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TOTAL

Relative role of electricity and gas in a carbon-neutral future: insights from an energy system optimization model

Reaching carbon neutrality in France by 2050

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Introduction

Motivation

- European Climate law: Climate-neutrality by 2050 (European Commission, 2019).
- French Energy-Climate law: Zero GHG emissions by 2050 (DGEC, 2019)
- French primary energy mix as of 2018 (CGDD, 2019):
  41% nuclear energy, 11.5% renewables (4.3% biomass, 1.3% bio-fuels, biogas <0.5%).
- The role of renewable gas in different future French energy scenarios for 2050:

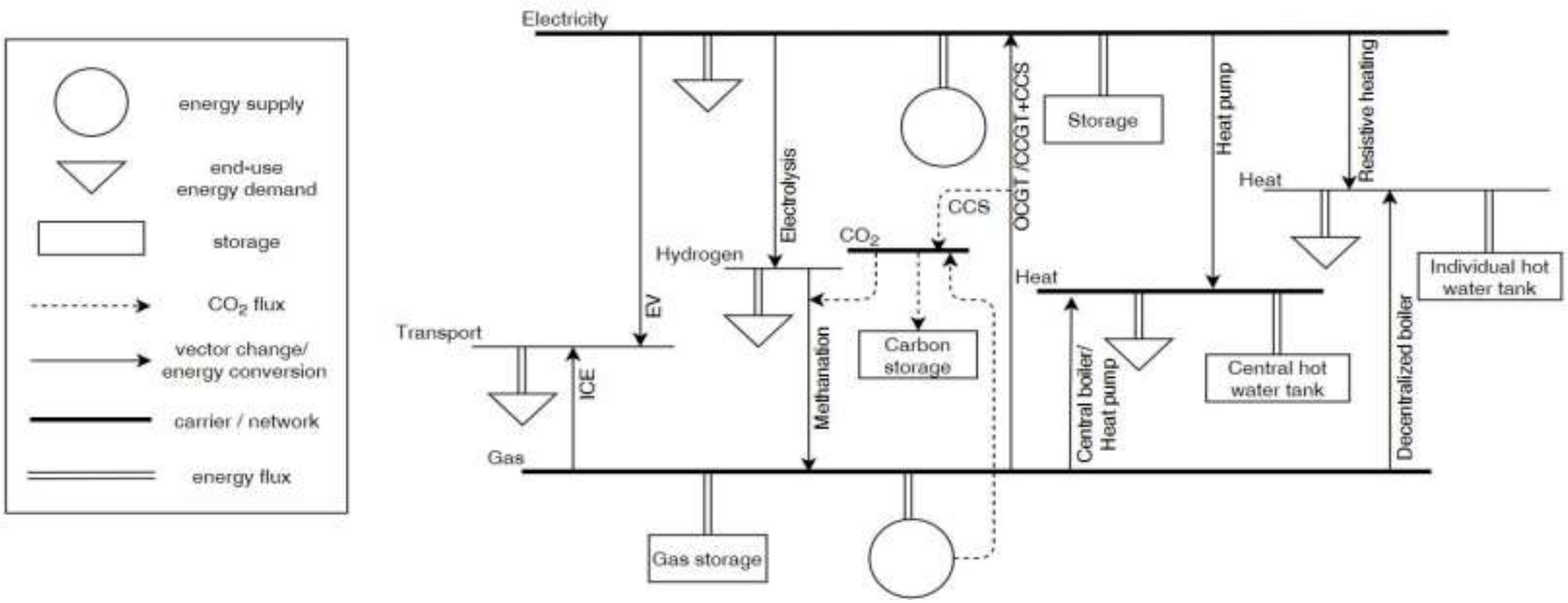
  SNBC2: ~20% ***NégaWatt: ~20%*** ***ADEME Visions: ~16%***

- National scenarios: top-down allocation of energy sources and carriers => no optimization
- A rigorous energy policy must be based on « Optimization » that:
  (1) Include the main energy sectors, **(2)** is based on endogenous carrier and technology choice, **(3)** includes the main low-carbon options, **(4)** has a high temporal resolution and **(5)** internalizes both positive and negative emissions.
- Existing optimization literature: Mainly electricity sector (Zeyringer et al, 2018, Schlachtberger et al, 2018 and etc.)
- Sector-coupling literature: ***lack of temporal precision*** (Doudard, 2018) or ***lack of endogeneity and limited representation of low-carbon options*** (Brown et al, 2018, Bloess et al, 2018, Victoria et al, 2019 and etc.), and in none, ***emissions are completely internalized***.

Questions adressed

- Relative role of **1)** different energy carriers (electricity and gas) and **2)** low-carbon energy supply technologies (renewables, nuclear power and carbon capture and storage)?
- **3)** Importance of Social Cost of Carbon (SCC)?

EOLES_mv



- Greenfield optimization on a single node.
- 4 energy vectors; electricity, gas, heat and hydrogen.
- All major energy sectors: Buildings, Agriculture, Industry and Transport.
- End-uses: mobility, heating, electricity and hydrogen for industry.

$$C(Q_i, E_{i,t}, SCC_{CO_2}) = \sum_i fc_i . Q_i + \sum_i \sum_t vc_i . E_{i,t} + SCC_{CO_2} . \sum_i \sum_t e_i . E_{i,t}$$

Installed capacity of technology *i*

Hourly energy production of technology *i* at hour *t*

Social cost of carbon

Fixed costs of technology *i*

variable costs of technology *i*

CO2 emission rate of technology *i*

Bio-methane production

- Methanization

152 TWh_{th}/year

Organic waste → Anaerobic digestion → Biogas : 60% CH_4, 30% CO_2, 10% other → Purification → CH_4

Purification → CO_2

Micro-organisms in a digester

Investment : 300€/kW_{th}
Fixed O&M :30€/kW_{th}/year
Variable O&M : 50€/MWh_{th}

- Pyro-gasification

122 TWh_{th}/year

Energy wood & Biomass → Gasification → Syngas : 34-45% H_2, 15-25% CO_2, 20-30% CO, 8-12% CH_4, 3-5% N_2 → Methanation → CH_4

77 TWh_{th}/year

Methanation → Others

r = 63%

Investment : 2500€/kW_{th}
Fixed O&M : 225€/kW_{th}/year
Variable O&M : 32€/MWh_{th}

EU JRC (2015) : Bioenergy potentials for EU and neighbouring countries

ADEME (2018) : Un mix de gaz 100% renouvelable en 2050 ?

