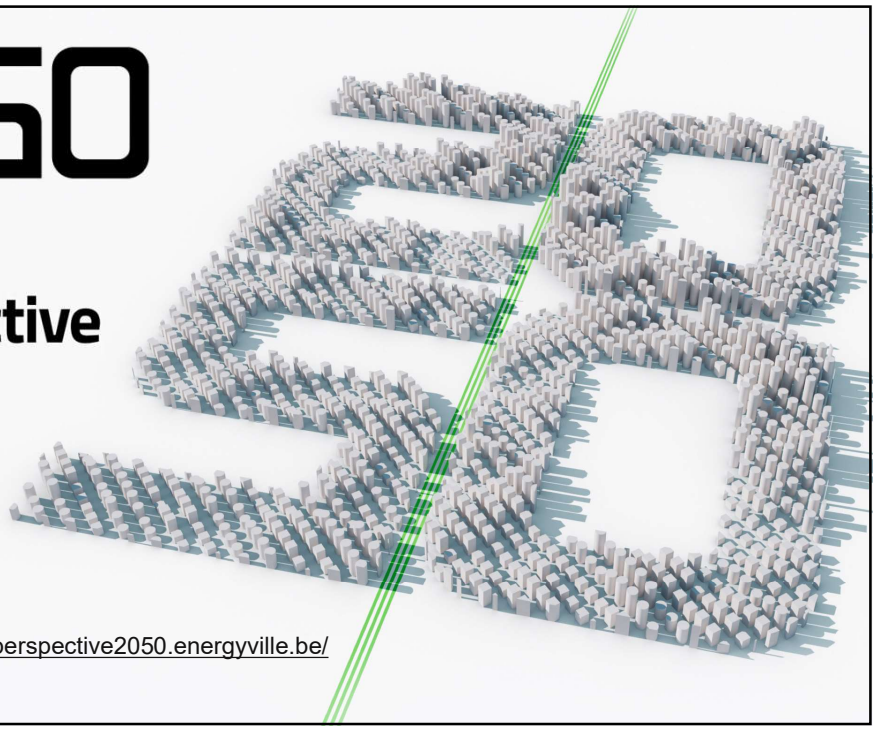
PATHS 2050

The Power of Perspective



https://perspective2050.energyville.be/

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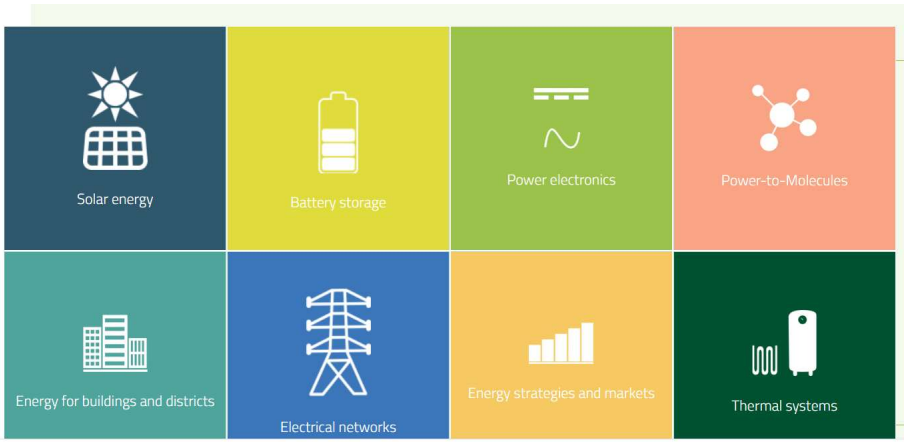
EnergyVille

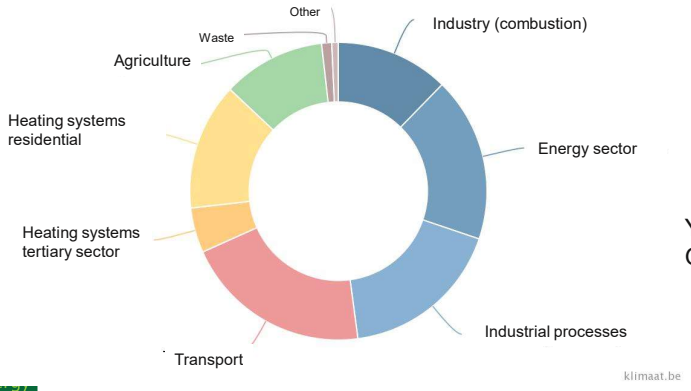
- Energy teams of VITO, KULeuven, Imec and Uhasselt, +/- 500 employees
- www.energyville.be
- Pieter.vingerhoets@energyville.be



2

The challenge in Belgium

Percentage of different sectors in Belgian emissions 2020 (106 Mton $CO2_{eq}$)
Not including emissions for international shipping and aviation



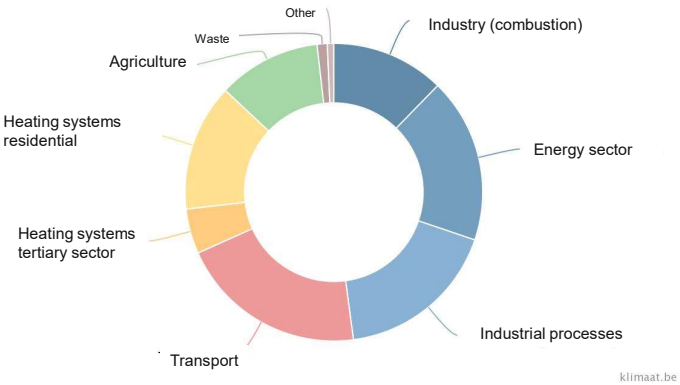
Replace 2GW of nuclear power plants
With natural gas power plants
=> ~5Mton of CO_2,eq emissions extra

Yearly emissions EU: ~ 3.5Gt CO_{2eq}
Global emissions: ~ 40Gt CO_{2eq}

3

The challenge in Belgium and EU

Percentage of different sectors in Belgian emissions 2020 (106 Mton $CO2_{eq}$)
Not including emissions for international shipping and aviation



Energy balance 2019 (TWh)	EU (TWh)	BE (TWh)
Gross available energy	~17000	~750
Energy supply	~16000	~640
Final energy consumption	~11000	~420
Final non-energy consumption	~1000	~84
Final electricity consumption	~2500	~82

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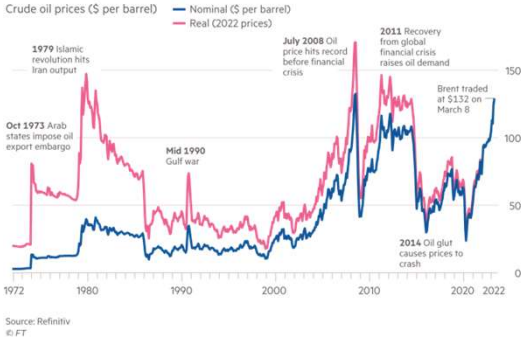
What about 2023-2025?

- Unprecedented energy crisis in EU
- Origin of long-term energy system modelling – IEA ETSAP group and TIMES starts at the first oil crisis, 1978
  - Insights in 2030-2050 will not solve today's problems BUT
  - Will set a clear trajectory to make our energy system more robust

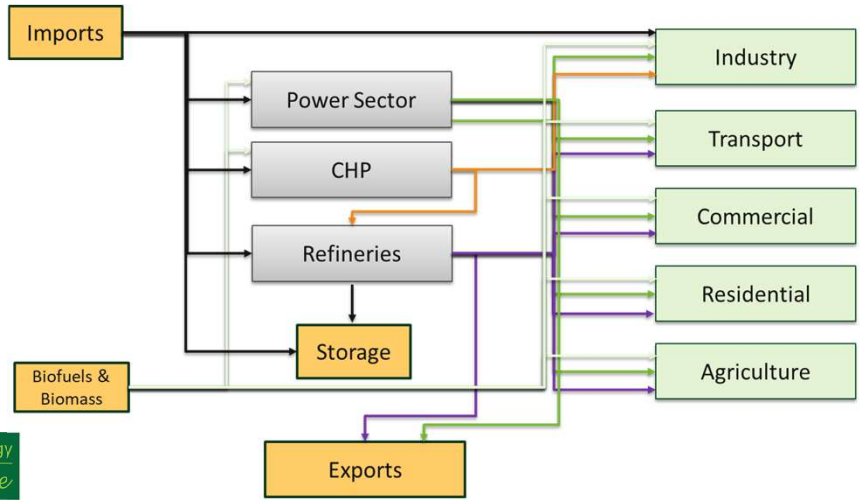
US president Carter: "The oil crisis is the moral equivalent of war".

