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Energy Systems Analysis of CCS development in Europe

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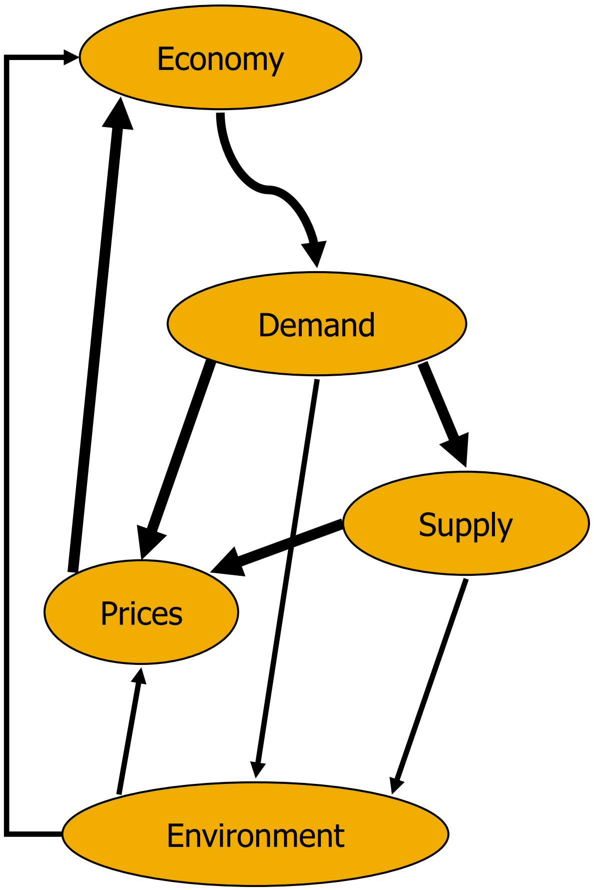
Energy Systems Analysis of CCS development in Europe

- Impact assessment of CCS deployment through scenario based policy analysis
- Combination of
  - Emission target: 20% in 2020, 30% in 2030
  - Renewable target: 20% in 2020, continuous effort thereafter
  - Measures for promoting CCS deployment

Energy Systems Analysis of CCS development in Europe



The PRIMES Energy Systems Model

- Large Scale Energy system model: mixed bottom-up (engineering) and top-down (microeconomic behaviors)
- Modular, with separate modules for demand and supply by sector
- Comprehensive Energy – Environment – Economy System coverage
- Coverage of all Member States of the EU-27

Energy Systems Analysis of CCS development in Europe

- Two ways of CCS deployment
  - Typical new power plants with CCS
  - Retrofitting of power plants initially built without CCS
- Three candidate CCS technologies
  - Pre-combustion
  - Post-combustion
  - Oxy-fuel

Energy Systems Analysis of CCS development in Europe

- Complete techno-economic data with learning by doing and learning by research dynamics
- Non-linear cost curves for transport and storage per Member State

