VOLTA CHEM

Electrification of the Chemical Industry

Deep decarbonisation of the Dutch heavy industry through electrification of the production of basic materials and transportation fuels

Toon van Harmelen, Clemens Schneider, Yvonne van Delft, Robert de Kler, Mathieu Baas, Vincent Kamphuis

Powered by: TNO innovation for life, ECN, Wuppertal Institute for Climate, Environment and Energy

Key Findings

- Three what-if electrification scenarios demonstrate that reduction of life cycle CO_2 emissions to near 0 in 2050 is technically possible;
- Required renewable electricity potentials are large: 1,5 – 2,5 times the Dutch North sea wind energy potential;
- Life cycle CO_2 emissions of heavy industry and transport are comparable to total Dutch GHG emissions (219 Mt CO_2 eq);
- Two scenarios, All electric and Big on hydrogen, show possibilities for fossil fuel independence. The Competition scenario shows the possibilities while relying partly on conventional technology with CCS;
- Each scenario needs its own infrastructure with its challenges;
- A favourable scenario is likely a combination.

Content

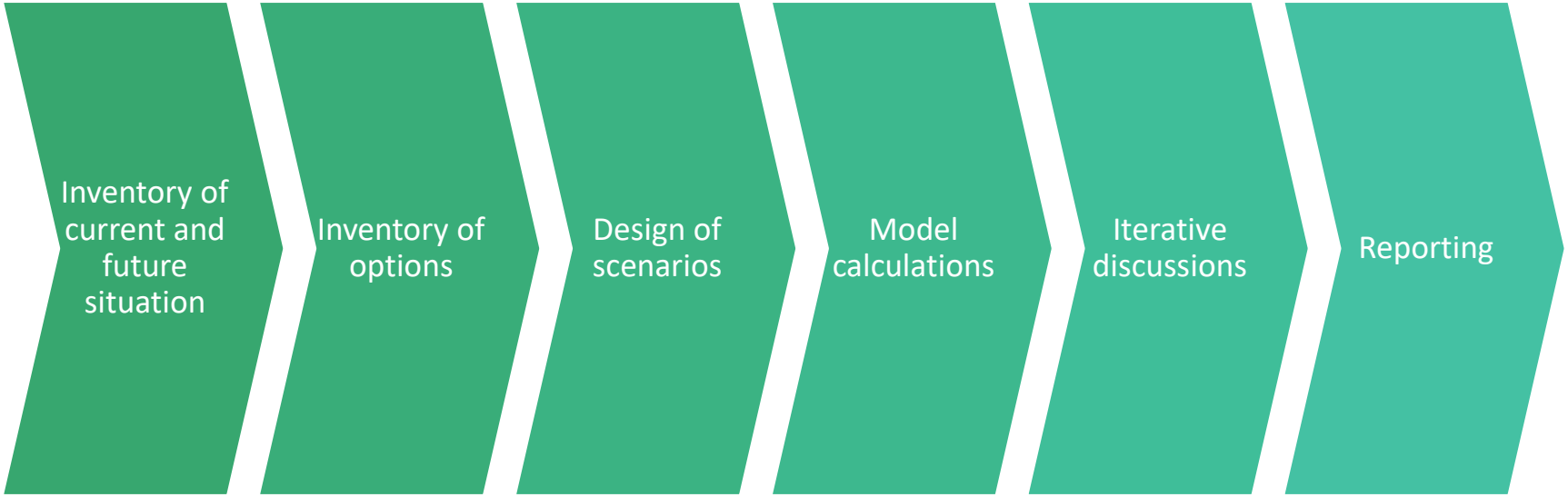
- Objective
- Approach & model set-up
- Methodology & assumptions
- Three what-if electrification scenarios
- Results
- Conclusions & recommendations

Objective

To explore deep decarbonisation scenarios for the demand of the Dutch heavy industry in 2050, through electrification of the production of basic materials and transportation fuels

- identify the technical feasibility,
- required feedstock and energy potentials and
- pros and cons of different electrification pathways

Approach


Inventory of current and future situation
Inventory of options
Design of scenarios
Model calculations
Iterative discussions
Reporting

Model set-up

Input

- Production levels of basic materials, fuels, food and paper (2010, 2050)
- Production technology (2010, 2050)
- Energymix (2010, 2050)
- Carbon resources

- *Renewable energy potential*

Calculation model

Output

- Energy demand of production process (electricity, H_2, syngas/FT-naphta)
- Feedstock demand (carbon and fuel) of production process (H_2, CO_2, syngas/FT-naphta)
- Direct CO_2
- Indirect CO_2

Parameters

- Energy/production [TWh/Mton]
- Feedstock/production [TWh/Mton]
- Direct CO_2/production [Mton/Mton]
- Indirect CO_2/production (energy, carbon feedstock, combustion of fuels, end-of-life) [Mton CO_2-eq/Mton]

Based upon: Decarbonising the energy intensive basic materials industry through electrification - Implications for future EU electricity demand, Stefan Lechtenböhmer et al (2015, Wuppertal Institute & Univ of Lund)

Methodology & assumptions

- Life cycle CO_2 to 0: direct fossil based CO_2 emissions at production, use phase, end-of-life of products (also of exports)
- What-if electrification scenarios sketching three distinct technology based pathways
- Modest volume growth, no structural changes ("High growth" scenario from Prosperity & environment, CPB/PBL 2015)
- Using North Sea wind power potentials, incl. 23% battery storage losses for maintaining security of supply:
  - NL: 34 GW ~ 130 TWh (PBL, 2011)
  - North Sea: 250 GW ~ 1000 TWh (Energy Odessey)
  - 90% one-way battery efficiency (projected battery efficiency, TNO 2018)

Domestic use and export

- Currently, refineries and chemical industry produce approximately ¼ for the domestic and ¾ for foreign markets;
- In scenarios for 2050, the chemical industry is assumed to maintain its production of mainly plastics for the foreign market;
- In scenarios for 2050, transport fuel for export and international bunkers (navigation and aviation) is assumed to be disappeared (electricity, hydrogen or biomass is not supplied from the Netherlands);
- For a clear analysis, the same assumption is applied for both the current situation as the 2050 scenarios.