White House: installed water tank heating solar panels on the roof and a wood-burning stove in the living quarters



TIMES-BE model - simplistic

One large techno-economic **optimization** including all technologies, energy carriers and processes



The EnergyVille TIMES Be model

- Setting a new benchmark
- Most detailed, full system optimization model of the Belgian energy system, to date
  - Cross-vector: covering energy use (fossil fuels, renewables, clean molecules and electricity), feedstock
  - Cross-sector: covering all supply (refineries, power sector) and end-use demand sectors (industry, residential, commercial, transport, agriculture)
  - Cross-border: projected and timesliced import/export cost curves for electricity from other EU countries included, possible import of clean molecules included
- Cost optimization from now to 2050: gives insights into pathways to 2050 with intermediate 2030 milestones
- Reporting on combustion and process scope 1 CO_2 emissions = 85% of Belgian GHG emissions today
  - Scope 2 emissions from imported electricity included but not reported in this project.
  - Bunker fuels for international maritime and aviation sector not included
  - No agricultural CH_4 or N_2O emissions

EPOC

BREGILAB

Procura

economie

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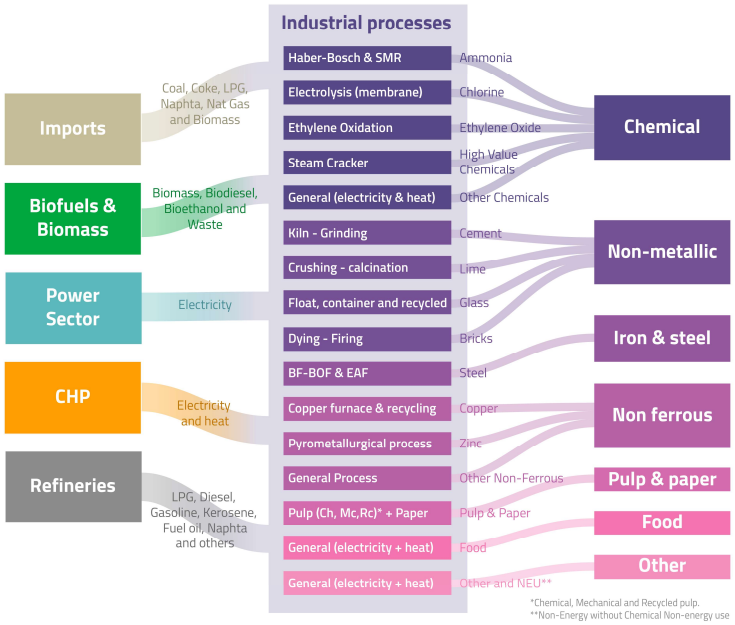
TIMES-BE model: Industrial sector representation



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Offshore North Sea

2050: ~212 GW

- EU countries ambitions 2030 …
- 16 GW Direct access for Belgium

Electricity import

~6.5 GW → 13 GW by 2040

(Source: ENTSO-E)

Carbon Capture Utilization & Storage

- Access to commercial phase?
- How much CC(U)S needed?

Offshore Belgium

>2030 max.: 8 GW

(Source: Fed Gov.)

Industry

Output levels constant to 2050

Refineries cf. EU decrease with 43% in 2050 to 2014

RES techn. Potential

Roof Solar ~104 GW

Onshore ~20 GW

(Source: Bregilab)

Import of Green Molecules

Carrier: H_2, CH_4, CHOH, NH_3

Shipping + pipeline import

(Source: H_2 Import Coalition, Agora EW)

New Nuclear technology

Small Modular Reactors

By 2050, compliant with EU taxonomy

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The 3 storylines

Electrification

- Direct access to additional 16 GW of offshore wind potential
- Allow new SMR technology > 2045

+

Central

- Industrial product demand stable
- Population growth → buildings, transport
- Technical renewable potential: 104 GW rooftop PV, 20 GW onshore, 8 GW offshore wind
- Interconnection from 6,5 GW to 13 GW by 2040
- Set of net-zero options for all sectors
  - Energy efficiency
  - Electrification
  - Clean molecules
  - CCS/CCU options

+

Clean Molecules

- Lower cost range of hydrogen/molecule import
- Limited access to CO_2 storage: 5 Mton/y

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Scenario overview: assumptions

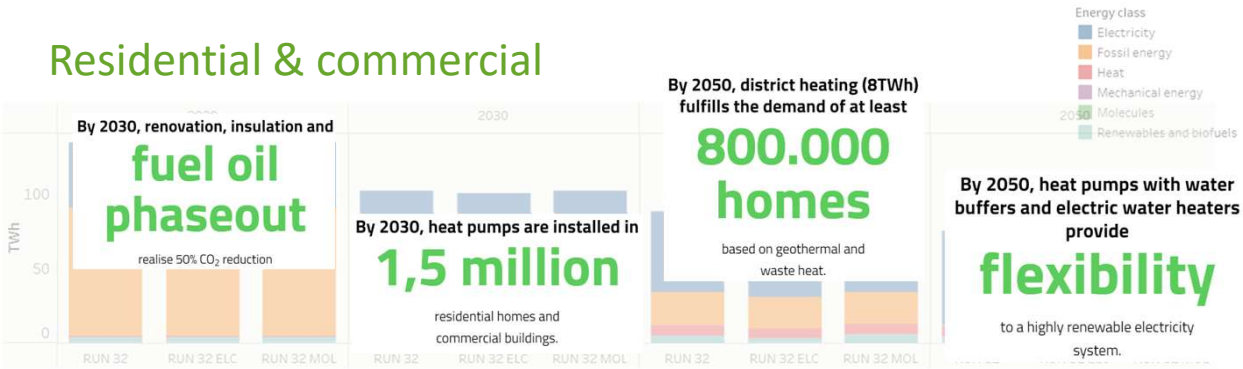
	Central scenario	Direct access to far offshore wind & allow investments in SMR	Decreased cost of molecule import & carbon storage limited to 5 Mton/y
New nuclear (SMR)	No investments in new nuclear possible	***Investment in new SMR possible, in operation >2045 SMR in line with EU taxonomy***	= Central assumption
Offshore	Offshore potential limited to Belgian North Sea: 8 GW Capacity factor 40%	***Investment in direct access to 16 GW far offshore projects possible, capacity factor 60%***	= Central assumption
Carbon capture & storage (CCS)	No limitation on carbon capture & storage	= Central assumption	***Carbon capture process not limited, but limited access to storage potential to 5 Mton/y***
Molecule import	Molecule import at H_2 cost (LCOH) of 2020: 4,5 €/kg (150 €/MWh) 2030: 2,9 €/kg (97 €/MWh) 2050: 2,4 €/kg (79 €/MWh)	= Central assumption	***Molecule import at lower H_2 cost (LCOH) of 2020: 4,5 €/kg (150 €/MWh) 2030: 2,2 €/kg (72 €/MWh) 2050: 1,7 €/kg (55 €/MWh)***

Final energy demand

Electrification & Efficiency improvements go hand in hand

- Final energy demand in 2050 is **28-36% lower** than today depending on the scenario.
- **Fossil fuels** representing more than 70% of the final energy demand in 2020 will decrease and **ultimately phaseout by 2050**.
- **Electrification** plays a pivotal role in achieving the presented **energy efficiency improvements -** more than **doubling** of the current electricity demand
- The role of **clean molecules grows but remains limited** in all scenarios and will represent 11 to a maximum of 14% of the final energy demand in 2050

Residential & commercial



	2020	2030
Final demand	122 TWh	-25 % → 91 TWh
Fossil	80	40 - 44 TWh
Electricity	40	42 – 44 TWh
District heat		
Clean molecules	/	/
CO_2	18 Mton	-50% → 9 Mton

Final energy demand Belgium

Final energy demand decreases by a

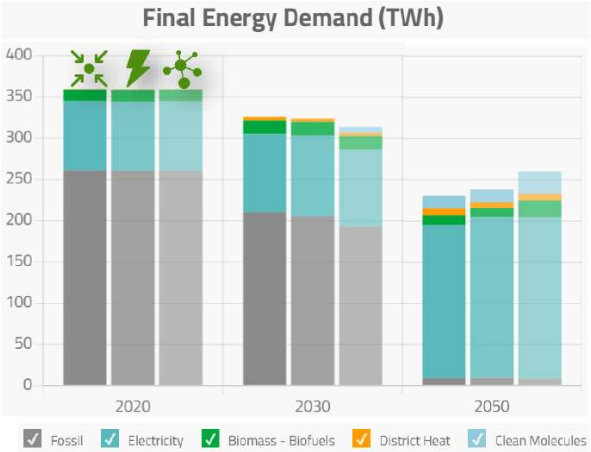
third

regardless of the scenario.

Electricity demand more than

doubles

in the 3 scenarios.



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Residential & commercial

Renovation & electrification

By 2030, renovation, insulation and

fuel oil phaseout

realise 50% CO_2 reduction

By 2030, heat pumps are installed in

1,5 million

residential homes and commercial buildings.