Energy Systems Analysis of CCS development in Europe

	Difference from non CCS plant								
	Capital Cost (€/kW)		Net Thermal Efficiency (rate)		Fixed Cost (€/kW)		Non fuel Variable Cost (€/MWh)		Net CO_2 avoided
Constant Euros of 2005	2020	2030	2020	2030	2020	2030	2020	2030	
Pulverised Coal Supercritical CCS post combustion	893.5	833.1	-11.8%	-11.7%	7.01	6.85	0.51	0.51	84%
Pulverised Lignite Supercritical CCS post combustion	882.2	818.6	-11.3%	-11.2%	6.97	6.81	0.51	0.52	84%
Fuel Oil Supercritical CCS post combustion	893.5	833.1	-13.0%	-12.6%	7.01	6.85	0.51	0.51	83%
Integratedl Gasification Fuel Oil CCS pre combustion	558.6	558.1	-6.7%	-6.5%	14.86	14.45	2.00	1.94	89%
Pulverised Coal Supercritical CCS oxyfuel	685.4	654.8	-8.8%	-8.7%	7.63	7.50	2.00	1.94	99%
Pulverised Lignite Supercritical CCS oxyfuel	666.2	634.9	-8.4%	-8.3%	7.66	7.53	2.01	1.96	99%
Integrated Gasification Coal CCS post combustion	796.6	775.7	-6.7%	-6.5%	14.86	14.45	2.00	1.94	86%
Integrated Gasification Coal CCS pre combustion	467.3	431.2	-7.7%	-7.5%	9.65	9.36	0.51	0.51	87%
Integrated Gasification Coal CCS oxyfuel	434.0	425.3	-6.5%	-6.5%	9.33	9.01	1.40	1.38	99%
Integrated Gasification Lignite CCS post combustion	520.4	505.2	-4.8%	-4.6%	7.12	6.84	1.06	1.04	86%
Integrated Gasification Lignite CCS pre combustion	456.6	417.3	-7.4%	-7.3%	9.56	9.25	0.51	0.52	87%
Integrated Gasification Lignite CCS oxyfuel	434.0	425.3	-6.0%	-6.0%	9.33	9.01	1.40	1.38	99%
Gas combined cycle CCS post combustion	520.4	505.2	-7.0%	-6.5%	7.12	6.84	1.06	1.05	86%
Gas combined cycle CCS pre combustion	400.9	388.2	-8.5%	-8.1%	4.17	3.98	0.47	0.47	87%
Gas combined cycle CCS oxyfuel	434.0	425.3	-8.8%	-8.6%	9.33	9.01	1.40	1.38	99%

Energy Systems Analysis of CCS development in Europe

- Three CCS promoting policies
  - Mandatory CCS in all new coal, lignite and fuel oil power plants from 2020 onwards
  - Mandatory CCS in all new power plants including gas from 2020 onwards
  - Obligatory capture ready design of all fossil fuelled power plants built until 2015 and mandatory CCS enforcement thereafter

Energy Systems Analysis of CCS development in Europe

- Two EU-ETS implementation methods:
  - Grandfathering under perfect competition
  - Full auctioning (no returns in the energy sector)
- Systems Analysis with PRIMES model of 13 main scenarios and 4 sensitivity cases

Energy Systems Analysis of CCS development in Europe

Scenario	Emission Target	RES target	Full CCS	Limited CCS	CCS-ready	Additional measures
BASELINE	NO	NO	NO	NO	NO	-
BASE-CCS1	NO	NO	NO	YES	NO	-
BASE-CCS2	NO	NO	YES	NO	NO	-
CVtar-A	YES	NO	NO	NO	NO	-
RVCVtar-A	YES	YES	NO	NO	NO	-
RVCVtar-A-CCS1	YES	YES	NO	YES	NO	-
RVCVtar-A-CCS2	YES	YES	YES	NO	NO	-
RVCVtar-A-CCS1R	YES	YES	NO	YES	YES	-
RVCVtar-A-CCS2R	YES	YES	YES	NO	YES	-
RVCVtar-A-CCS2N	YES	YES	NO	NO	NO	Higher storage cost
RVCVtar-A-CCS2Nuc	YES	YES	NO	NO	NO	Nuclear policy
RVCVtar-A-noCCS	YES	YES	NO	NO	NO	No CCS
RVCVtar-A-subs	YES	YES	NO	NO	NO	10% subsidy