Three what-if electrification scenarios

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Scenarios: leading indicators

	Low political driver	High political driver
High technical driver	***"competitive transition"*** A lot of debate on climate and GHG emissions Renewable and fossil technologies compete on a financial basis Public opinion, NGO's and visionary companies (big brands) drive the change	***"revolutionary transition"*** Climate and GHG link is accepted Strong political actions: CO2-tax, fuel excise, car tax, subsidies for R&D, Capex and write-off. Governments lead the change
Low technical driver	***"no transition"*** Climate change and GHG reduction will be disputed No carbon tax Offshore wind projects will peter out No investment in transnational grids Paris targets will not be met Fossil carbon will become scarce over time, prices will go up	***"painful transition"*** Climate change and need for CO2 reduction are not disputed There is carbon tax Offshore wind and solar projects will require subsidies Energy expensive, economic growth suppressed, political struggles Technology Investments driven by CO2-reduction per dollar invested)

Scenario All electric & Big on hydrogen

Current situation

Scenario Competition

This study: Deep decarbonisation

Port of Rotterdam Sustainability activities

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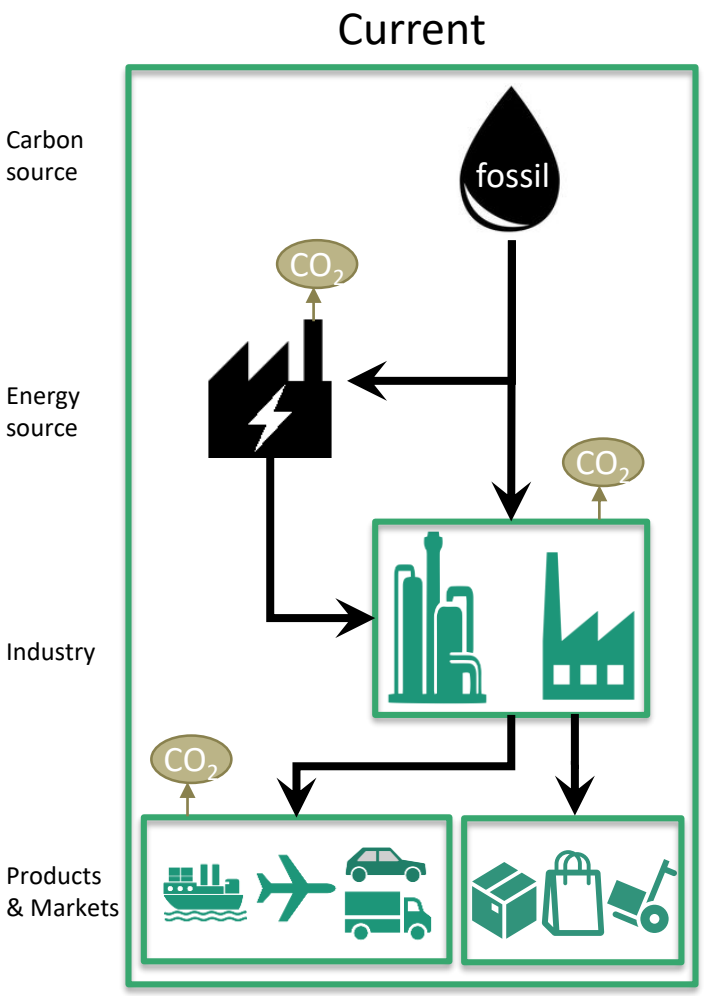
Indicators give insight in the transition process towards electrification. Based on the TNO study "Electrification options for the Port of Rotterdam", a case study for Smart Port by Robert de Kler et al. 2017