By 2050, district heating (8TWh) fulfills the demand of at least

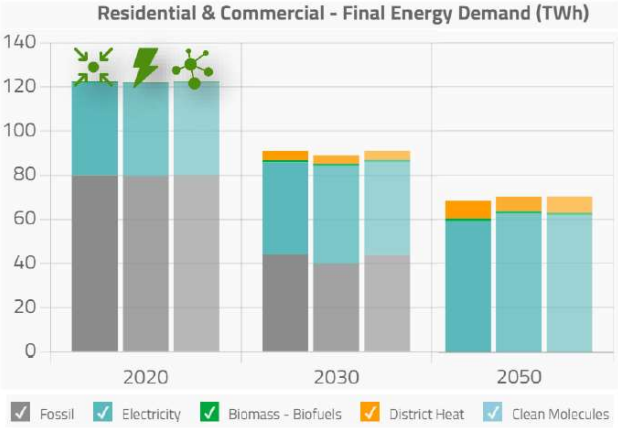
800.000 homes

based on geothermal and waste heat.

By 2050, heat pumps with water buffers and electric water heaters provide

flexibility

to a highly renewable electricity system.



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Residential & commercial

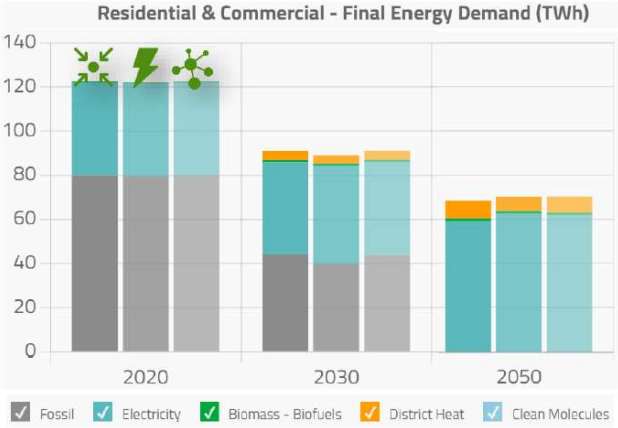
Renovation & electrification

Vision COGEN Europe:

of Europe's energy system. In particular, the market should support the deployment of more decentralised, efficient and flexible ways of generating electricity – including cogeneration technologies that can make the best use of precious renewables like biomethane and clean hydrogen, whilst also capturing valuable heat that can be used locally.

PATHS 2050 model results:

- Heat pumps where possible
- Value negative emissions not included in study
- Aviation sector not included



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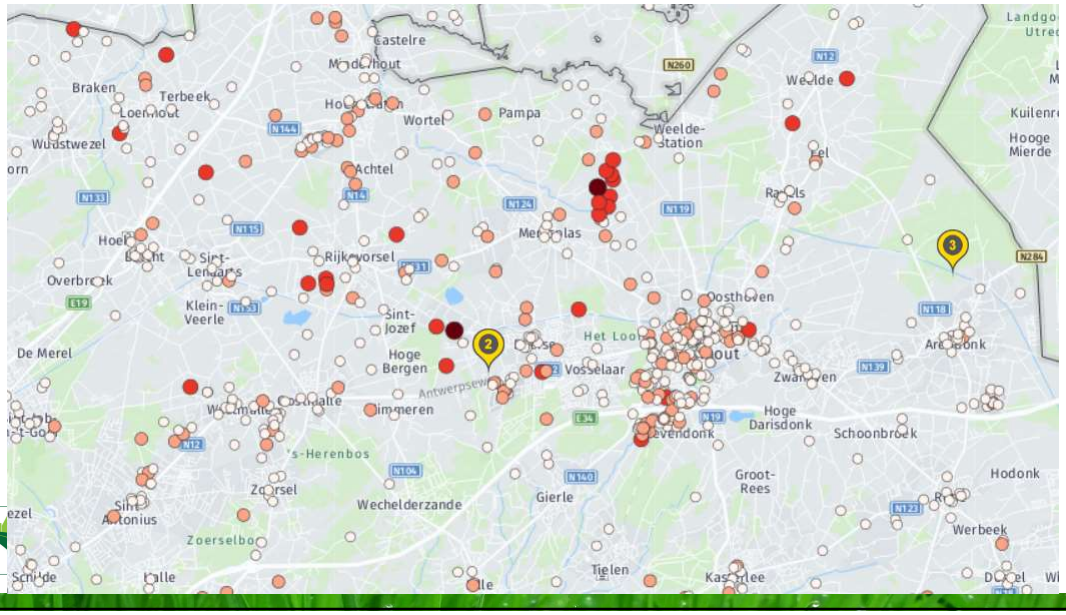
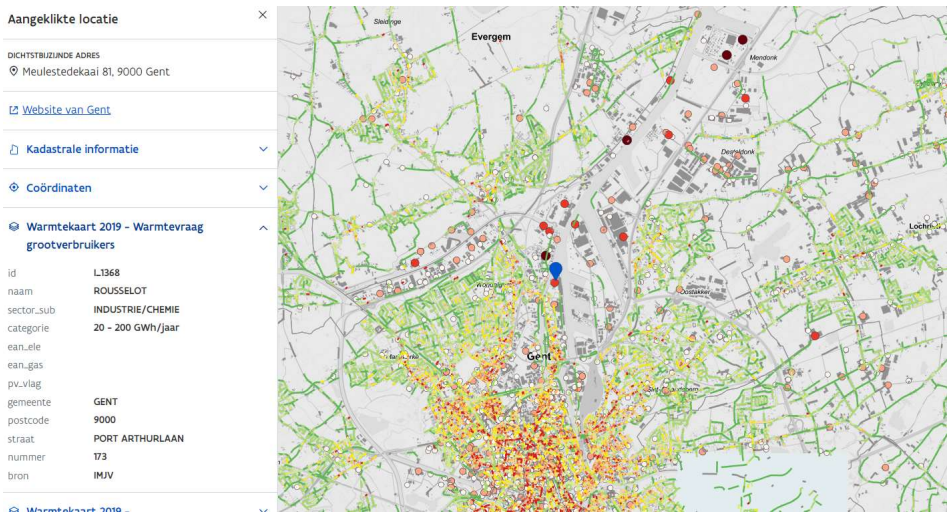
De warmtekaart



Where to build heating grids?

- Public data for Flanders
- Very location-dependent



Publicly available at geopunt.be

Transport

By 2030, investing in more than

2 million

electric person vehicles would be cost effective and puts us on track to net-zero 2050.

By 2050 our road transport is

fully electrified

By 2050, electrification leads to an efficiency improvement of

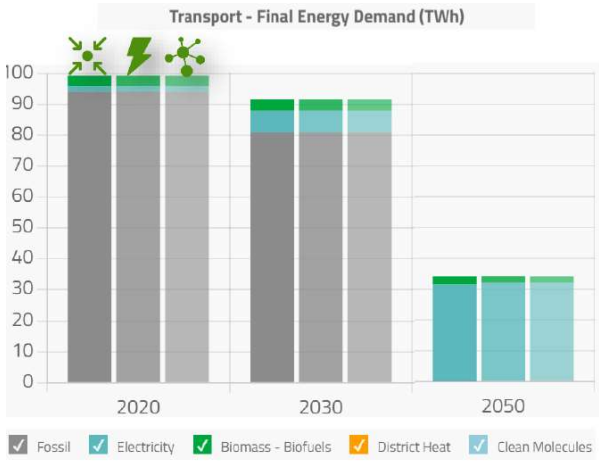
76%

Total energy demand decreases from 100 TWh today to 34 TWh.

By 2050, at least

1,1 million

smart charging stations (average 7,5 kW peak) are needed to provide demand flexibility.



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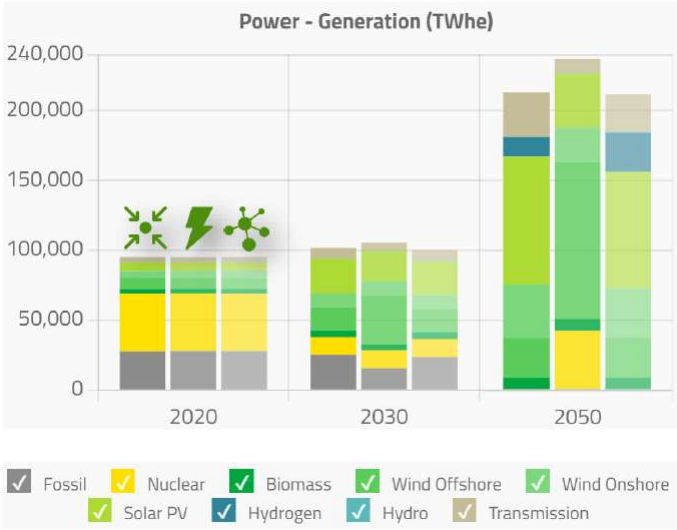
Power sector - Generation

From 2040 onwards the need for

flexibility of demand

grows drastically: smart charging, heat pump with buffers, battery storage, hydrogen electrolysers.



