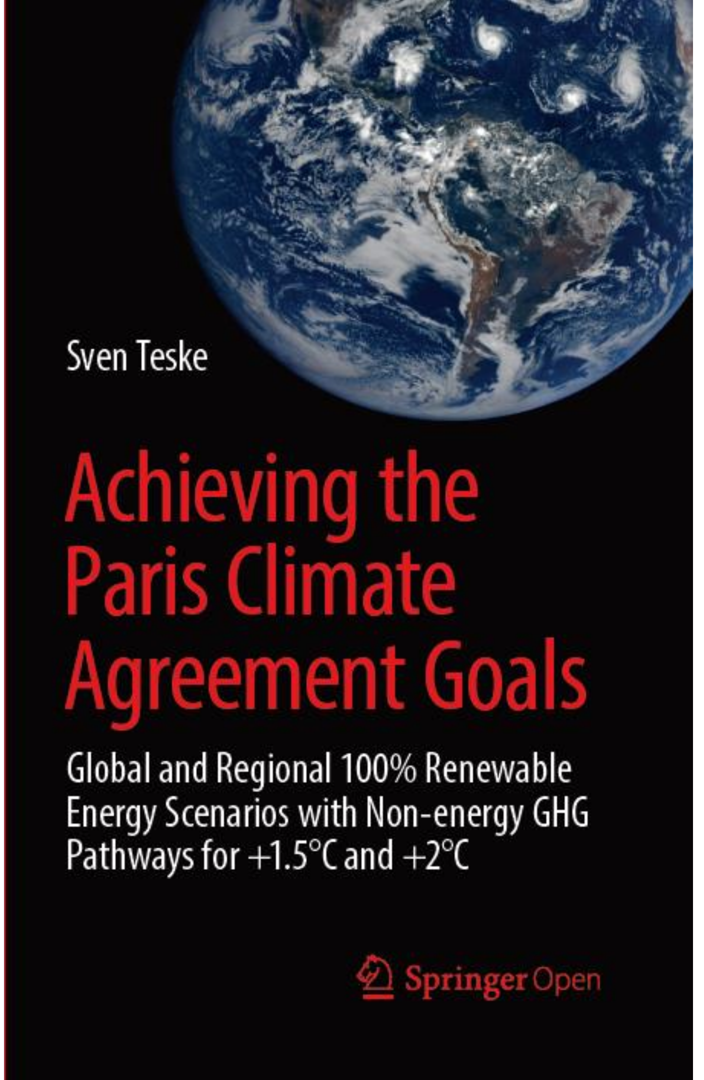
2019 International Forum on

Long-term Energy Scenarios for the Clean Energy Transition

Dr. Sven Teske



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Global Trends in the Energy Sector

- New Power Generation Capacity mainly solar PV and Wind as most economic
- High shares of variable power generation = the end of base load power plants
- Digitalisation of electricity:
  - Decentralised generation and Storage
  - Consumer turn into Prosumer
- Sector-Coupling:
  - Increased electrification in transport and heating sector

The One Earth Climate Model takes those trends into account.