Current situation



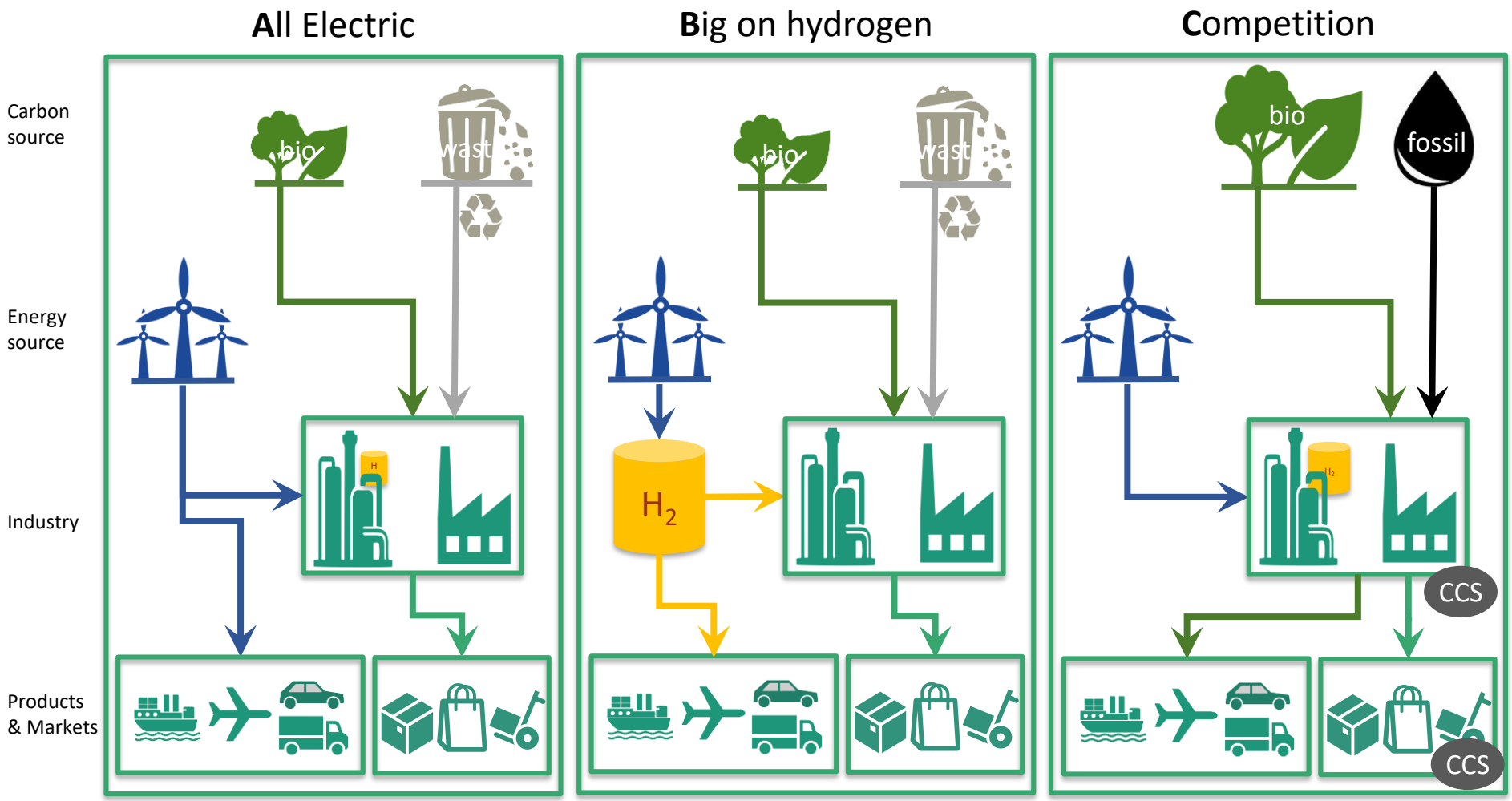
Products

- Basic Chemicals
  - Olefins
  - Ammonia
  - Chlorine
- Metal
  - Iron & steel
  - Aluminum
- Food
- Minerals
  - Glass & ceramics
  - Cement
- Paper & pulp

Transport Fuels

  - Road Transport
  - Aviation
  - Navigation

What-if scenarios A, B and C



What-if scenarios: Three distinct technological pathways

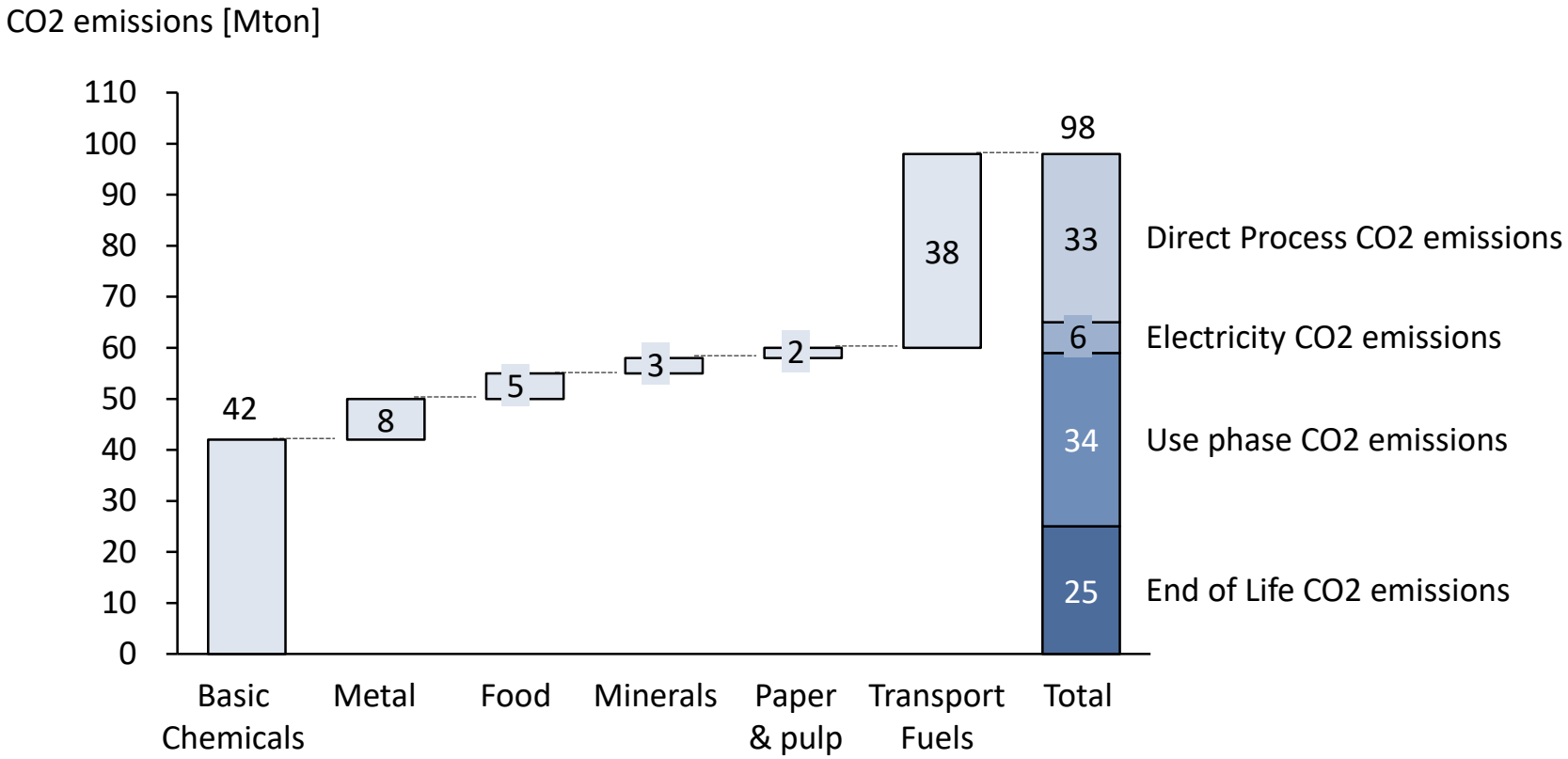
Scenario	Current situation	A. All electric	B. Big on hydrogen	C. Competition
Short description	**Production is largely fossil based**	**Renewable electricity as energy carrier in industry and transport.** Maximal direct electrification with storage issues. Refineries are closed	**Hydrogen as final energy carrier for transportation and industry,** produced with conversion losses by renewable electricity**.** Refineries are closed. Add H2 infrastructure	**A mix of energy carriers, renewable electricity (indirect electrification, hydrogen), fossil fuels with CCS and bio(syn)fuels.** Add CO2 infrastructure
Carbon source and CO2 emissions	Fossil based energy and feedstock, **high CO2 emissions**	Partly closed carbon cycle, waste & bio (growth) used as feedstock (olefins), **near zero CO2 emissions**	Partly closed carbon cycle, waste & bio (growth) used as feedstock (olefins), **near zero CO2 emissions**	Crude oil for olefins and coal for steel combined with CCS; scarce bio based synfuels used for transportation and small sectors, **near zero CO2 emissions**
Leading stakeholders	Gas and petrochemical industry	Power sector (DC grid)	Gas sector (H2 grid)	Petrochemical industry and others
Demand projection	Product and service demand projections are from the PBL scenario high growth, combined with assumed high energy efficiency improvements up to a factor 2			