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APPLICATION

- Applied to continental France.
- The time horizon is 2050: energy demand, cost, technical and availability constraints and etc. are all 2050 forecasts.
- Historical weather data for VRE profiles; 2006 as representative weather year (previous study over 19 years: from 2000-2018; Shirizadeh et al, 2019)

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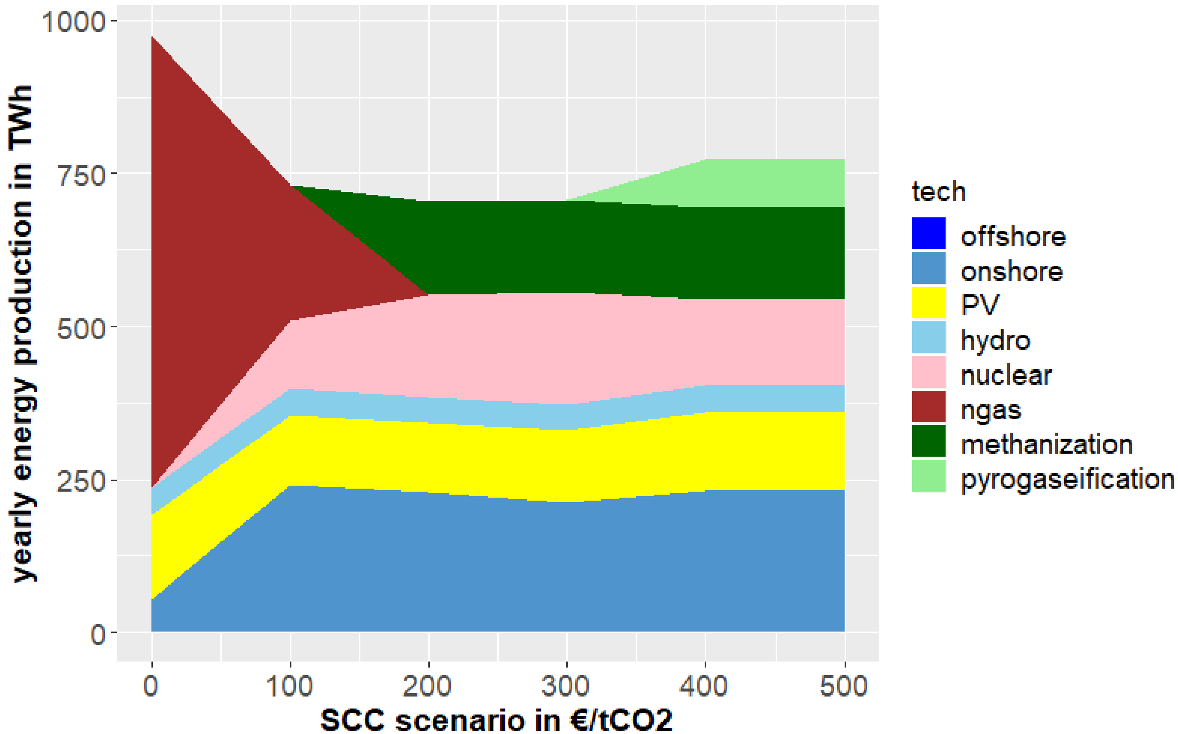
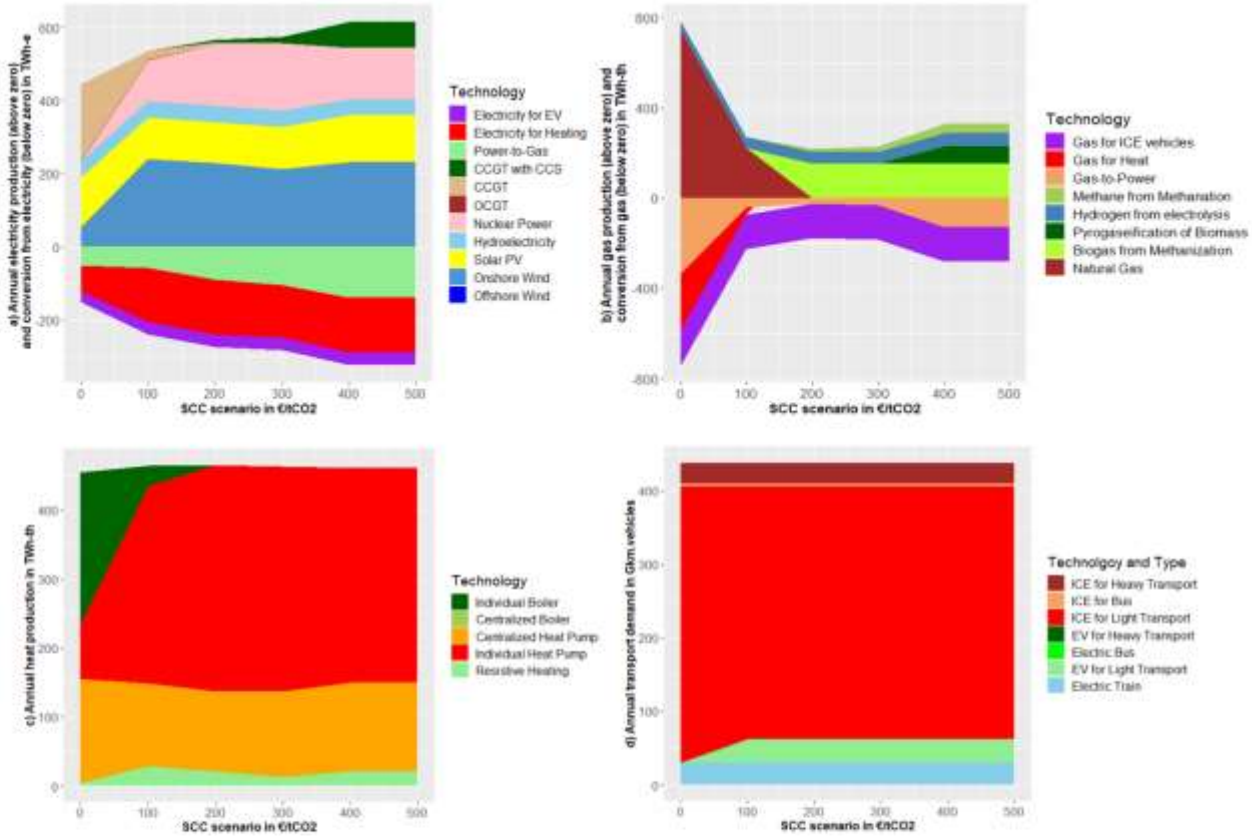
RESULTS

Results: Primary energy production



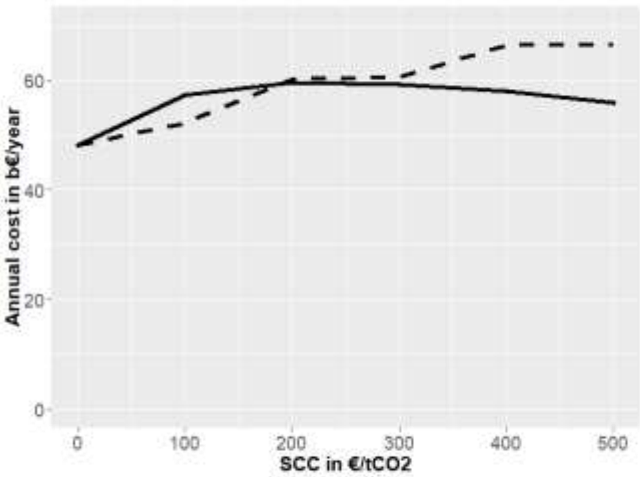
- With no SCC 75% of primary energy production from natural gas.
- SCC of €200/tCO2 leads to natural gas phase-out.
- Gas provides at least 22% of primary energy supply.
- Nuclear power appears for 100€/tCO2 of SCC, maximal share of nuclear power at €300/tCO2 (25%), but generally less than 20%.