Energy Systems Analysis of CCS development in Europe

	Carbon Value in Euro per t CO2			Renewable Value in Euro per MWh			Total CO2 Emissions from Energy (Mt CO2)			Total Renewables (Mtoe primary)		
Scenarios	**2020**	**2025**	**2030**	**2020**	**2025**	**2030**	**2020**	**2025**	**2030**	**2020**	**2025**	**2030**
Baseline	22.0	23.0	24.0	0	0	0	4253	4307	4264	197	217	237
Base-CCS1	22.0	23.0	24.0	0	0	0	4229	4277	4159	195	219	246
Base-CCS2	22.0	23.0	24.0	0	0	0	4212	4244	4138	197	219	242
CVtar-A	50.8	54.2	57.6	0	0	0	3419	3301	3012	197	217	240
RVCVtar-A	40.4	43.1	45.9	38.0	44.3	47.5	3323	3216	3050	273	314	347
RVCVtar-A-CCS1	40.2	42.9	45.6	38.0	44.3	47.5	3372	3264	2973	273	314	348
RVCVtar-A-CCS2	40.3	43.0	45.7	38.0	44.3	47.5	3360	3269	2906	273	314	349
RVCVtar-A-CCS1R	38.0	40.6	43.1	38.0	44.3	47.5	3346	3194	2937	273	314	348
RVCVtar-A-CCS2R	37.8	40.3	42.8	38.0	44.3	47.5	3347	3182	2843	273	315	349
RVCVtar-A-CCS2N	40.3	43.0	45.7	38.0	44.3	47.5	3365	3284	2964	273	314	349
RVCVtar-A-CCS2Nuc	40.3	43.0	45.7	38.0	44.3	47.5	3272	3185	2865	273	314	348
RVCVtar-A-noCCS	41.0	44.3	67.0	38.0	44.3	47.5	3367	3256	2925	273	314	349
RVCVtar-A-subs	40.4	43.1	45.9	38.0	44.3	47.5	3373	3261	3045	273	313	347

Energy Systems Analysis of CCS development in Europe

	CO2 Captured (Mt/year)			CO2 captured as % of CO2 from Power and Steam			CO2 captured as % of CO2 from all Energy		
Scenarios	**2020**	**2025**	**2030**	**2020**	**2025**	**2030**	**2020**	**2025**	**2030**
Baseline	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Base-CCS1	0.0	4.3	62.0	0.0	0.2	3.6	0.0	0.1	1.5
Base-CCS2	0.0	5.0	90.5	0.0	0.3	5.2	0.0	0.1	2.2
CVtar-A	27.2	150.5	483.3	2.2	11.1	32.8	0.8	4.5	15.9
RVCVtar-A	7.0	19.7	160.7	0.6	1.7	13.2	0.2	0.6	5.2
RVCVtar-A-CCS1	6.9	20.6	266.9	0.6	1.8	22.2	0.2	0.6	8.9
RVCVtar-A-CCS2	6.9	26.5	391.3	0.6	2.2	31.0	0.2	0.8	13.3
RVCVtar-A-CCS1R	37.2	118.1	326.2	3.2	10.0	26.9	1.1	3.7	11.0
RVCVtar-A-CCS2R	75.0	176.5	517.1	6.2	14.4	39.5	2.2	5.5	17.9
RVCVtar-A-CCS2N	0.0	3.5	272.6	0.0	0.3	22.7	0.0	0.1	9.1
RVCVtar-A-CCS2Nuc	7.1	22.6	352.1	0.7	2.1	29.7	0.2	0.7	12.2
RVCVtar-A-noCCS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RVCVtar-A-subs	0.2	21.6	210.7	0.0	1.8	17.3	0.0	0.7	6.9

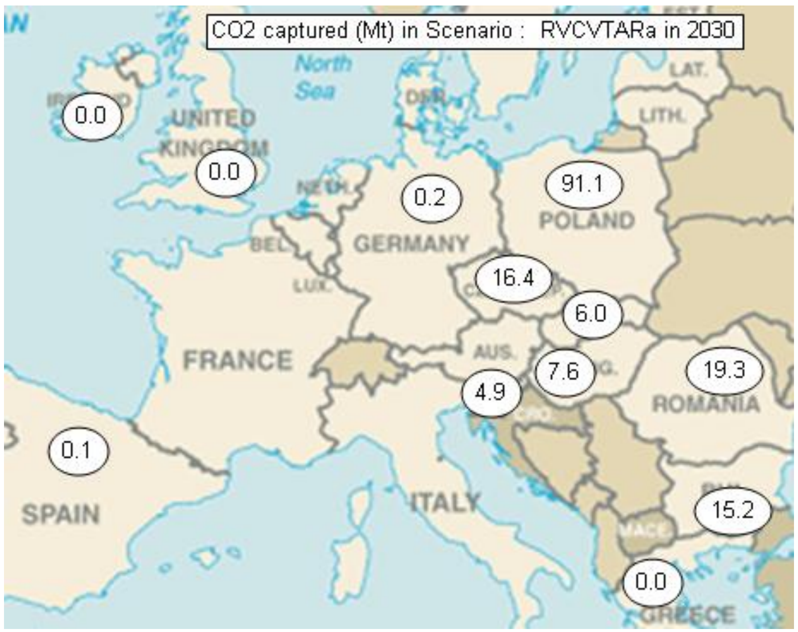
Energy Systems Analysis of CCS development in Europe