Technological options by subsector and scenario

Sector	Subsector	Product	Processes			
			Current situation	**A. All electric**	**B. Big on hydrogen**	**C. Competition**
Basic chemicals	Olefins (High Value Chemicals)	Ethylene, propylene, other	Current crude oil based processes	Bio (for export) and waste (domestic) based MTO/MTA are used for olefin production	Bio (for export) and waste (domestic) based MTO/MTA are used for olefin production	Use crude oil refining and naphta and gasoil steam cracking and residue gasification via MTO to produce olefins/aromatics (CCS waste incineration)
	Chlorine		Current electrical process	Current electrical process	Current electrical process	Current electrical process
	Ammonia	Fertilizer	Current natural gas based processes	Direct electrical ammonia synthesis	Indirect electrical ammonia synthesis via H2	Current gas based, decarbon electricity + CCS
Transport	Freight road	Diesel	Combustion engines	Electric vehicles	H2 fuel cells	Biobased syndiesel or OME
	Passenger road	Gasoline, diesel, CNG and electricity	Combustion engines	Electric vehicles	H2 fuel cells	Biobased syndiesel or OME
	Aviation	Kerosene	Combustion engines	Electric airplanes	H2 fuel cells	Biobased kerosene
Oil refinery	Basic chemicals		Crude oil refining	None	None	Crude oil for feedstock
	Fuels		Crude oil refining	None	None	None
Metal	Iron & steel:	Primary steel	Blast oxygen furnace	Electrowinning	Direct reduction H2 + EAF	HISARNA or TGR + Carbon Capture
		Secondary steel	EAF, Secondary steel from scrap	EAF, Secondary steel from scrap	EAF, Secondary steel from scrap	EAF, Secondary steel from scrap + CCS
	Aluminium		Current process	Current process	Current process	Current process
Minerals	Glass	Container glass, flat glass, glass fibre	Current processes	Electric oven	H2 oven	Synthetic CH4 oven + CCS
	Cement	Cement	ENCI	None	None	None
	Lime	Lime	No lime production	None	None	None
Food		Milk powder, potato & sugar represent sector	Steam boilers	Heat pumps + compression + HT storage, breakthroughs	Heat pumps + compression + H2/fuel cells, fuel mix change	Biogas BAT, decarbon electricity
Paper & pulp		Paper	Steam boilers	Heat pumps + compression + HT storage, breakthroughs	Heat pumps + compression + H2/fuel cells, fuel mix change	Biogas BAT, decarbon electricity

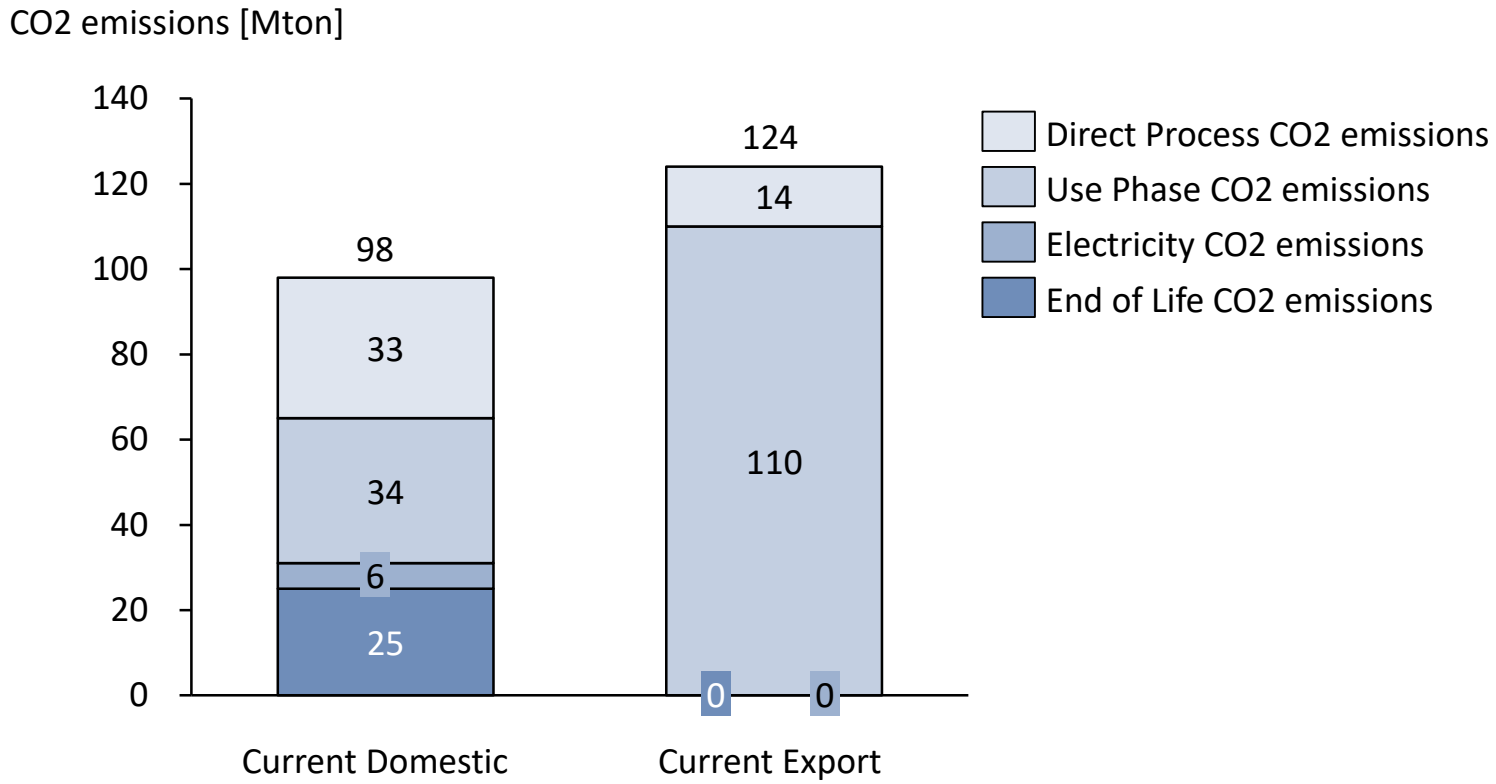
Results

Current domestic CO_2 emissions (2010)