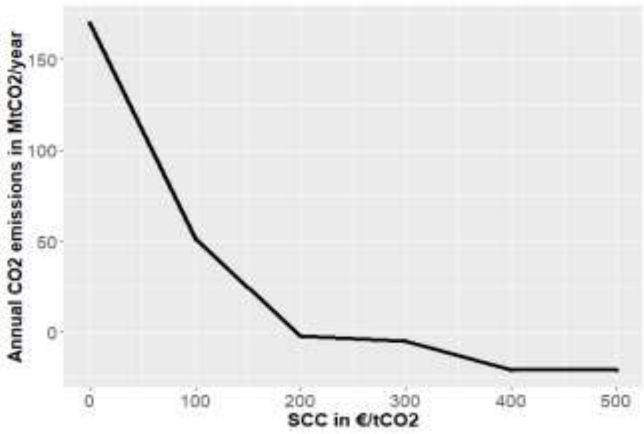
Results: Energy mix for each end-use

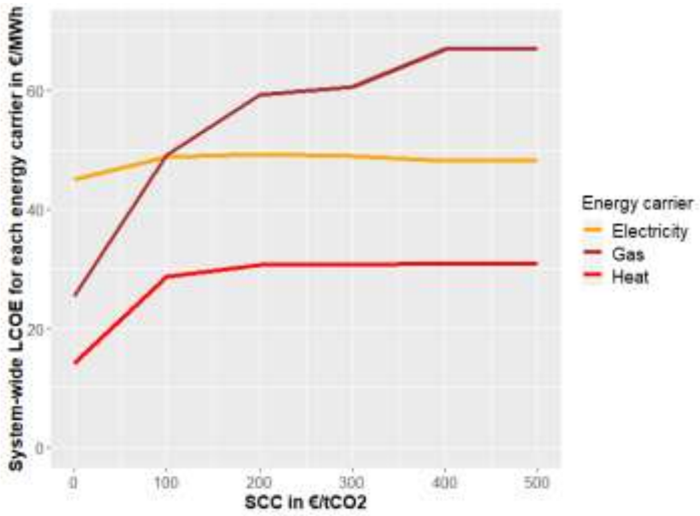


- **Whatever the SCC is, the transport sector is dominated by ICE, even for light vehicles.**
- **Without SCC value, half of heat demand is satisfied by gas-to-heat, but from the first SCC value heat is electrified and for SCC of €200/tCO2 it is fully electrified (important role of heat network).**

Results: Cost & Emissions

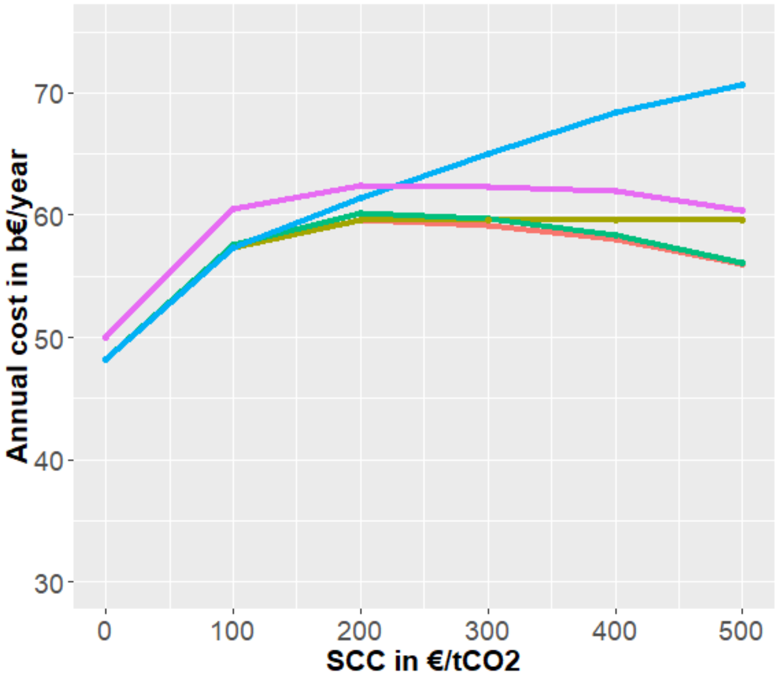


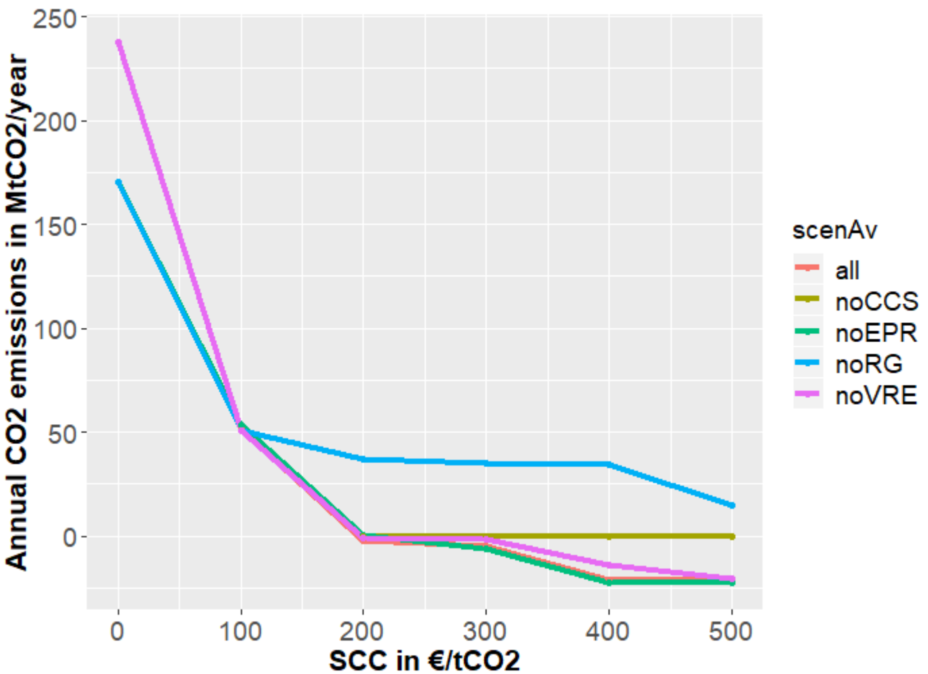




- **CO2 neutrality for €200/tCO2 of SCC.**
- **For SCC> €200/tCO2 negative emissions.**
- **Up to 21MtCO2/year of negative emissions.**
- **The divergence between technical cost and the cost including SCC: not significant for SCC of < €400/tCO2**
- **For SCC of €500/tCO2 = 16% of technical cost (€10.5b/year)**