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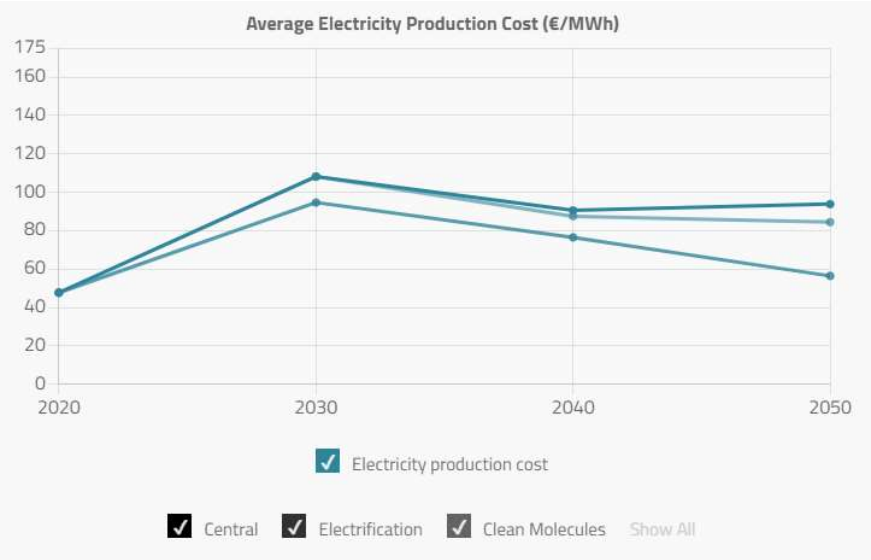
Wholesale price proxy

Access to offshore wind is key!



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Annual Belgian energy system costs

- Extra cost wrt 50EUR/ton scenario
- 1 to 2-4% of current GDP

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Industry – final energy use

Until at least 2030, fossil fuels remain

dominant

in the industry as final energy demand.

By 2050, electrification of industrial processes leads to an increase of

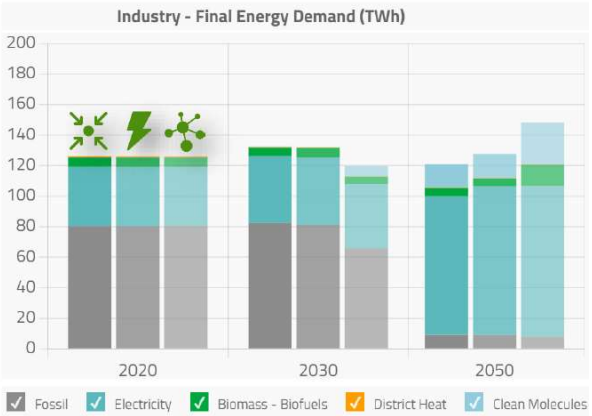
x 2

the current electricity demand in all scenarios.

By 2050, clean molecules amount to

21-25 %

of the final energy demand in industry.



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Industry – CO_2 emissions

By 2030, Carbon Capture and Storage (CCS) removes

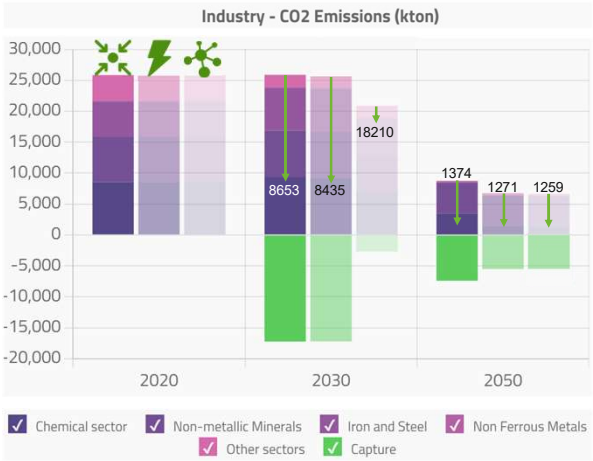
20 Mton

of CO_2 emissions from the atmosphere

By 2050, CCS is limited to

9,4 Mton

and applied in cement, lime, high value chemicals and supply sector.



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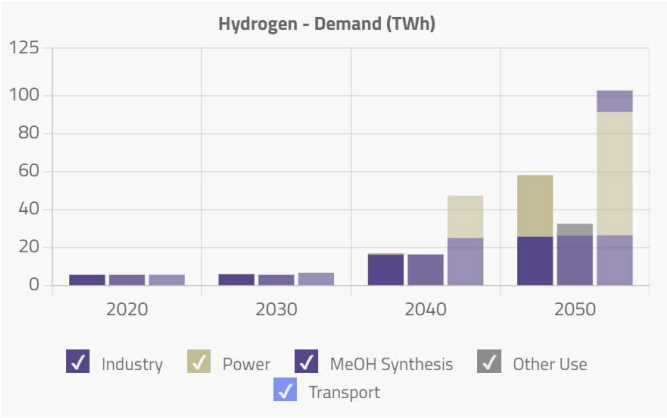
Paths2050: The hydrogen balance

- Industry and power system
- Synthetic fuels for aviation/maritime
- No buildings or road transport



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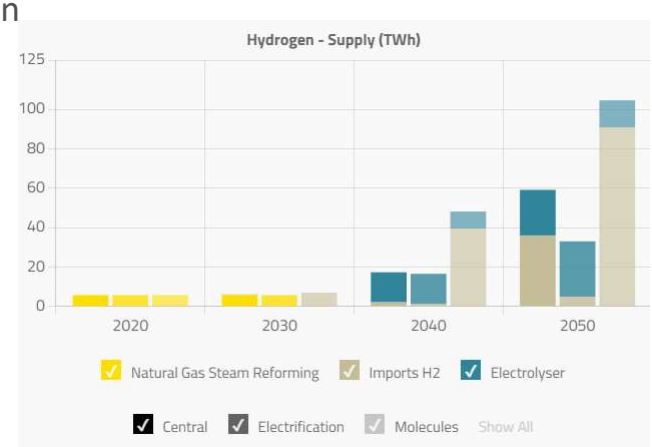
Paths2050: The hydrogen balance

- No upscale of green hydrogen production before 2030
- Blue hydrogen can be an interesting transition phase
- Import should focus on hydrogen derivates such as ammonia



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Taking into account import – export of electricity

- Amount of hours per year with electricity generation cost <40EUR/MWh for electrolysis.

#hours of the year with cheap electricity<40€/MWh for electrolysis	2030	2033	2035	2040	2045-2050
TYNDP 2020 National Trends	1800			4300	
TYNDP 2018/2020, Distributed Generation			1500	4300	
TYNDP 2018 in Denmark (Energynet), GCA			1900	5700	
PBL KEV2021		4334*			
Agora Energiewende	1900*			1757*	1920*
Elia Adequacy and Flexibility**	400-1000				

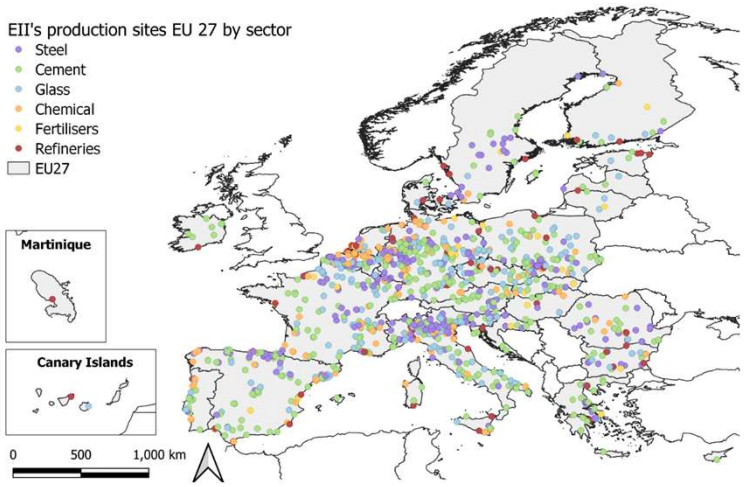
TYNDP results are EnergyVille model based on TYNDP data

*, ** it is unclear how Agora and PBL results are calculated

The TRILATE project: Follow-up project including Elia, Fluxys, TNO and Dechema

AIDRES

WP2: Map industrial sites in the EU27 - RESULT



Sector	#Production sites
Steel	372
Refinery	112
Cement	436
Glass	319
Chemical	258
Fertilisers	39
Total	**1536**

A **production site** is the geographical unit that combines production installations from one sector and specific company in space. E.g., a chemical production site (BASF Ludwigshafen) can group more than 40 production installations from the chemical sector at one site.

19/09/20

Fit-for-55 by 2030 ?