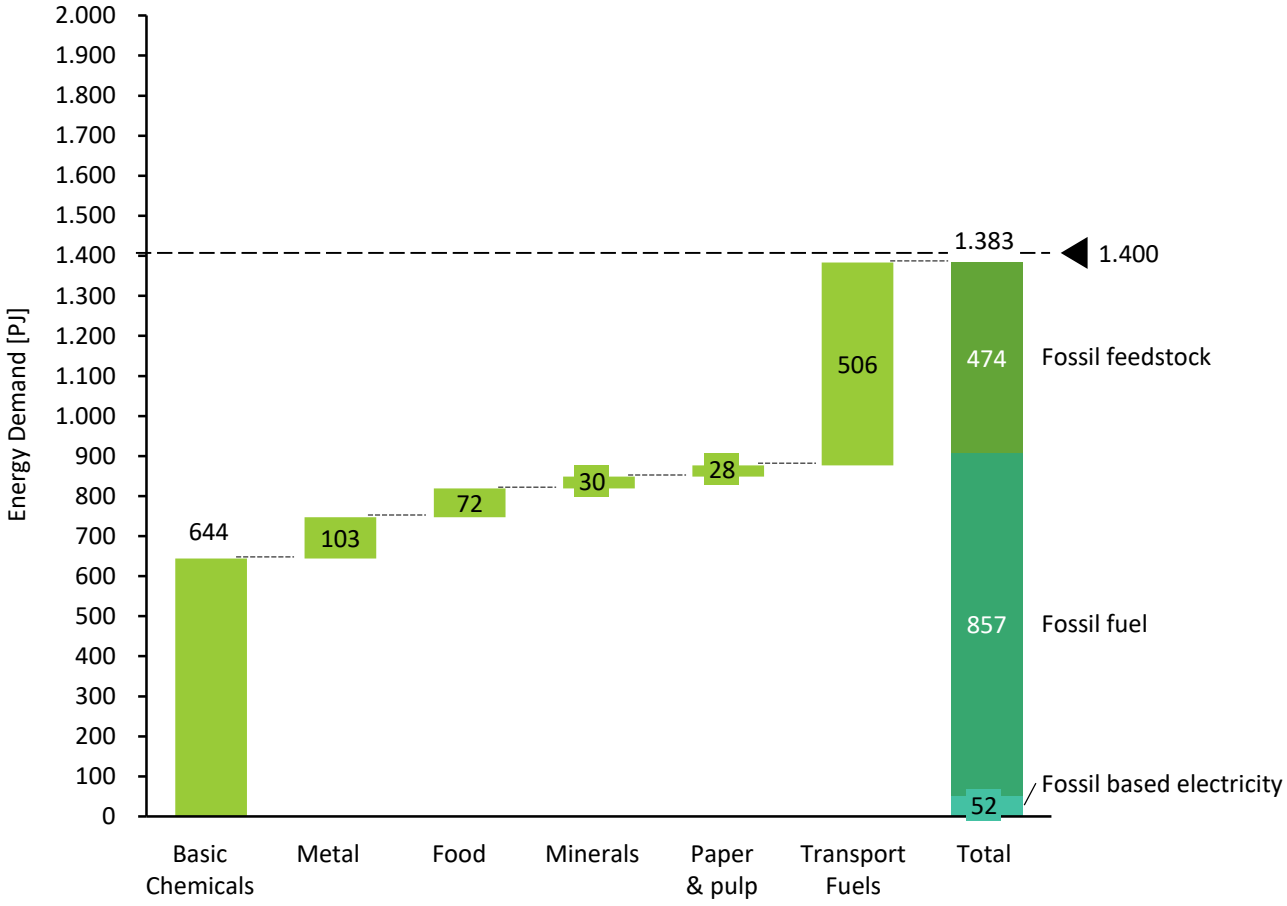
Basic chemicals (incl. export) and transport (excl. export) are dominant

Current CO_2 including exported fuels



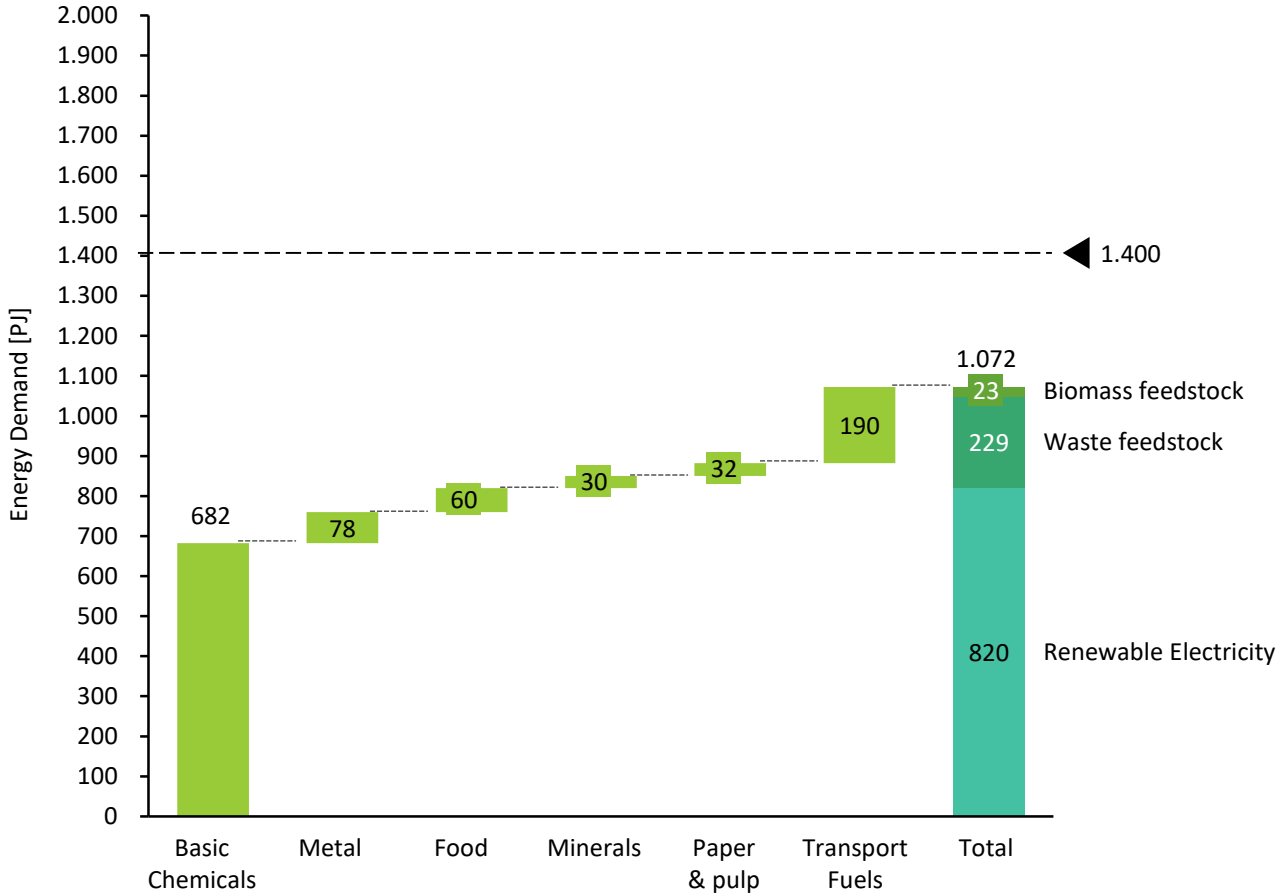
Current CO_2 of industrial life cycle are comparable to total Dutch GHG emission (219 Mton)