Results: Relative role of different options

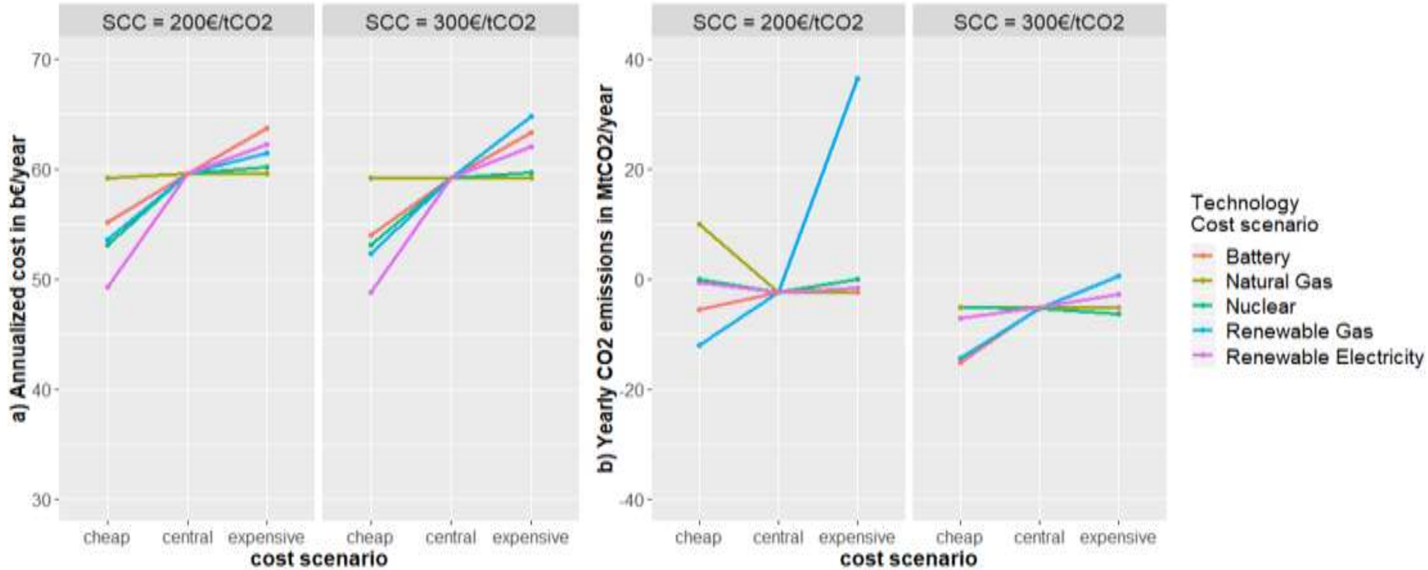




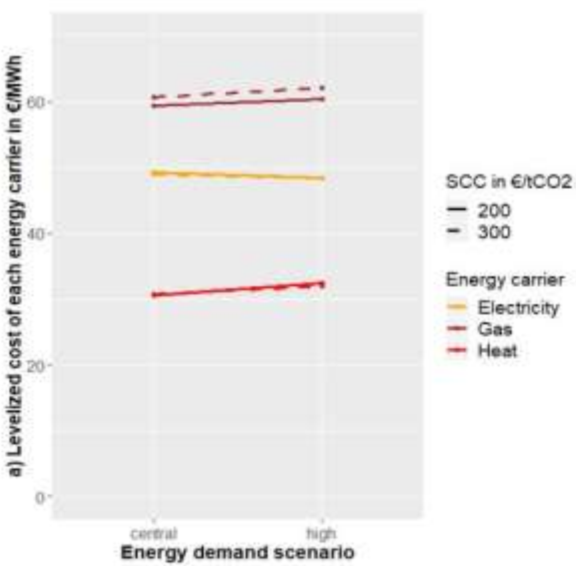
- **VREs are the man enablers of cost reduction for low SCC, and renewable gas is the main enabler for high SCC values.**
- **In case of availability of renewable gas, an SCC value of 200€/tCO2 leads to carbon neutrality for all the availability scenarios.**
- **Nuclear power doesn’t play an important role neither from emissions point of view nor from economic point of view.**

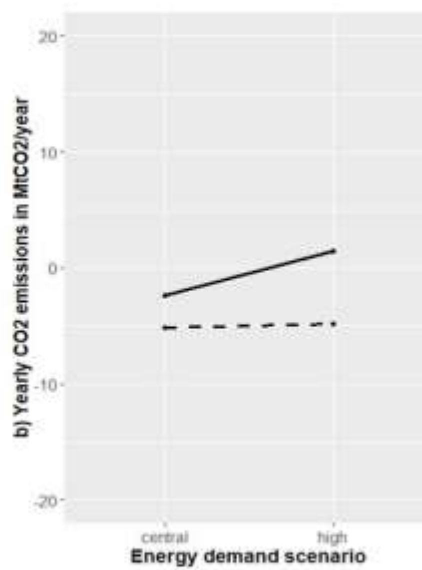
Results: Robustness of SCC

Cost variation



Higher energy demand





- **A robust SCC of €300/tCO2 can lead to carbon-neutrality or negative emissions.**

Conclusion

- A carbon-neutral or negative emission energy system can be reached with a SCC of €300/tCO_2, when cost and demand uncertainties are taken into account.
- Energy supply is highly electrified, but **renewable gas provides at least 22% of the primary energy in a carbon-neutral energy system**.
- **Without renewable gas even a SCC of 500€/tCO_2 wouldn't lead to carbon neutrality.**
- **Renewables become the main source of the primary energy supply (up to >80%).**
- **A very big proportion of transport demand is satisfied by gas-powered internal combustion engine vehicles (~90%).**
- In a carbon-neutral energy system, heating is fully electrified.
- **If we are to prioritize some technologies for investment, renewable gas and electricity technologies are the most important ones, while nuclear power does not play an important role in reaching climate goals in cost optimal ways.**

Limits & Future Research (1/2)

▪ Methane leakage

- Existing gas infrastructure for transport and distribution will lead to methane leakage (Alvarez et al, 2012).
- Methane has >20x greenhouse effect than carbon-dioxide.
- It can erode all the climate benefits (Union of concerned scientists, 2017).