Evaluation limited to CO_2 emissions

- This study does not present policy projection or prognosis
- Belgian CO_2 emissions 1990: **120 Mton** CO_2 emissions excluding net CO_2 from LULUCF
- Central scenario 2030: **52 Mton**
  → **reduction of -57%**

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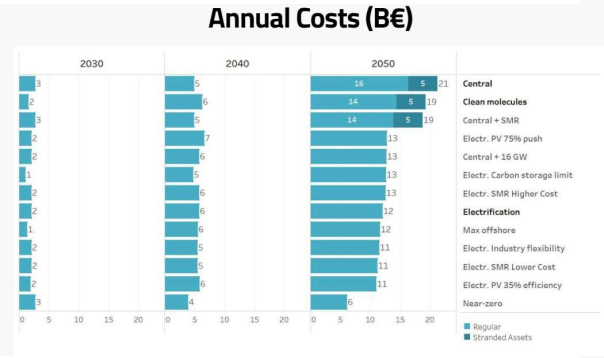
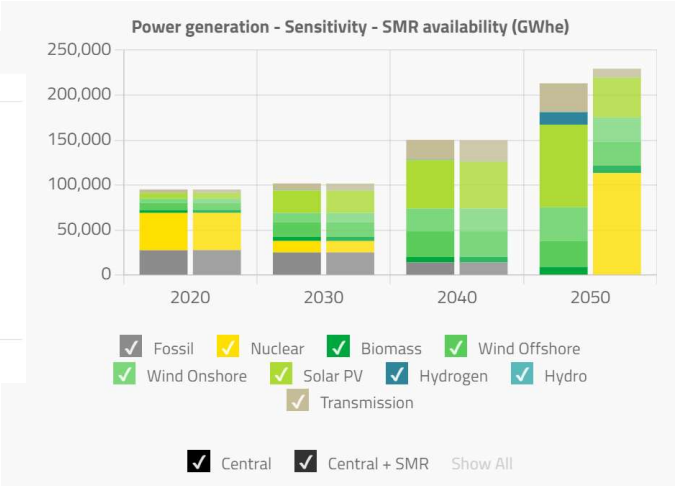
More sensitivities at

www.perspective2050.energyville.be

- E.g. Small modular nuclear sensitivity with no extra offshore wind available





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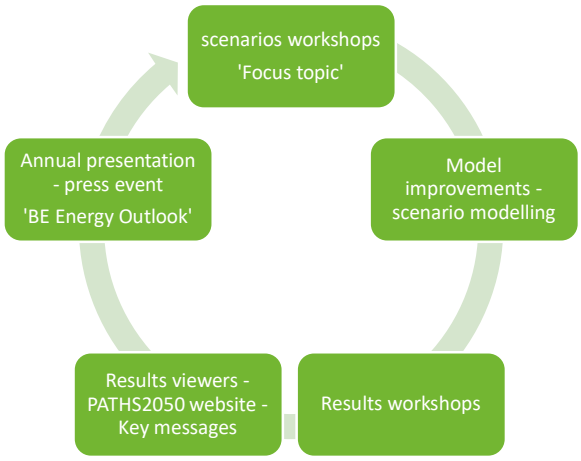
Next steps

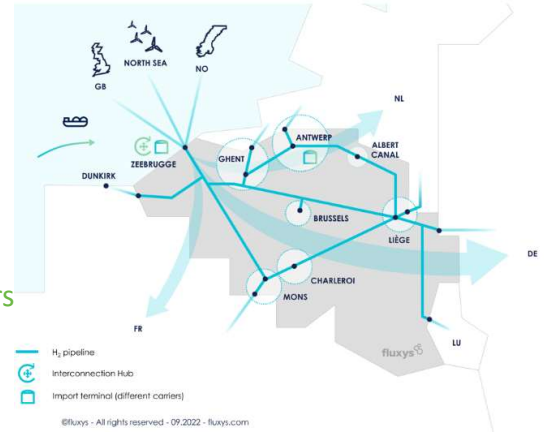
The PATHS 2050 coalition

- 15-20k€/year for membership fee ~4 years
- Scenario definition of simulations
  - Technology driven
  - Impact of (European or national) policy
  - Societal cost optimization
  - …
- Early access to simulation results
- Insight in impact EU legislative packages on cost-optimal investments
- Yearly up-to-date results



Ongoing work: the Trilate project

- Energy Transition Funds
- Process modelling (Uliege)
- Industrial symbiosis (UGent)
- Elia – Fluxys: energy infrastructure needs
- Regionalization of hydrogen demand
- Link with EnergyVille crosssectoral modelling
- Collaboration with Dutch and German partners



Next steps

- Energy infrastructure: we need a fundamental re-thinking of the role of energy infrastructure
  - Follow up project Trilate for long term modelling with Elia and Fluxys
  - Follow up project Cirec on the role of materials and circularity
- Cross-border scenarios: we need to tackle the industrial energy transition in a cross-border way and align scenarios with Dutch and German energy clusters. **Investment uncertainty for industries needs to be reduced**.
- We need to update scenarios constantly with new evolutions
- We need a broad discussion on societal boundary conditions to energy system scenarios. This includes a discussion on human acceptance towards the deployment of infrastructure, and the necessity to retain certain industrial activity in the region. This Paths 2050 study should be the start of such a discussion, and not the end.

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PV1

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Thanks!

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KU LEUVEN vito imec UHASSELT

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Dia 34

PV1 Pieter Vingerhoets; 2/12/2021

Hydrogen

- Amendment 13 and definition of green hydrogen via PPA tips the economic balance towards local hydrogen generation, import via shipping will not be competitive.
- This may strongly interfere with the ambitions of Belgium as a transit hub for molecules and the efficiency of the energy transition as a whole.

Operating hours

Electricity price [€/MWh]	500	1000	1500	2000	2500	3000	3500	4000	4500	5000	5500	6000	6500	7000	7500	8000	8500
0	237	118	79	59	47	40	34	30	26	24	22	20	18	17	16	15	14
2	240	121	82	62	50	42	37	33	29	27	24	23	21	20	19	18	17
4	243	124	85	65	53	45	40	35	32	30	27	26	24	23	22	21	20
6	246	127	88	68	56	48	43	38	35	32	30	28	27	26	25	24	23
8	249	130	91	71	59	51	45	41	38	35	33	31	30	29	27	26	26
10	252	132	94	74	62	54	48	44	41	38	36	34	33	31	30	29	28
12	254	135	96	77	65	57	51	47	44	41	39	37	36	34	33	32	31
14	257	138	99	80	68	60	54	50	47	44	42	40	39	37	36	35	34
16	260	141	102	82	71	63	57	53	50	47	45	43	41	40	39	38	37
18	263	145	105	85	74	66	60	56	52	50	48	46	44	43	42	41	40
20	266	148	108	88	76	69	63	59	55	53	51	49	47	46	45	44	43
22	269	150	111	91	79	71	66	62	58	56	53	52	50	49	48	47	46
24	272	153	114	94	82	74	69	64	61	58	56	55	53	52	51	50	49
26	275	156	117	97	85	77	72	67	64	61	59	57	56	55	53	52	52
28	278	159	120	100	88	80	74	70	67	64	62	60	59	58	56	55	55
30	281	162	123	103	91	83	77	73	70	67	65	63	62	60	59	58	57
32	283	165	125	106	94	86	80	76	73	70	68	66	65	63	62	61	60
34	286	168	128	109	97	89	83	79	76	73	71	69	68	66	65	64	63
36	289	171	131	111	100	92	86	82	79	76	74	72	70	69	68	67	66
38	292	174	134	114	102	95	89	85	81	79	77	75	73	72	71	70	69
40	295	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	84	82	80	78	76	75	74	73	72
42	298	179	140	120	108	100	95	91	87	85	82	81	79	78	77	76	75
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46	304	185	146	126	114	106	101	96	93	90	88	86	85	84	82	81	81
48	307	188	149	129	117	109	103	99	96	93	91	89	88	87	85	84	84
50	310	191	151	132	120	112	106	102	99	96	94	92	91	89	88	87	86
52	312	194	154	135	123	115	109	105	102	99	97	95	94	92	91	90	89
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70	339	220	180	161	149	141	135	131	128	125	123	122	120	118	117	116	115
72	341	223	183	164	152	144	138	134	131	128	126	124	123	121	120	119	118
74	344	226	186	167	155	147	141	137	134	131	129	127	125	124	123	122	121
76	347	229	189	169	158	150	144	140	136	134	132	130	128	127	126	125	124
78	350	232	192	172	160	153	147	143	139	137	135	133	131	130	129	128	127
80	353	234	195	175	163	155	150	146	142	140	137	136	134	133	132	131	130
82	356	237	198	178	166	158	153	148	145	143	140	139	137	136	135	134	133
84	359	240	201	181	169	161	156	151	148	145	143	141	140	139	138	137	136
86	362	243	204	184	172	164	159	154	151	148	146	144	143	142	140	139	139
88	365	246	207	187	175	167	161	157	154	151	149	147	146	144	143	142	141
90	368	249	209	190	178	170	164	160	157	154	152	150	149	147	146	145	144