Current situation



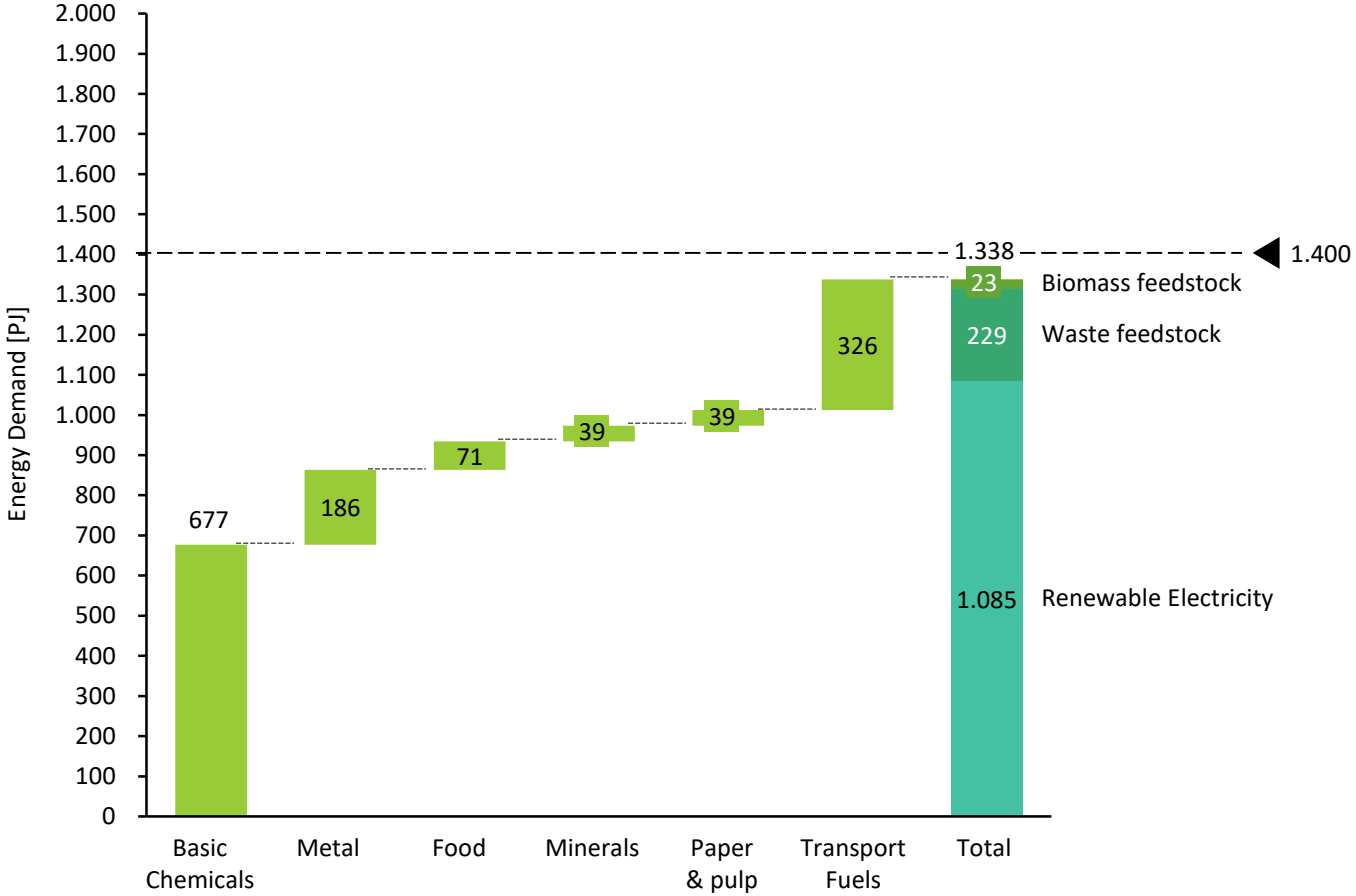
Energy and feedstocks almost completely fossil based