▪ Particulate pollution

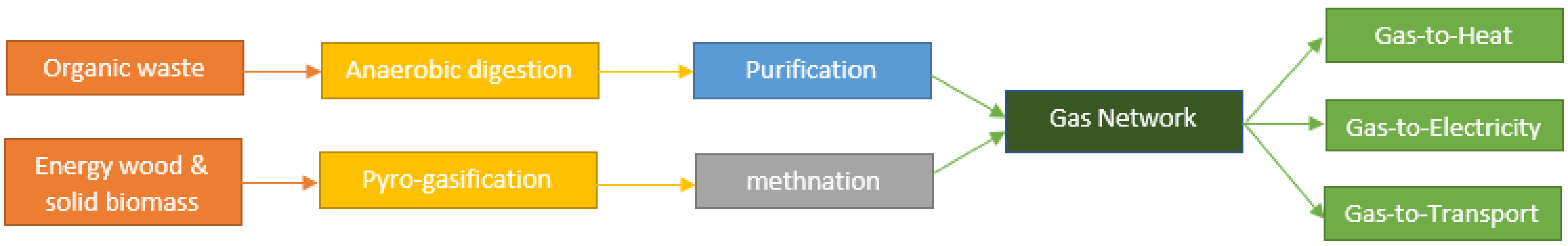
- particulate pollution by gas-fueled ICE vehicles has been highlighted as an important environmental disadvantage (Suarez-Bertoa et al, 2019).

▪ Narrower analysis of bioenergies

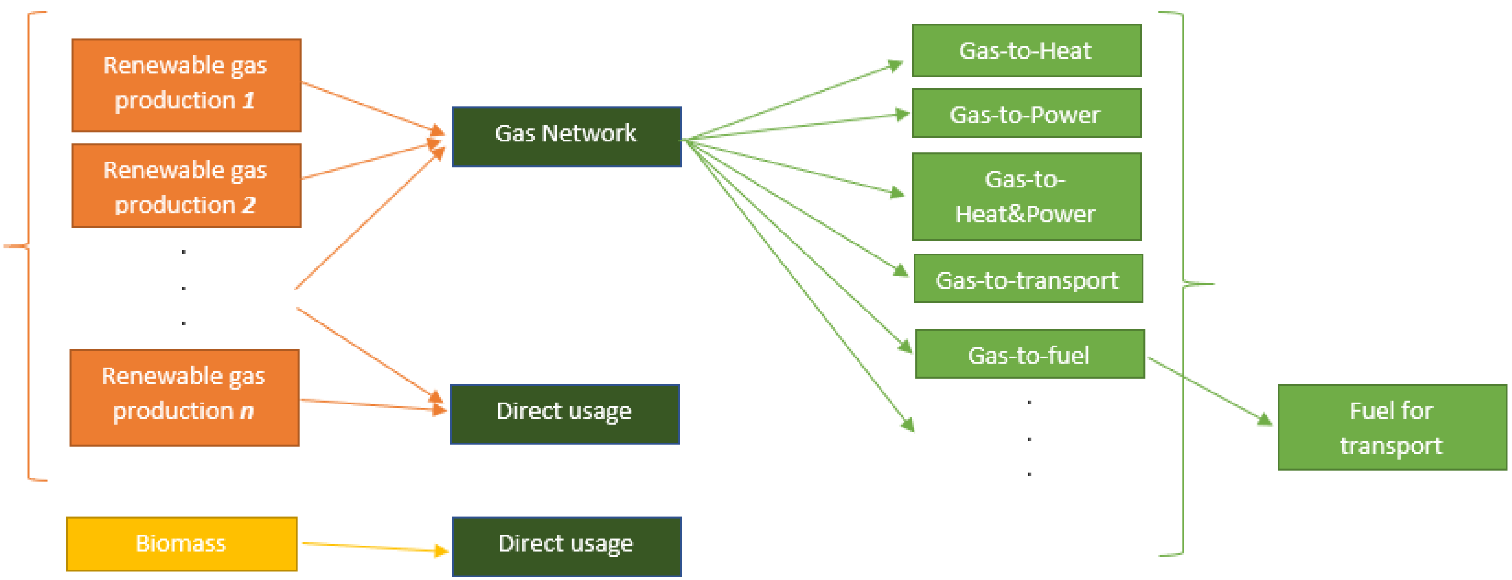
- The whole biogas value chain? By-products? Biofuels?

Limits & Future Research (2/2)

- **What we modelled:**



- **What can be modelled?**



Merci!

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This paper is available in FAERE and SSRN working paper series. EconPapers link of the paper:

https://econpapers.repec.org/paper/faewpaper/2020.19.htm

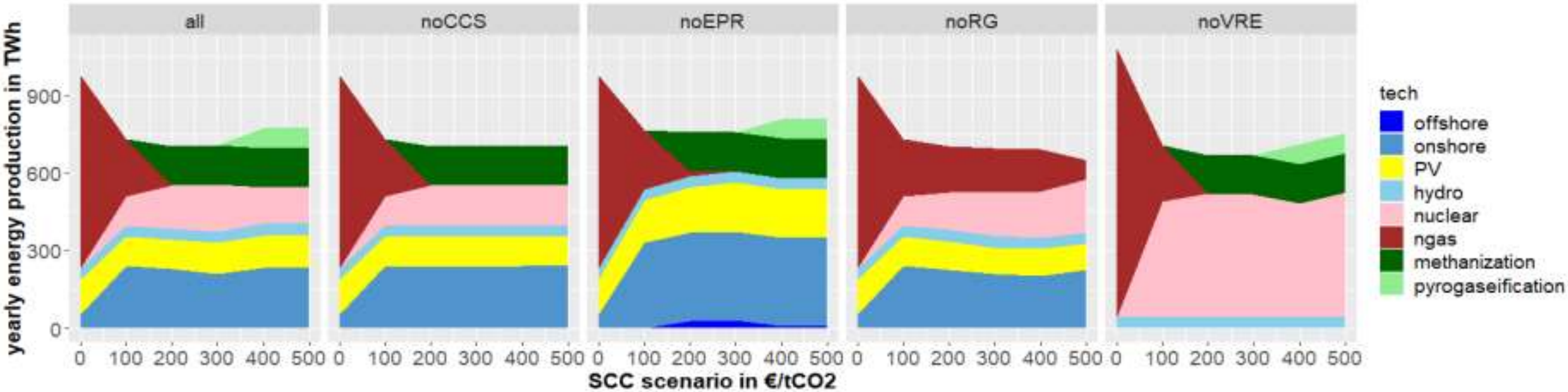
Appendix 1. The main results (1/2)