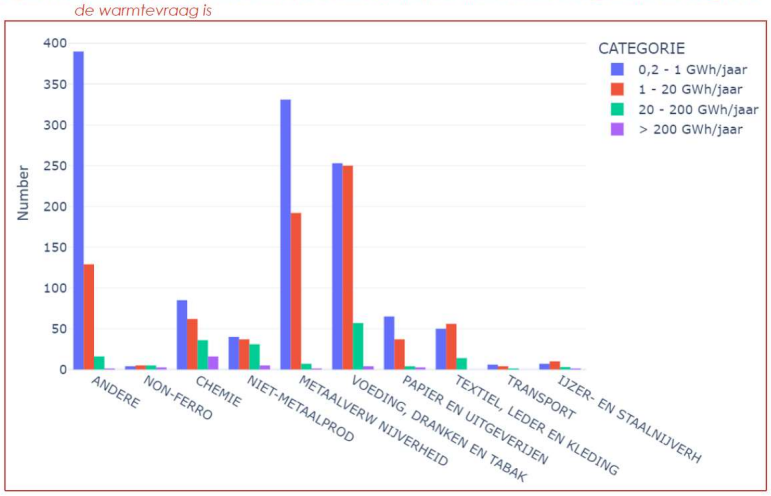
104 €/MW

120 €/MW

- LCOH of hydrogen per MWh using an electrolyser at load hour X and electricity price Y. Source: [illegible] meters from the Future of hydrogen. CAPEX: €700/kWe, OPEX: 1.5% excl. electricity. CAPEX, lifetime: 20 years, return rate: 8%, efficiency: 69% (IEA, 2019). X-axis shows the number of hours an the electrolyser is operating at a given electricity price indicated on the Y-axis. Simulation done with an import price in 2030 of delivered hydrogen of [illegible] €/MWh via ammonia (Agora Energiewende, 2021) and 104 €/MWh via ship from Spain (The hydrogen Import coalition, 2020).

Industry, decarbonizing the heating demand

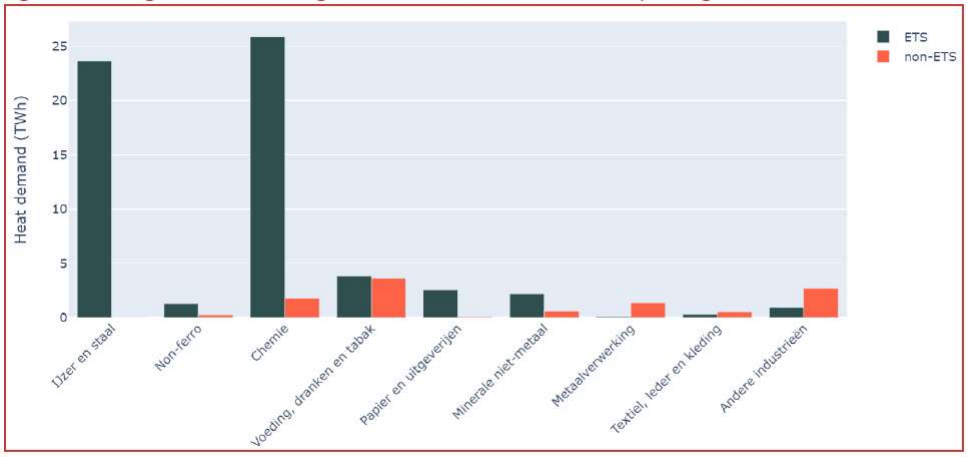
Figuur 4 Aantal bedrijven in Vlaanderen per sector, waarbij een kleurencode aangeeft wat de range van de warmtevraag is



Source: EnergyVille/VITO iov Vlaio: Vergroening potentieel warmtevraag industrie

Industry, decarbonizing the heating demand

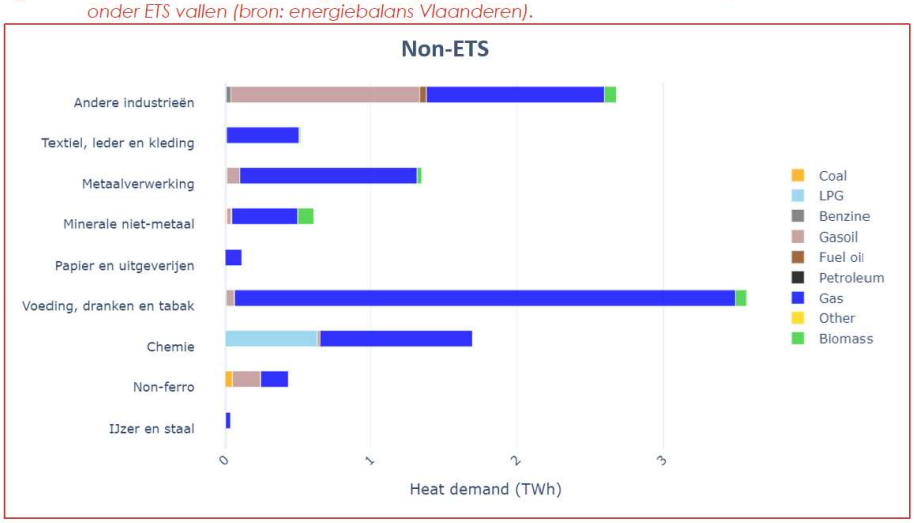
Figuur 5 Nuttige warmtevraag industriële sectoren met uitsplitsing ETS en niet-ETS



Bron: berekening VITO obv energiebalans Vlaanderen 2019 (publieke data Vlaanderen.be)

Industry, decarbonizing the heating demand

Figuur 6 Uitsplitsing van warmtevraag per energiedrager in de industriële sectoren, installaties die niet onder ETS vallen (bron: energiebalans Vlaanderen).



Bron: VITO o.b.v. data energiebalans Vlaanderen

Temperature ranges

T. Naegler *et al.* Quantification of European industrial heat demand

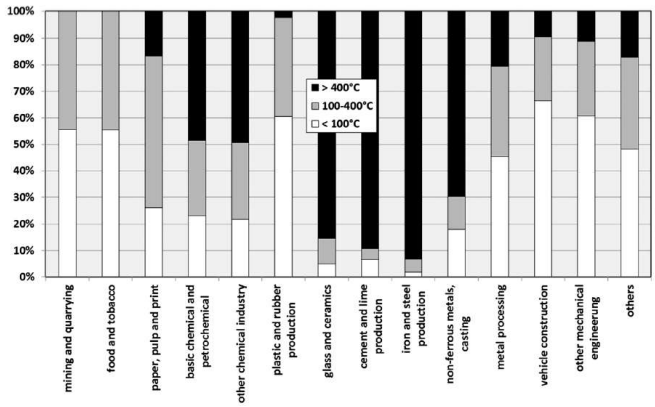


Figure 1. Estimates of the share of temperature ranges in total heat demand (process heat, space heat and hot water) for different industry branches in Germany for 2001 (dataset DS1-1, data source: [26]).

Question

- A waste incinerator produces 400°C steam at 40 bar
  - ⇒ Would you be able to use this steam to replace gas demand? At which temperatures?
  - ⇒ Possibility of valorising excess heat?

https://www.vlaanderen.be/bouwen-wonen-en-energie/groene-energie/warmtekaart

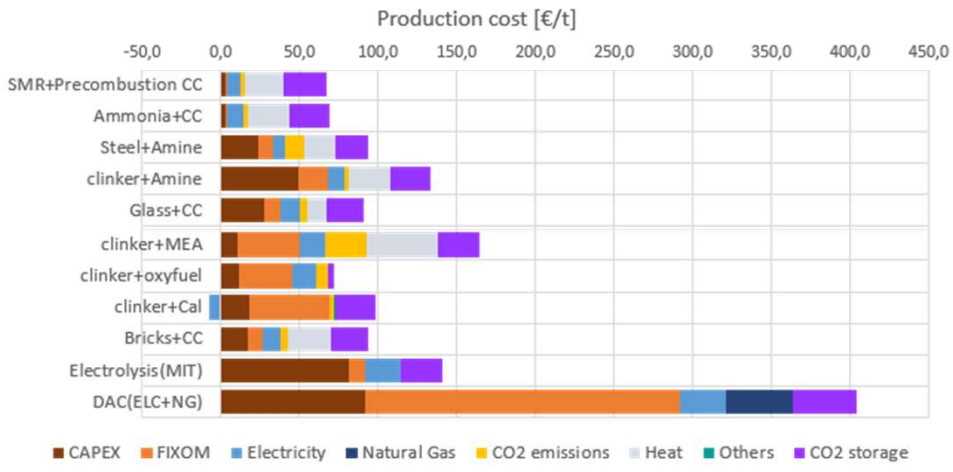
Question

- Heat pump
- Electrolysis
- Heat storage
- …

- Large difference between cost of electrolyser, and cost of the total installation, scarcely covered by literature. Any experience?