2050 Scenario All electric



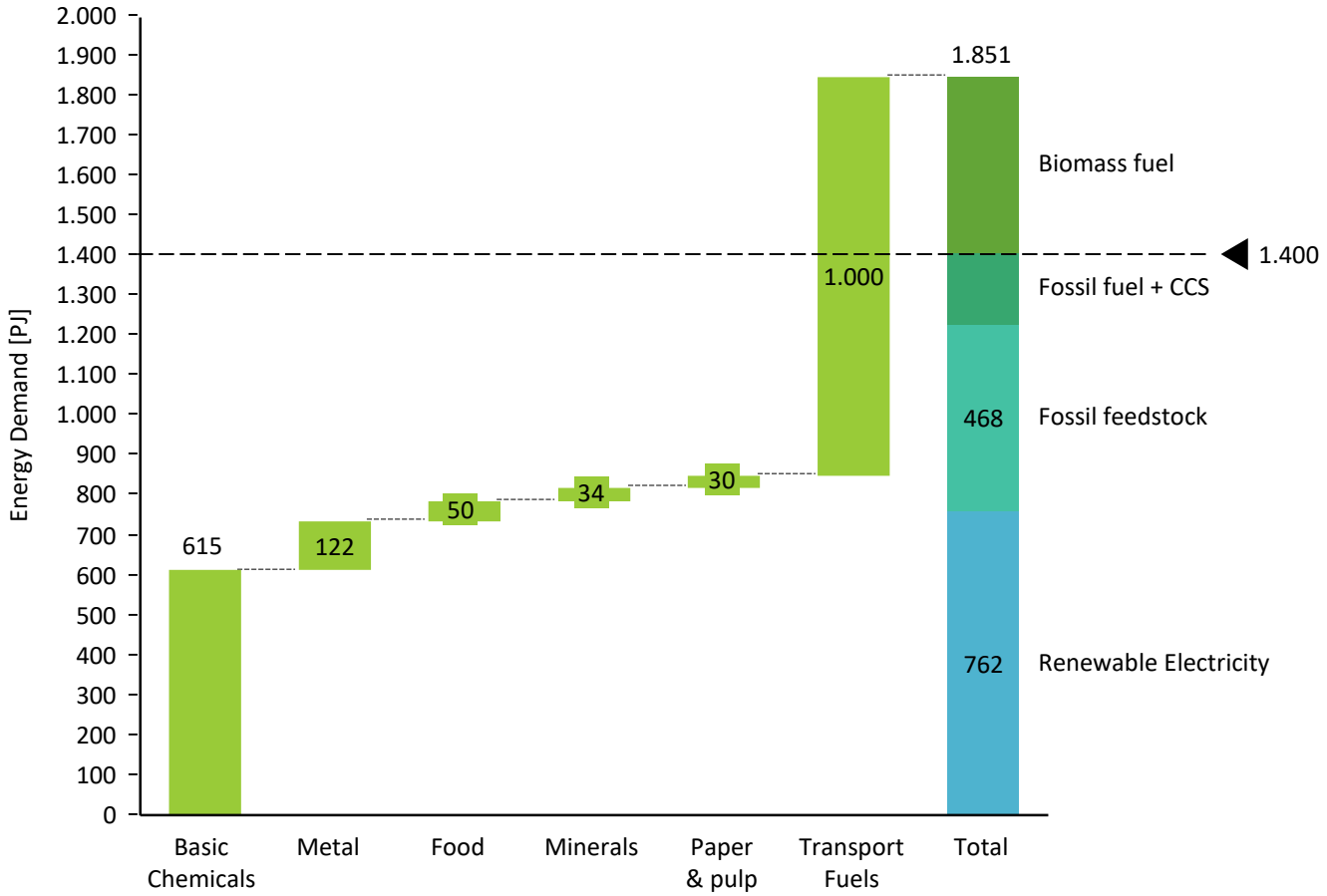
Direct electricity reduces energy demand with 20%; 2x NL North Sea wind, 25% total NS; completely fossil independent

2050 Scenario Big on hydrogen



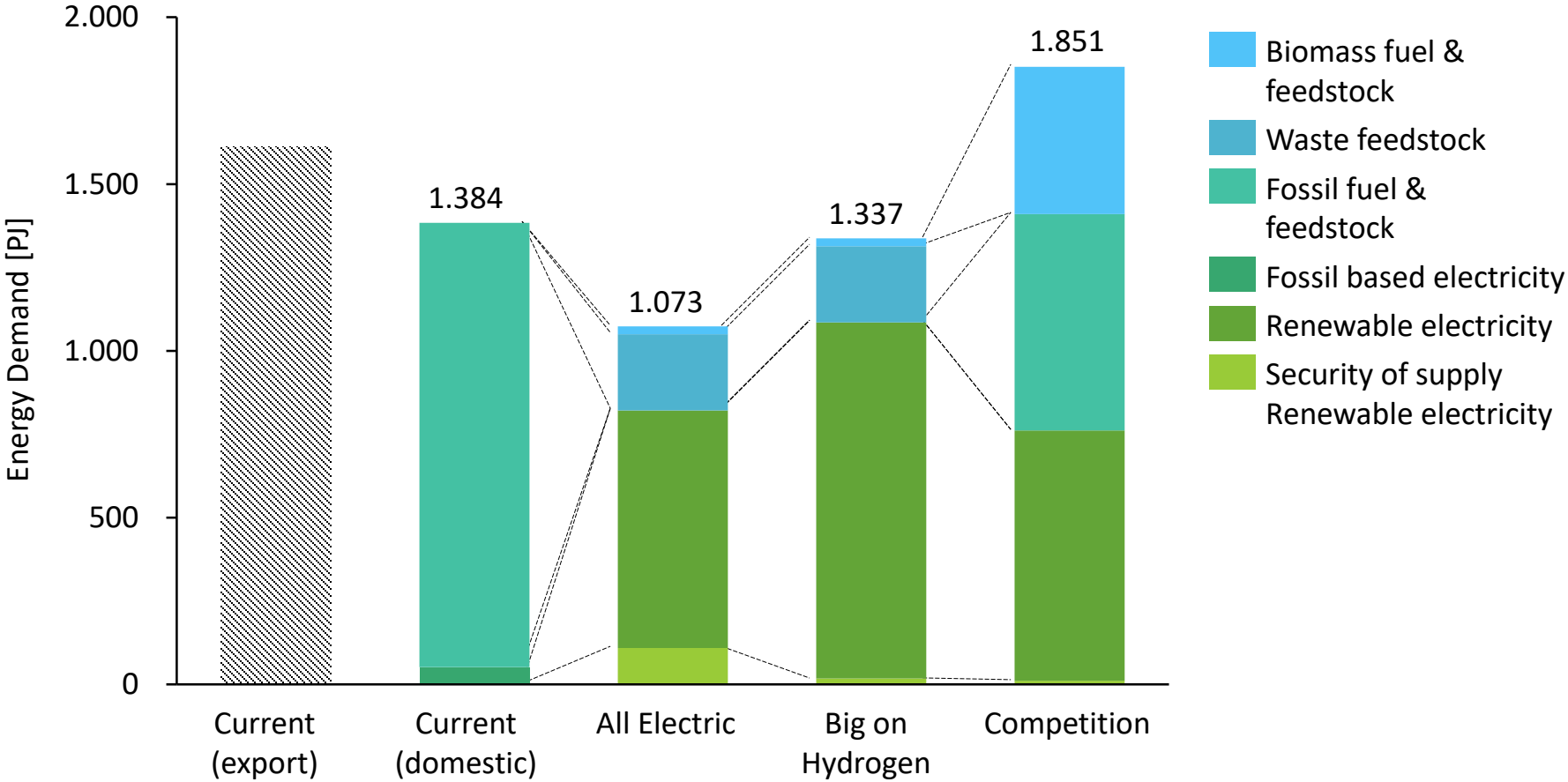
Indirect electricity via hydrogen results in a more or less stable energy demand, completely fossil independent