SCC (€/tCO_2)	0	100	200	300	400	500
technology	**Installed capacity in GW**					
Offshore wind	0	0	0	0	0	0
Onshore wind	19.41	84.58	80.34	74.58	81.74	81.71
Solar PV	96	80.36	79.32	82.20	89.20	89.79
Run of river	7.5	7.5	7.5	7.5	7.5	7.5
Lake and reservoir	12.86	12.86	12.86	12.86	12.86	12.86
Nuclear	0	15.28	22.64	23.87	18.19	18.11
Natural gas	-	-	-	-	-	-
Methanization	0	0	17.35	17.35	17.35	17.35
Pyro-gasification	0	0	0	0	8.79	8.79
OCGT	2.75	4.58	2.09	0.69	0	0
CCGT	35.51	14.13	5.20	0.75	0	0
CCGT with CCS	0	0	5.47	11.5	17.24	17.31
Power-to-hydrogen	4.65	6.11	6.37	6.74	7.16	7.16
Power-to-methane	0	0	3.37	5.29	6.27	6.25
Heat network	18.23	34.29	46.66	43.73	45.68	45.63
Central HP	18.23	26.59	26.79	28.80	30.97	34.01
Individual HP	9.23	37.40	41.50	41.90	40.08	40
Resistive heating	6.14	21.15	17.92	13.51	14.53	14.82
Central boiler	0	0	0	0	0	0
Decentralized boiler	60.04	16.30	0	0	0	0
Battery	3.83	5.56	4.78	4.83	5.87	5.92
PHS	9.30	9.30	9.30	9.30	9.30	9.30
Gas storage	0	0	24.29	25.48	27.68	27.67
CTES	18.23	34.29	46.66	43.73	45.68	45.63
ITES	20.27	41.26	39.31	37.23	38.48	33.95

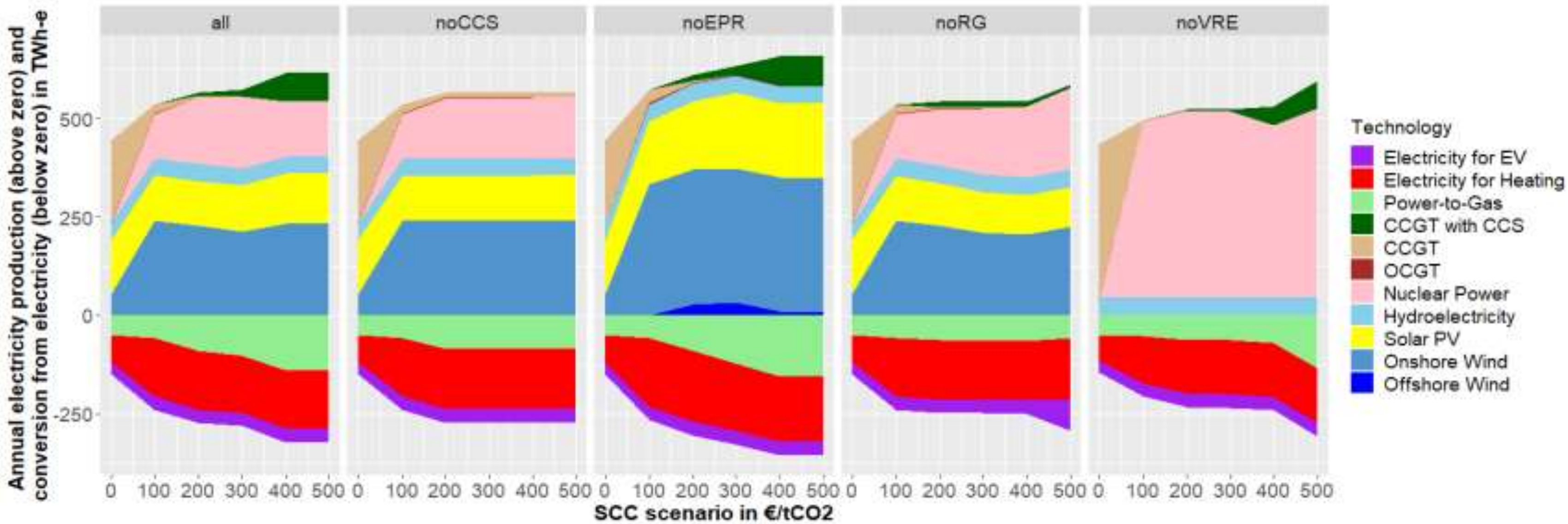
Appendix 1. The main results (2/2)

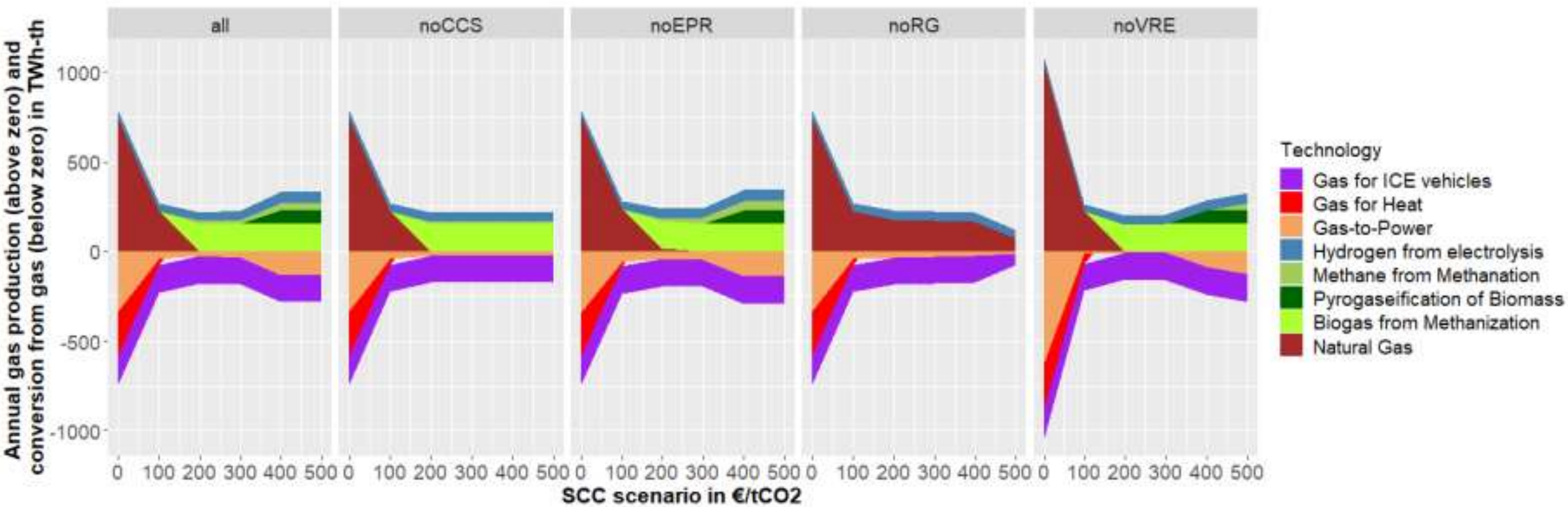
SCC (€/tCO$_2$)	0	100	200	300	400	500
technology	Annual energy production in TWh					
Offshore wind	0	0	0	0	0	0
Onshore wind	55.22	240.58	228.53	212.13	232.51	232.99
Solar PV	136.51	114.27	112.79	114.89	126.84	127.68
Run of river	28.48	28.48	28.48	28.48	28.48	28.48
Lake and reservoir	15.30	15.30	15.30	15.30	15.30	15.30
Nuclear	0	111.35	167.70	182.99	140.42	139.60
Natural gas	740.62	222.60	0	0	0	0
Methanization	0	0	152	152	152	152
Pyro-gasification	0	0	0	0	77	77
OCGT	1.75	2.29	1.04	0.33	0	0
CCGT	208.97	22.70	4.74	0.40	0	0
CCGT with CCS	0	0	8.26	17.66	71.63	71.75
Power-to-hydrogen	40.71	46.34	51.20	52.66	59.04	59.04
Power-to-methane	0	0	16.24	24.14	41.38	41.38
Central HP	151.06	120.16	116.75	123.55	129.42	129.26
Individual HP	79.87	285.205	328.30	326.89	311.46	311.17
Resistive heating	4.37	29.20	20.86	13.29	20.93	21.44
Central boiler	0	0	0	0	0	0
Decentralized boiler	219.30	30.59	0	0	0	0
Light EV	0	3.94	3.97	3.98	4.02	4.14
Heavy EV	0	0	0	0	0	0
Electric bus	0	0	0	0	0	0
Train (electric)	30	30	30	30	30	30
Light ICE	97.92	89.71	89.65	89.63	89.54	89.30
Heavy ICE	56.97	56.97	56.97	56.97	56.97	56.97
ICE bus	6.47	6.47	6.47	6.47	6.47	6.47
Battery	0.55	0.34	0.35	0.40	0.57	0.61
PHS	14.14	20.59	20.30	19.86	17.21	17.42
Gas storage	0	0	25.28	41.99	58.51	58.62
CTES	0.13	31.03	34.44	27.64	21.77	21.93
ITES	8.91	9.72	7.78	8.53	8.90	8.84