Carbon capture technologies

- Different literature based costs based on e.g. purity of CO2 stream



Industry – CO_2 emissions

	2020	2030 – 2050	2030 – 2050	2030 – 2050
CO_2	26 Mton	8,7 – 1,4 Mton	8,4 – 1,3 Mton	18 – 1,3 Mton
CCS		17 – 7,4 Mton Mainly from iron&steel, **high value chemicals, cement/lime** and ammonia production	17 – 5,5 Mton	2,7 – 3 Mton Cement sector
CCU		0 Mton	0 Mton	0 – 2,5 Mton methanol synthesis

Power sector

Renewables to the limits

- **2030**: PV x4, wind onshore & offshore x2 due to growth constraint
  - No regret, in all scenarios
- Central **2050**: total capacity x5 reaching 135 GW, all renewables up to the technical potential in Belgium
  - High flexibility on demand side and behind the meter essential: smart charging, batteries, heat pump with buffers, electrolysers, …
  - 8 GW hydrogen peak plants
- Electrification: +16 GW offshore wind + 6 GW SMR significantly reduces investments in PV capacity, onshore wind and hydrogen peak plants
  - Availability of offshore and 'baseload' reduces need for flexibility
- Clean Molecules: Access to cheap clean molecules has a limited impact on the power sector, increasing the capacity of **hydrogen peak plants** to **12 GW**

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Power sector - Capacity

By 2030, Solar PV capacity needs to increase

x 4

up to >20 GW in all scenarios, to be on track to net-zero 2050.

By 2030, wind onshore and offshore

x 2

as no regret in all scenarios.

By 2050 hydrogen turbines grow to a capacity of

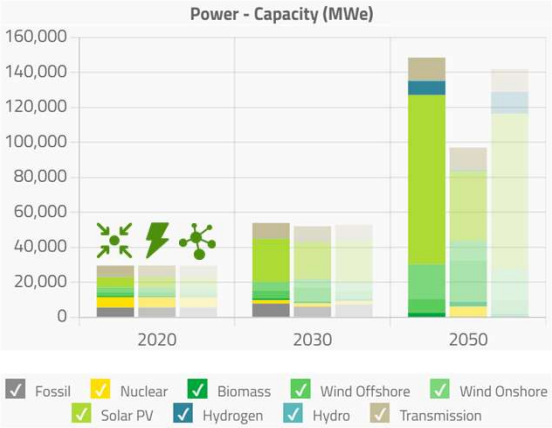
8 GW

in the Central scenario to provide peak power.

By 2050, additional 16 GW offshore and 6 GW nuclear SMR's

halves

investments in solar PV and onshore wind in Belgium.



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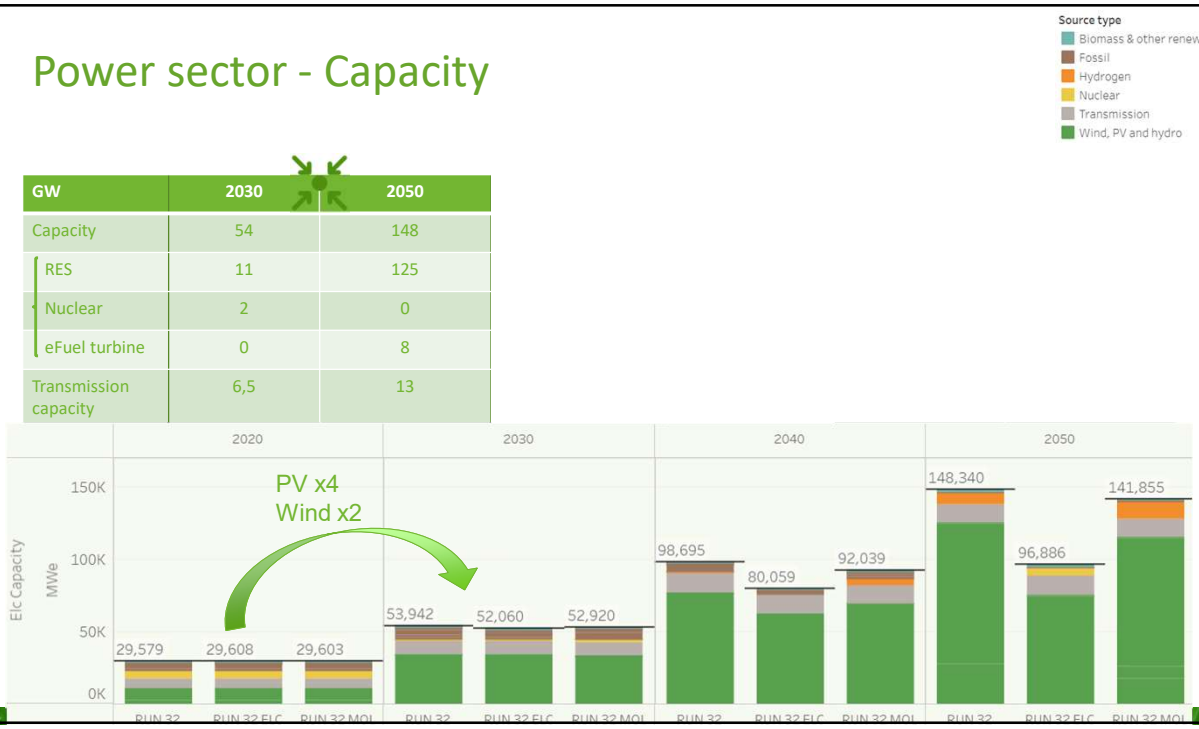
Power sector - Capacity

GW	2030	2050
Capacity	54	148
RES	11	125
Nuclear	2	0
eFuel turbine	0	8
Transmission capacity	6,5	13



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Power sector - Generation

TWh	2030	2050	2030	2050	2030	2050
Generation	95	213	95	237	95	211
RES	19	158	19	**176**	19	148
Nuclear	13	0	13	**42**	13	0
eFuel turbine	0	14	0	**0**	0	**28**
Net import	3,8	32	3,6	**10**	3,7	27

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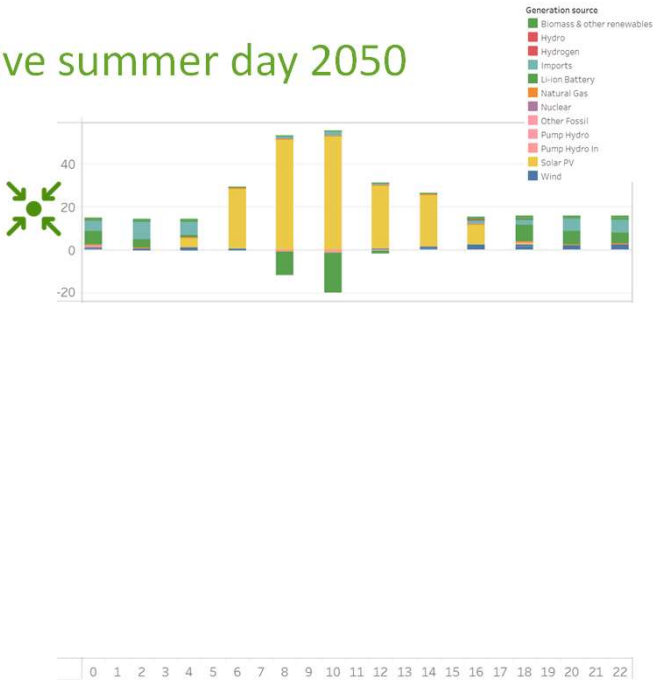
Power sector – representative summer day 2050

Production + storage

- Central
  - PV peak of 55 GW at noon
  - 18,8 GW battery storage
- Electrification
  - PV peak of <25 GW at noon
  - 5,6 GW battery storage
  - Constant 13 GW wind
  - 6 GW SMR during evening
- Molecules
  - Comparable with Central but
  - 13,5 GW battery storage
  - eFuel peak plants during evening



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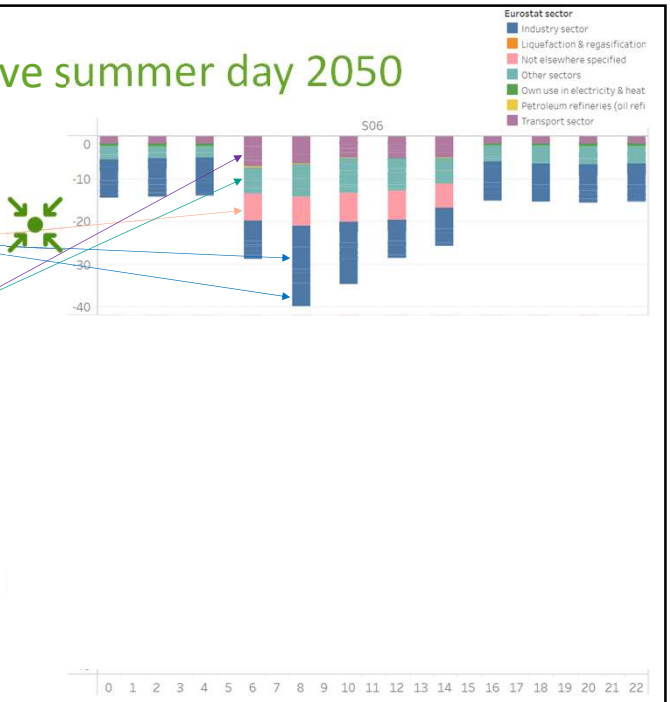
Power sector – representative summer day 2050

