts (as baseline) before CO_2 storage, and will last during and after CO_2 storage closure

The best practice available

- USA
- Canada
- Norway (Sleipner, Nothern Lights), UK clusters under development)
- Denmark – govermental support permitted to start CCUS activities including opening of CO2 storage site during two years!
- Iceland – the first industrial scale CO2 mineral carbonation project in basalt underground
- Governmental support in UK: number of clusters under development, including use of available infrastructure, hydrogen production, etc.

Mistakes that we should avoid in the future

- Regulatory
- Political
- Geological
- Public communication and very limited CCUS education

Do we need CCUS after 2050?

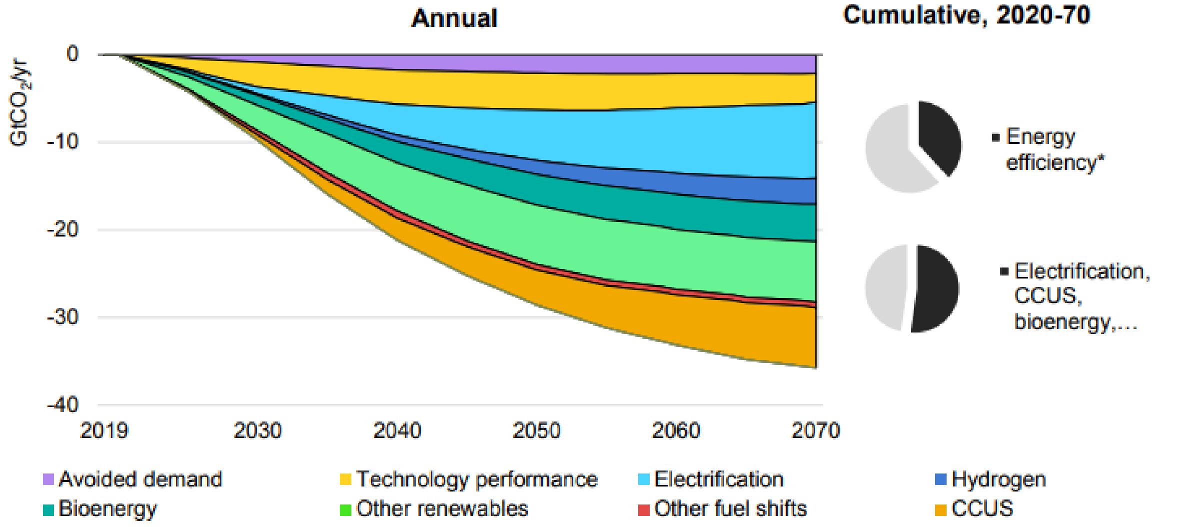
- According to available scenarios we could need CCUS for the industry until 2100, including BioCCS and DAC!

CCUS in Clean Energy Transitions

CCUS technologies offer significant strategic value in the transition to net-zero:

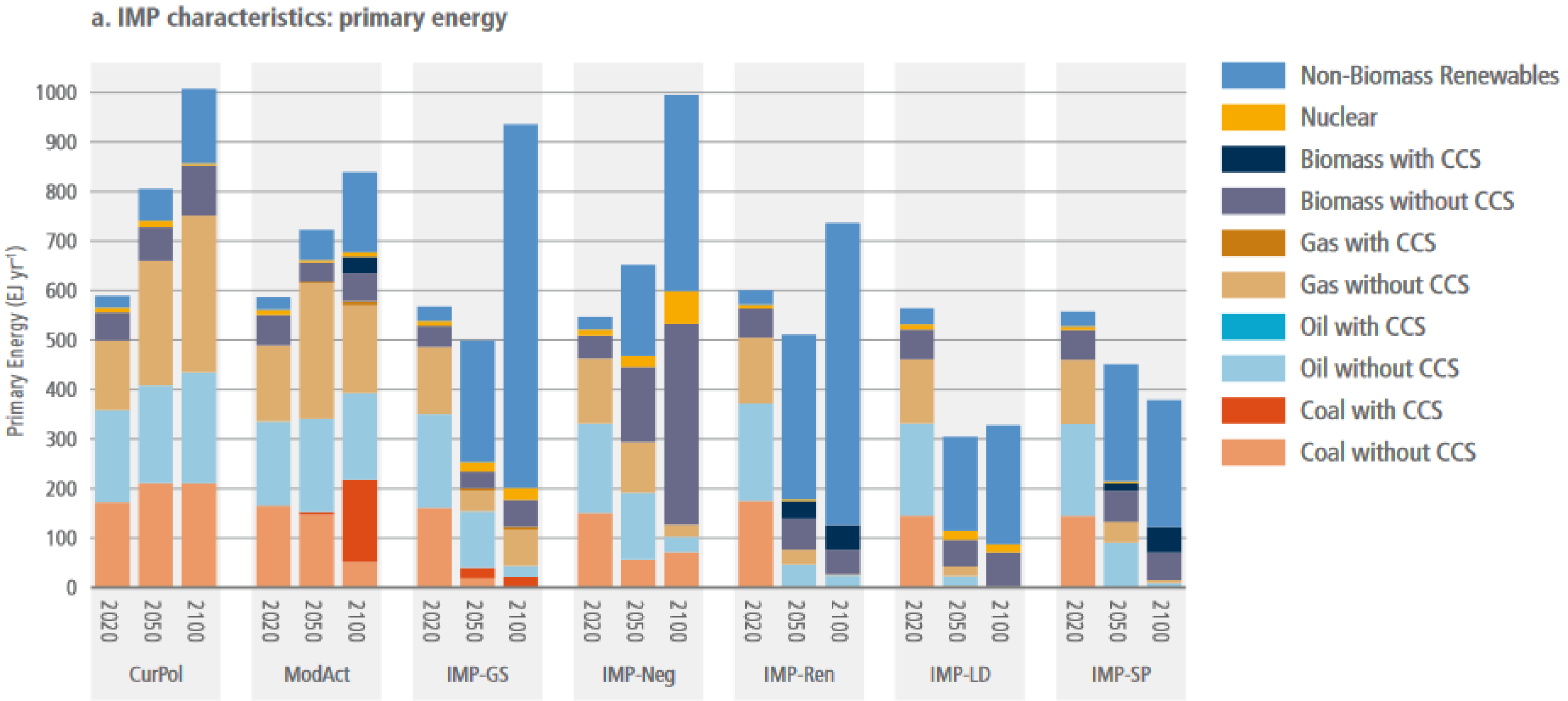
- CCUS can be retrofitted to existing power and industrial plants, which could otherwise still emit 8 billion tonnes (Gt) of carbon dioxide (CO2) in 2050.
- CCUS can tackle emissions in sectors where other technology options are limited, such as in the production of cement, iron and steel or chemicals, and to produce synthetic fuels for long-distance transport (notably aviation).
- CCUS is an enabler of least-cost low-carbon hydrogen production.
- CCUS can remove CO2 from the atmosphere by combining it with bioenergy or difficult to abate.

Figure 2.1 Global energy sector CO_2 emissions reductions by measure in the Sustainable Development Scenario relative to the Stated Policies Scenario, 2019-70



Mitigation Strategies

- The IMPs illustrate some options for different decarbonisation pathways with heavy reliance on renewables (IMP-Ren), strong emphasis on energy-demand reductions (IMP-LD), widespread deployment of CDR methods coupled with CCS (BECCS and DACCS) (IMP-Neg), mitigation in the context of sustainable development (IMP-SP) (Figure 3.16).
- For example, in some scenarios, a small part of the energy system is still based on fossil fuels in 2100 (IMP-Neg), while in others, fossil fuels are almost or completely phased out (IMP-Ren).
- Nevertheless, in all scenarios, fossil fuel use is greatly reduced and unabated coal use is completely phased out by 2050.
- Also, nuclear power can be part of a mitigation strategy (however, the literature only includes some scenarios with high-nuclear contributions, such as Berger et al. 2017).



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CCUS ZEN

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TAL TECH

BASRECCS

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Consulting & Solutions for future energy sector
CCUS /H_2/Energy storage /Geothermal energy recovery
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CO_2 net

ENOS
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SCHWENK

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