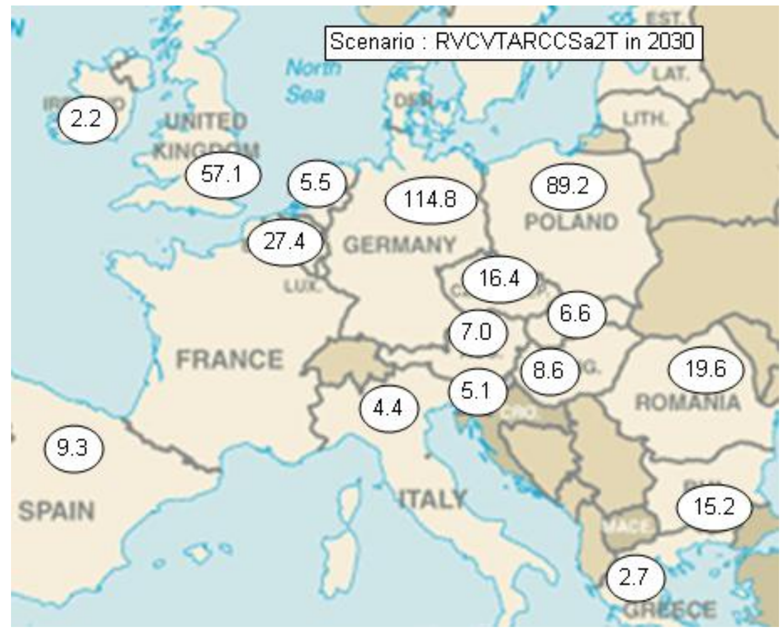
	Average Generation Cost in €/MWh			Power plants Investment Expenditure in billion €			Average Price of Electricity in €/MWh			Total Energy Cost as % of GDP		
Scenarios	2020	2025	2030	15-2020	20-2025	25-2030	2020	2025	2030	2020	2025	2030
Baseline	50.13	50.69	51.49	135	145	228	101.76	103.47	105.03	9.7	9.4	9.1
Base-CCS1	50.28	50.89	52.19	122	127	220	101.99	104.35	107.16	9.6	9.3	9.0
Base-CCS2	50.30	50.91	52.36	91	119	221	102.10	104.31	107.32	9.6	9.3	9.0
CVtar-A	61.96	63.05	63.00	125	193	309	127.72	130.73	129.53	10.2	9.9	9.8
RVCVtar-A	60.24	62.01	63.17	149	192	313	124.08	128.60	130.27	10.1	9.9	9.8
RVCVtar-A-CCS1	60.32	62.24	62.94	148	187	334	124.30	129.36	130.16	10.1	9.9	9.8
RVCVtar-A-CCS2	60.51	62.38	62.87	140	181	361	124.82	129.89	130.12	10.2	9.9	9.8
RVCVtar-A-CCS1R	60.39	62.08	62.84	162	206	319	125.25	129.55	129.96	10.1	10.0	9.8
RVCVtar-A-CCS2R	60.84	62.67	63.04	167	209	350	126.47	130.91	130.22	10.2	10.0	9.8
RVCVtar-A-CCS2N	60.53	62.41	63.05	139	179	350	124.85	129.95	130.71	10.2	9.9	9.8
RVCVtar-A-CCS2Nuc	59.95	61.92	62.42	142	170	314	123.46	128.82	128.89	10.2	10.0	9.8
RVCVtar-A-noCCS	60.36	62.29	66.26	148	193	302	124.39	129.54	137.67	10.2	10.0	10.1
RVCVtar-A-subs	60.22	61.97	63.01	148	193	321	124.00	128.49	129.91	10.1	9.9	9.8