Appendix 2. Energy mix for different availability scenarios (1/3)

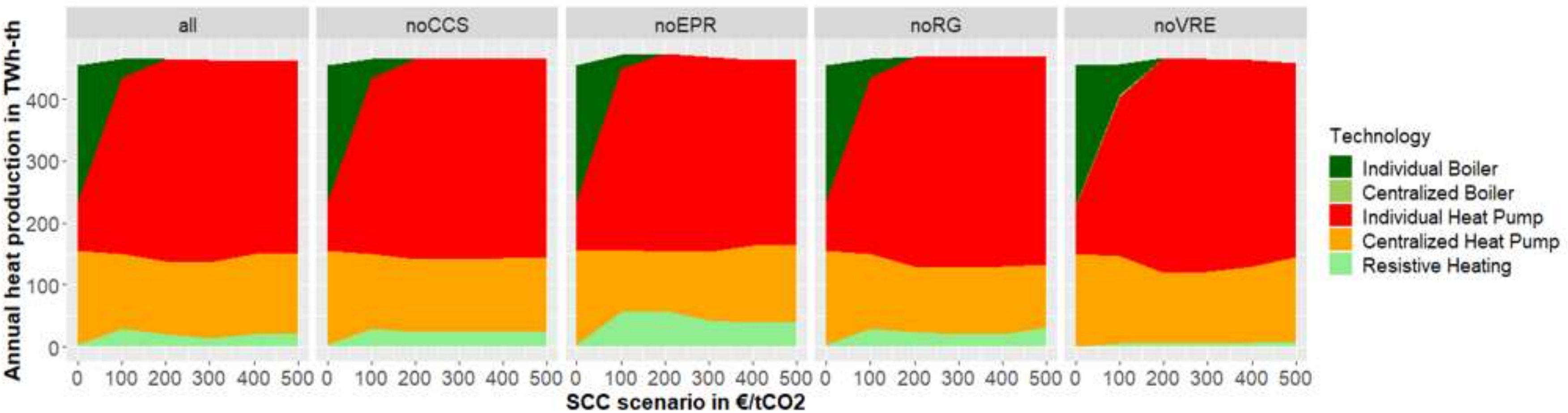


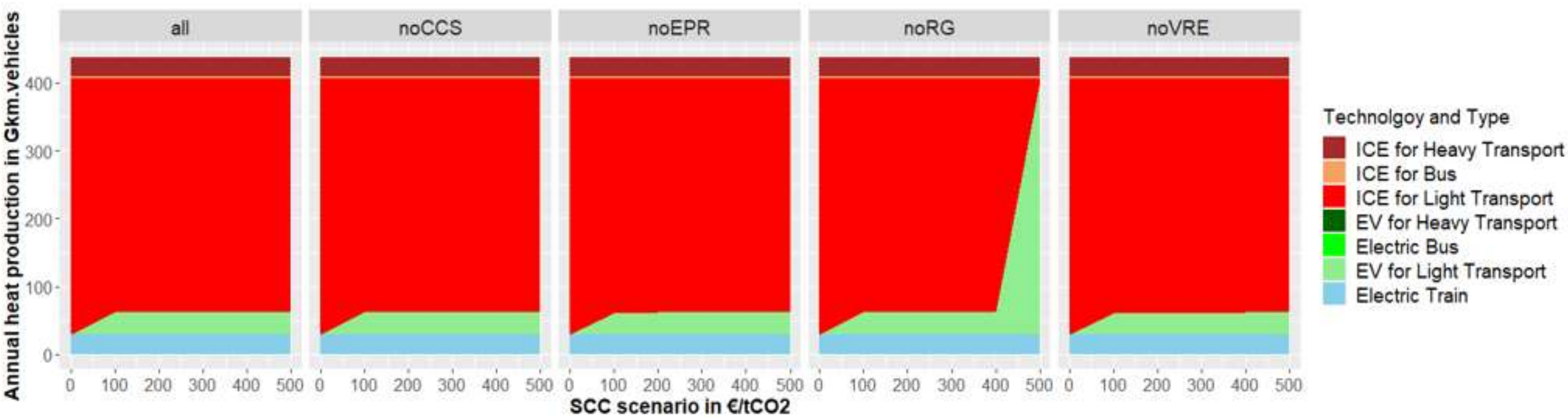
Appendix 2. Energy mix for different availability scenarios (2/3)