Demand sectors

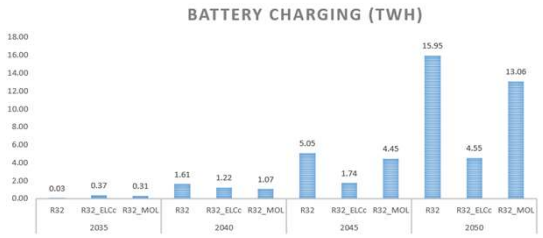
- Central, accommodate noon peak
  - Electrolysers: 13,2 GW (H_2 production)
  - Smart EV charging, water heating
- Electrification, more baseload
  - Electrolyser (8,2 GW) constant production
- Molecules
  - Electrolysers: 10,3 GW (H_2 production)
  - Smart EV charging, water heating

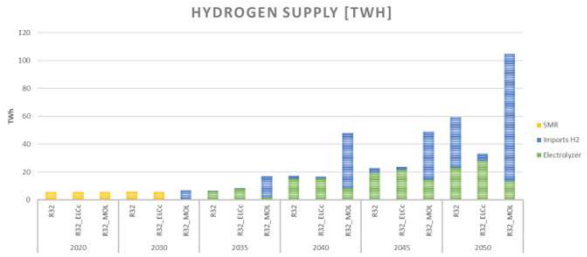


Flexibility needs in the energy system

- Growing from 2040 onwards, by 2050
  - Central: 18,8 GW
  - Electrification: 5,6 GW
  - Clean Molecules: 13,5 GW

- Hydrogen production in Be remains limited
  - Central: 23 TWh Belgian production and 36 TWh import
  - Electrification: Belgian production to 22 TWh and limits the import to 5 TWh
  - Clean molecules: much higher hydrogen demand in the power sector and industry (x2) and lower Belgian production (8 TWh)



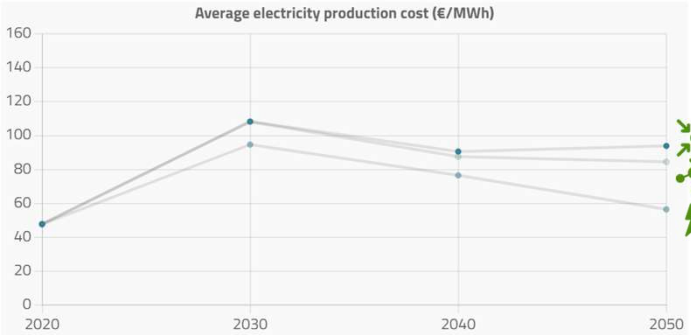


TIMES Be optimizes for the minimal amount of battery capacity needs at national level.
The model does not take local grid issues or short term balancing/frequency control needs into account

Average electricity production cost

Access to more offshore wind and SMR leads to lower production costs

- Central scenario leads to average production costs of 94 €/MWh
- Electrification scenario leads to lowest production cost of 56 €/MWh, mainly realized by 16 GW of offshore wind availability
- Clean molecules scenario leads to slightly lower costs compared to Central scenario of 84 €/MWh



Annual costs to net zero

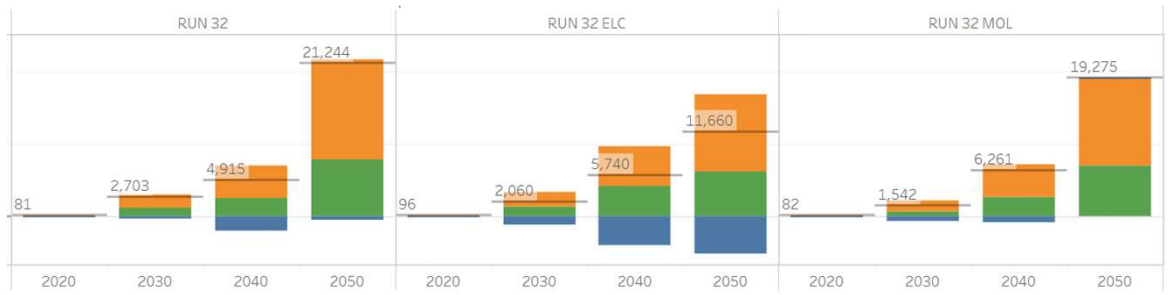
- Compared to a scenario without climate ambition (run at a carbon tax of 50 €/ton from now to 2050), annual cost to reach net-zero amount to
- 2030
  - 2 – 2,7 billion euro to reach a 'Fit-for-'55' compliant reduction
- 2050
  - Central: + 21,2 billion euro
  - Electrification: + 11,7 billion euro
    - Saving on electricity and hydrogen import, flexibility options (smart charging, batteries) and faster electrification of freight transport
  - Clean Molecules: + 19,3 billion euro

Annual costs per period

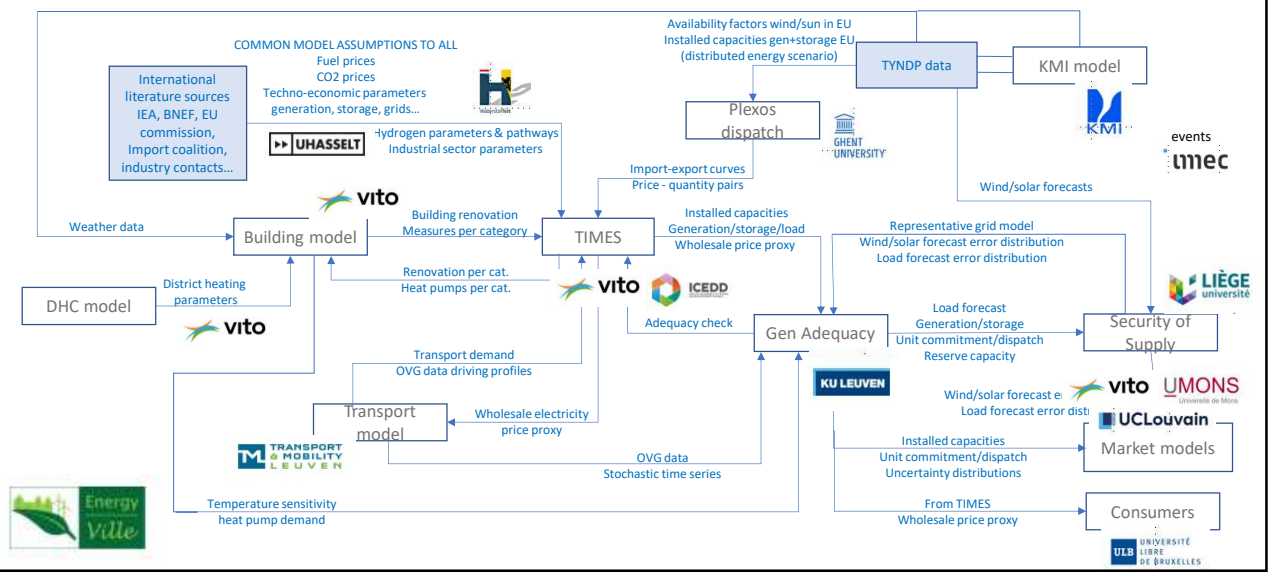
Comparison with scenario without net-zero Climate ambition

- Sum of the undiscounted, annual depreciation of investments, operational costs and imported clean fuels/electricity minus the costs of avoided fossil fuel imports
- From 50 €/ton → Net zero ambition leads in 2050 to annually
  - + 13,9 b€ annualized investments
  - + 7,8 b€ operational costs

} 2 - 4 % of Belgian GDP (2021)



EPOC: linking Model interactions



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Scenario overview table

	Unit	2030			2050		
Capacity	**GW**	**46.07**	**44.17**	**45.00**	**135.17**	**83.54**	**128.77**
Renewables	GW	35.53	35.37	34.95	126.30	76.69	115.67
Fossil	GW	7.86	6.10	7.39	0.15	0.17	0.19
Other	GW	2.68	2.70	2.66	8.72	6.68	12.91
Nuclear	GW	2.00	2.00	2.00	0.00	5.97	0.00
Other plants	GW	0.68	0.70	0.66	0.70	0.71	0.68
e-Fuel/H2 turbines	GW	0.00	0.00	0.00	8.02	0.00	12.23
Imports	GW	8.88	8.88	8.88	13.03	13.03	13.03
Storage (pumped hydro + batteries)	**GW**	**1.15**	**1.15**	**1.15**	**19.91**	**6.76**	**14.69**
Emissions	MtCO2eq	**12.67**	**9.61**	**12.07**	**0.39**	**0.39**	**0.39**
Energy balance	TWh						
Net imports	TWh	7.47	5.66	7.69	31.68	9.83	26.80
Demand	TWh	95.99	98.67	94.49	203.75	220.49	201.69
Losses and own consumption	TWh	5.84	6.83	5.69	9.33	16.29	9.76
Generation	TWh	94.36	99.84	92.48	181.40	226.95	184.64
Average ELC price	€/MWh	**108.24**	**94.67**	**108.15**	**93.86**	**56.49**	**84.49**

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Dia 55

PV1 Pieter Vingerhoets; 2/12/2021