Energy Systems Analysis of CCS development in Europe

Mt of CO_2 Captured in 2030	Base-CCS1	Base-CCS2	CVtar-A	RVCVtar-A	RVCVtar-A-CCS1	RVCVtar-A-CCS2	RVCVtar-A-CCS1R	RVCVtar-A-CCS2R	RVCVtar-A-CCS2N	RVCVtar-A-CCS2Nuc	RVCVtar-A-subs
Ireland	0.0	0.0	6.5	0.0	0.0	2.2	0.0	5.1	2.2	1.9	1.6
United Kingdom	0.0	0.0	15.9	0.0	1.0	57.1	3.9	62.1	57.1	52.5	9.9
Belgium	1.0	6.6	11.7	0.0	17.3	27.4	22.4	49.8	27.4	18.2	0.0
Luxembourg	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.8	0.2	0.0	0.0
Netherlands	0.0	0.0	0.0	0.0	0.0	5.5	2.7	13.9	5.5	4.9	0.0
Germany	32.5	39.5	129.1	0.2	74.3	114.8	134.7	185.8	114.8	84.2	56.3
France	0.0	0.0	0.1	0.0	0.0	0.0	3.0	3.0	0.0	0.0	0.0
Spain	0.0	0.0	26.8	0.1	9.2	9.3	11.4	13.0	9.3	14.9	0.8
Portugal	0.0	0.0	3.2	0.0	0.0	0.0	1.8	1.8	0.0	0.0	0.0
Denmark	0.0	0.0	4.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sweden	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Finland	0.0	0.0	6.1	0.0	0.0	0.0	0.9	0.9	0.0	0.0	0.0
Austria	0.0	0.0	7.2	0.0	0.0	7.0	1.1	11.1	7.0	6.7	0.0
Italy	0.0	0.0	17.0	0.0	4.5	4.4	7.8	10.2	4.4	4.3	0.0
Slovenia	1.8	2.7	4.8	4.9	4.9	5.1	4.9	5.2	0.7	5.0	4.9
Czech Republic	10.9	10.3	42.4	16.4	16.1	16.4	18.2	18.2	8.5	19.5	18.3
Slovakia	2.5	2.6	8.0	6.0	5.9	6.6	7.5	9.4	0.5	5.6	6.6
Poland	4.1	16.9	125.8	91.1	91.9	89.2	72.0	77.8	27.0	88.1	93.5
Hungary	1.4	4.0	12.7	7.6	7.7	8.6	7.5	12.0	1.4	8.7	8.2
Latvia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Estonia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1	0.0	0.0	0.0
Lithuania	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Romania	7.5	7.9	36.4	19.3	18.2	19.6	12.3	17.1	3.9	19.6	6.9
Bulgaria	0.3	0.0	18.8	15.2	15.2	15.2	14.2	15.9	0.0	15.2	2.6
Greece	0.0	0.0	6.1	0.0	0.8	2.7	0.0	3.2	2.7	2.9	1.0
Cyprus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Malta	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
EU27	62.0	90.5	483.3	160.7	266.9	391.3	326.2	517.1	272.6	352.1	210.7

Energy Systems Analysis of CCS development in Europe





Energy Systems Analysis of CCS development in Europe

- CCS develops after 2020 and close to 2030 – along with technological maturity
- CCS can contribute in emission reduction economically – it is one of the major mitigation options
  - CCS maximum deployment when only emission reduction is enforced without specific renewables target
- Prohibition of CCS leads to 60 billion € additional costs

Energy Systems Analysis of CCS development in Europe

- If CCS mandatory, use of old plants is higher and their lifetime is extended
- If CCS mandatory only in coal, use of gas increases – concerns about security of supply
- Capture-ready and retrofitting adds on costs with little benefits
- Mandatory CCS without ambitious emission targets entails high unnecessary costs

Energy Systems Analysis of CCS development in Europe

- Renewable target acts in competition against higher CCS deployment
- Nuclear lifetime extension has small effect on CCS deployment
- Subsidisation is not necessary but enhances deployment by ~30%
- Generally, the CCS support options help deployment by reducing future uncertainty and enabling faster learning-by-doing

Energy Systems Analysis of CCS development in Europe

- CCS is mainly developed in CEEC countries
- Low storage costs in east European countries
- Higher costs result in 30% reduction in CCS deployment
- Importance of (uncertain) transportation and storage costs