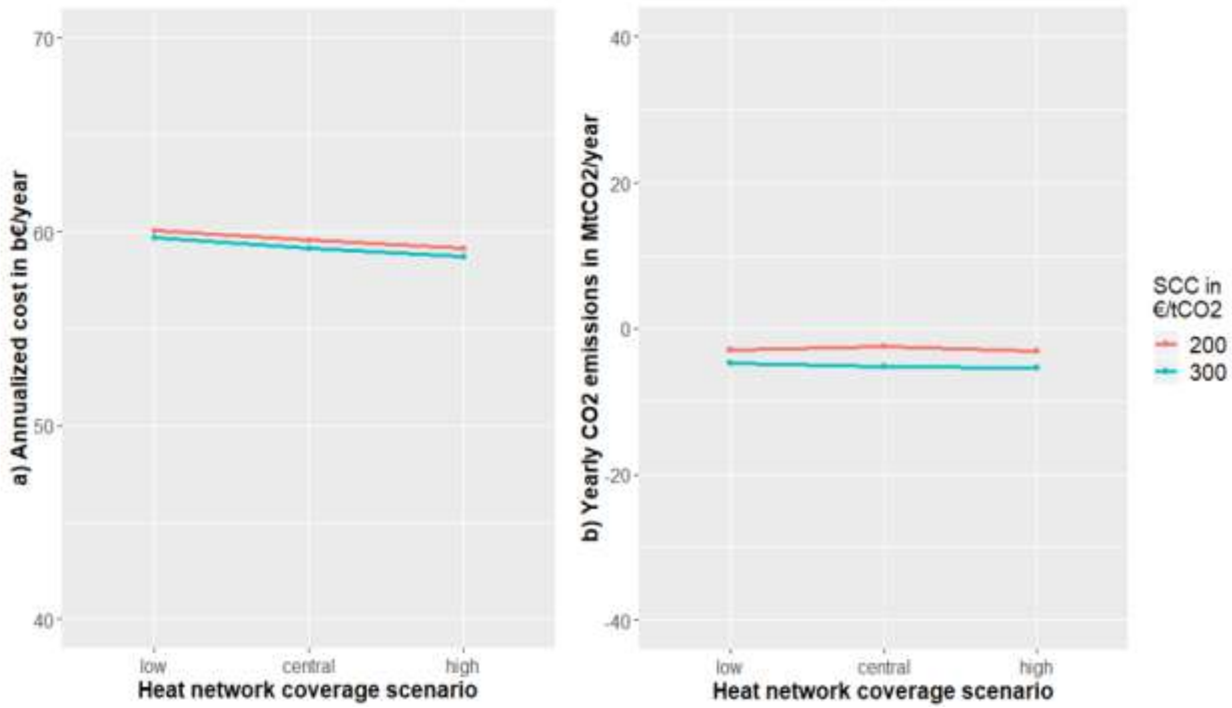


Appendix 2. Energy mix for different availability scenarios (3/3)

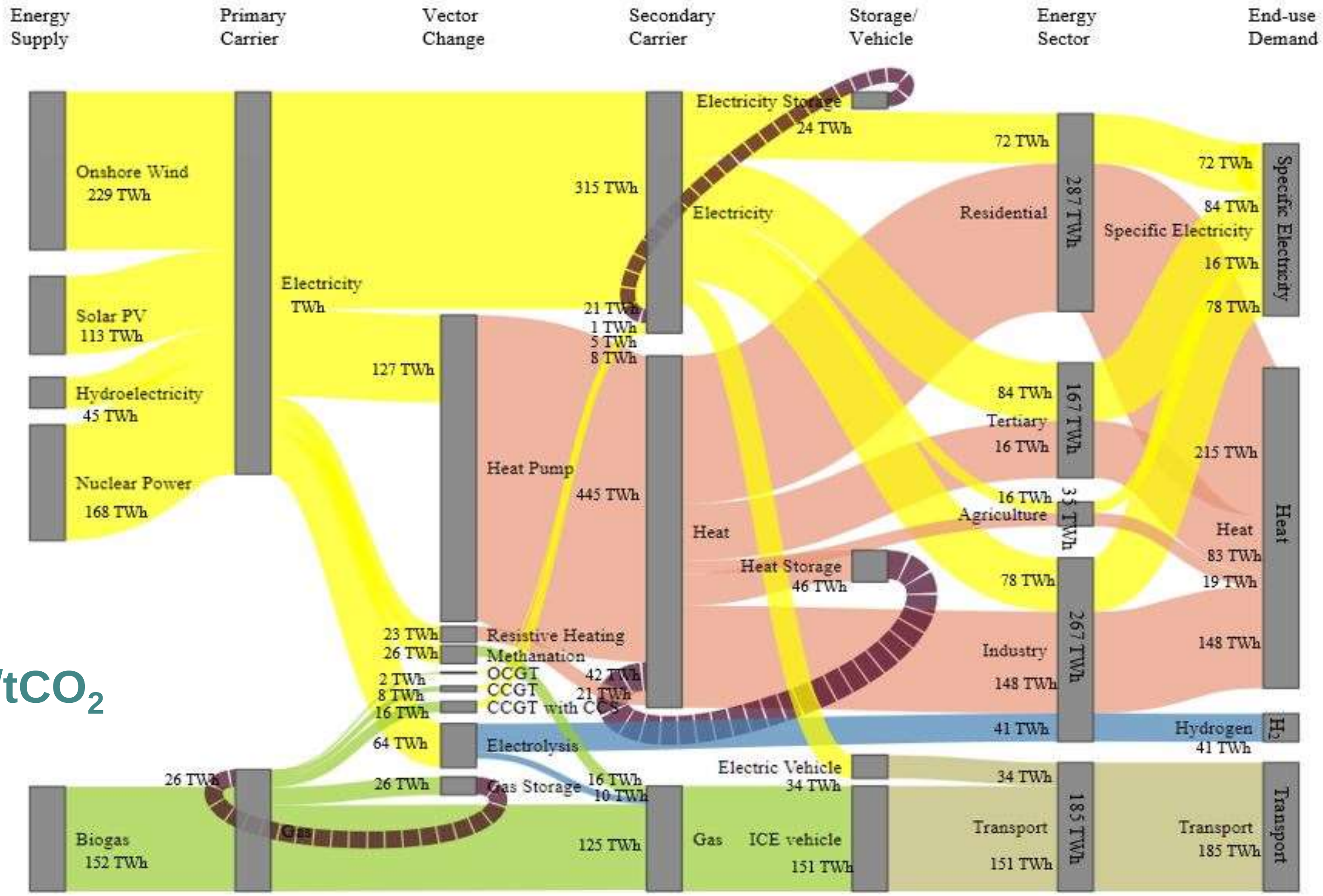




Appendix 3. Sensitivity to heat network coverage



Appendix 4. Sankey flow diagram for SCC of 300€/tCO_2



SCC 300€/tCO_2

Appendix 5. Sankey flow diagram for SCC of 300€/tCO_2 without nuclear power

SCC 300€/tCO_2