2050 Scenario Competition



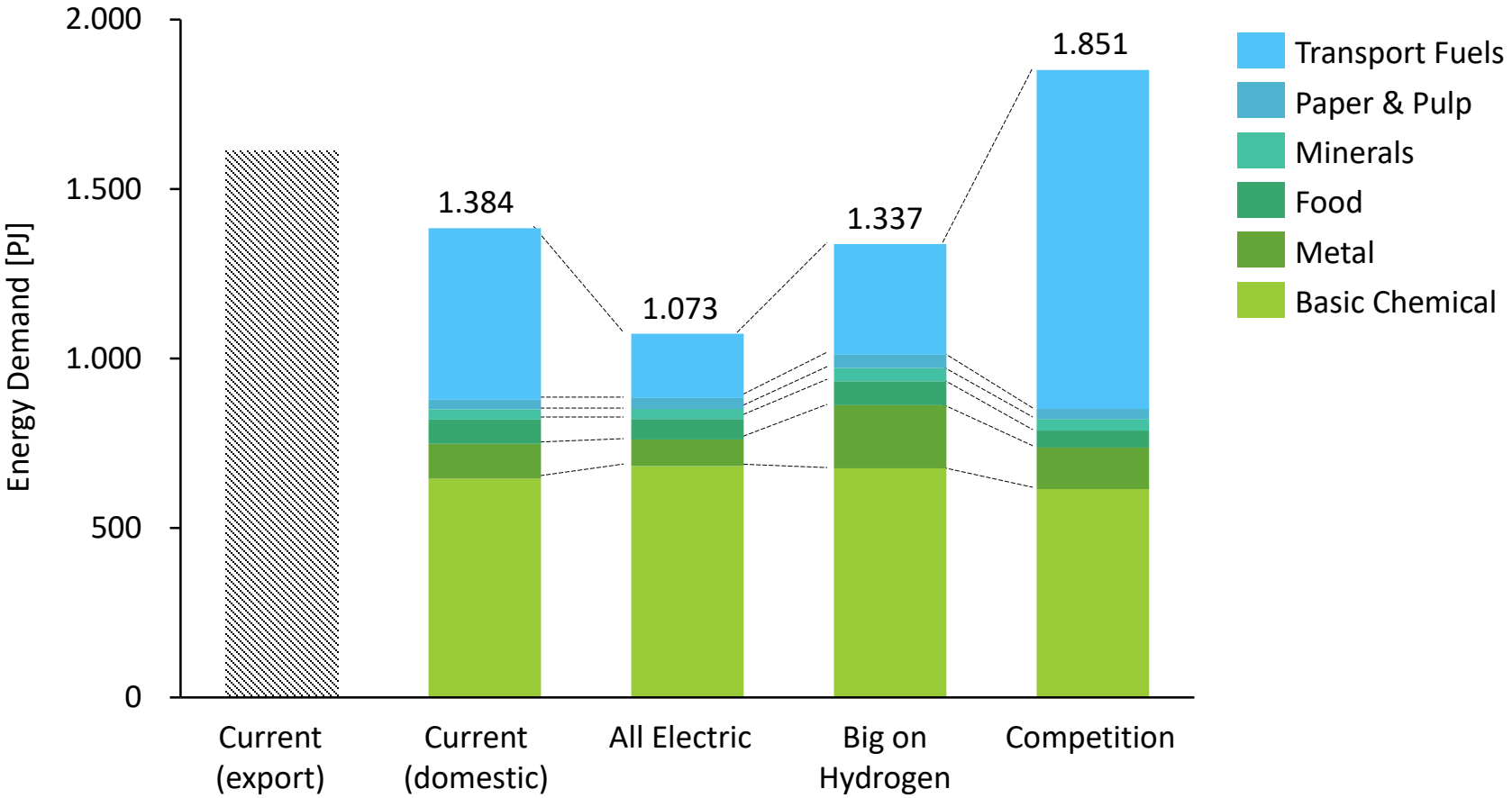
Increase of energy demand with 30%; biomass potential ~ 2 x NL; same electricity potential; crude oil and CCS needed

2050 Primary energy demand



North Sea wind potentials needed up to 2,5x NL North Sea wind, 30% total NS; C fossil dependent, biomass potential 2x NL

2050 Primary energy demand per sector



Sweet spots: All electric based transport & steel, Big on hydrogen based basic chemicals

Conclusions & recommendations

Conclusions

- It is technically possible to reduce life cycle CO_2 emissions to near 0 in the what-if scenarios All electric, Big on hydrogen and Competition in 2050;
- Current life cycle CO_2 emissions of the Dutch energy intensive industry & transport are comparable to the current total of Dutch direct GHG emissions (219 Mton);
- Required renewable electricity potentials are large: 1,5 – 2,5 times the Dutch North sea wind energy potential, equalling 20% - 35% of the total North sea wind potential;
- Energy use is comparable to the current situation in scenario Big on hydrogen, 20% lower in All electric and 30% higher in Competition (mainly due to transport);
- Two scenarios, All electric and Big on hydrogen, show possibilities for fossil fuel independence. The Competition scenario shows the possibilities while relying partly on conventional technology with CCS;
- Carbon sourcing in scenario A & B requires limited biomass potentials (10% of the Netherlands area) for plastic production growth, while in scenario C required potentials are large for transport (biomass potentials of 2x the Netherlands area) and fossil fuels for plastics;
- Each scenario needs its own infrastructure and has its own challenges (storage, transport, safety);
- A favourable scenario is likely a combination of different scenario elements applied in different markets / sectors: A. direct electrification in transport, steel & minerals; B. hydrogen in basic chemicals; C. renewable alternatives in food & paper.

Recommendations for further work

Further investigate:

- How to prepare the next decade for potential long term scenarios – identify critical & no-regret technologies, in general and per sector & product;
- Economic impacts and feasibility – for value chain and Dutch society;
- Necessary governance to support desired developments;
- Dutch export position on future decarbonised energy carriers for transportation (aviation and navigation) - currently 3x the domestic use.