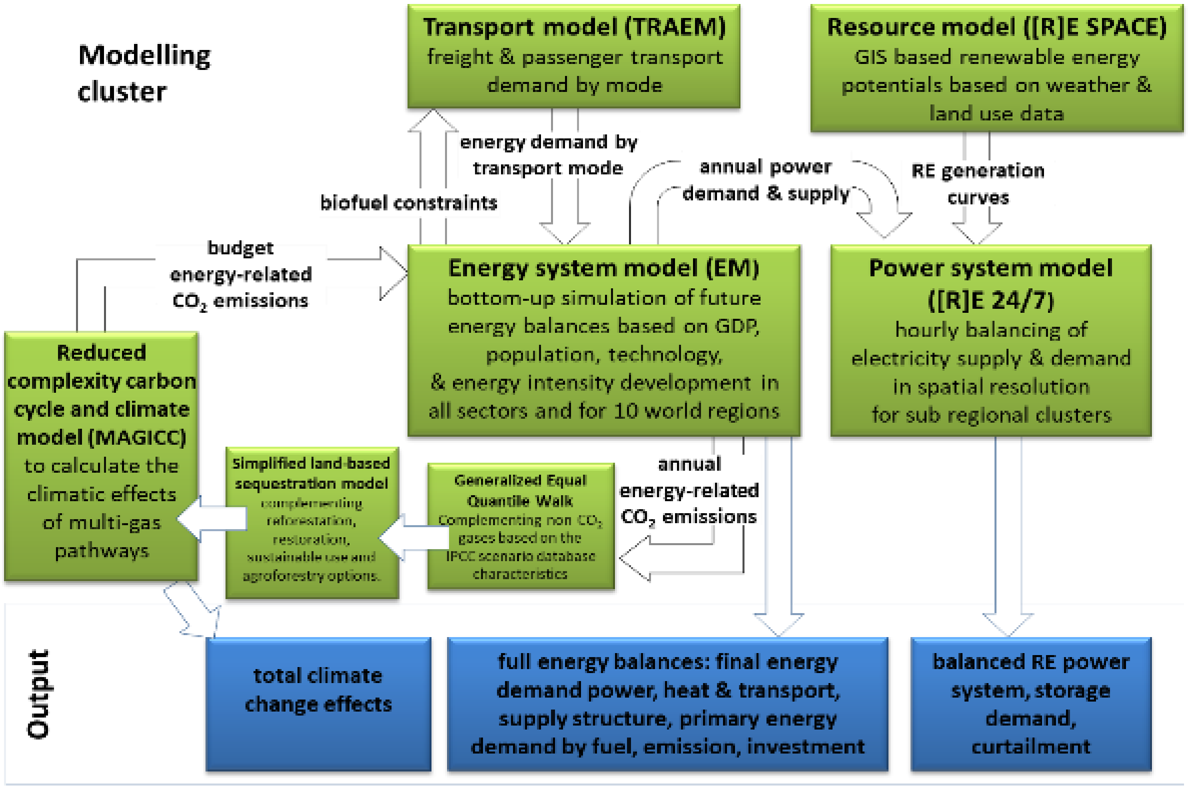
Project Scope

- Development of a 100% renewable energy scenario
- De-carbonization of the entire global energy sector within one generation (until 2050).
- Based only on technologies currently available or under development, excluding BECCS and nuclear energy.
- 10 World region scenario (based on IEA WEO)
- All sectors: power, buildings, industry and transport
- Power Sector Analysis: Modelled in hourly resolution to assess
  - storage demand
  - Increased interconnection between regions

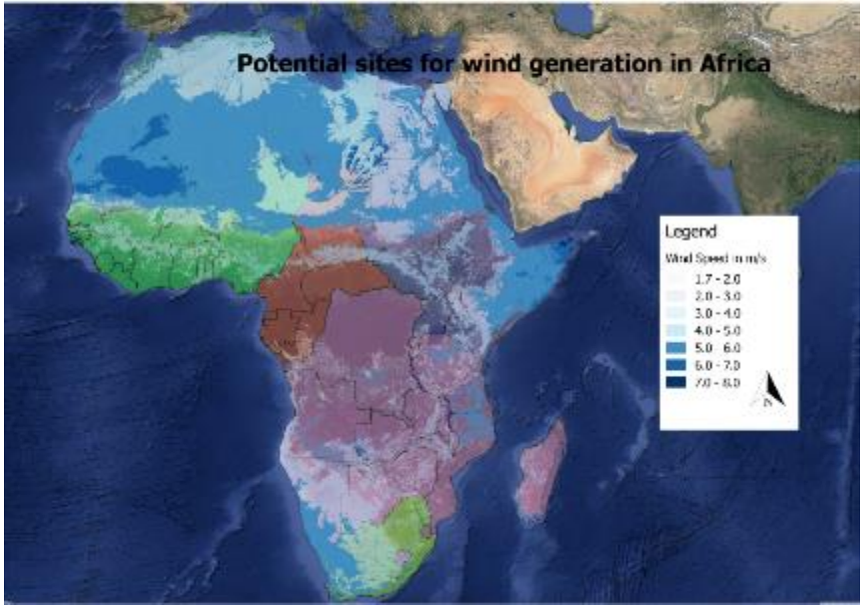
  requirements for the integration of high shares of variable renewable energy, such as solar and wind for all regions.
- Non-energy related green-house-gas (GHG) emission scenarios -to define a sustainable pathway for land-use change.

All pathways are evaluated in regard to their implicit use of the carbon budget and their exceedance probabilities for 1.5°C and 2°C

Methodology: Interaction of Models



Methodology: Regional Renewable Energy Potential



Renewable Resource Assessment [R]E-SPACE:

RE-SPACE is based on a Geographic Information Systems (GIS) approach and provides maps of the solar and wind potentials in space-constrained environments. GIS attempts to emulate processes in the real world, at a single point in time or over an extended period (Goodchild 2005). The primary purpose of GIS mapping is to ascertain the renewable energy resources (primarily solar and wind) available in each region. It also provides an overview of the existing electricity infrastructures for fossil fuel and renewable sources.

To assess the renewable energy potential based on the area available, all scenario-relevant regions and sub-regions were analysed with the [R]E-SPACE methodology, to quantify the available land area in square kilometres with a defined set of constraints:

- Residential and urban settlements;
- Infrastructure for transport (e.g. rail, roads);
- Industrial areas;
- Intensive agricultural production land;
- Nature conservation areas and national parks;
- Wetlands and swamps;
- Closed grasslands (as the land-use type).

Assumptions– Transport Model

The 5.0°C Scenario (reference scenario):

- International Energy Agency (IEA) World Energy Outlook Current Policy Scenario
    - IEA's projections only extend to 2040, we extrapolate their key macroeconomic and energy indicators forward to 2050.
    - existing international energy and environmental policies
    - continuing progress in electricity and gas market reforms, the liberalization of cross-border energy trade, and recent policies designed to combat environmental pollution.
    - No additional policies to reduce GHG emissions.

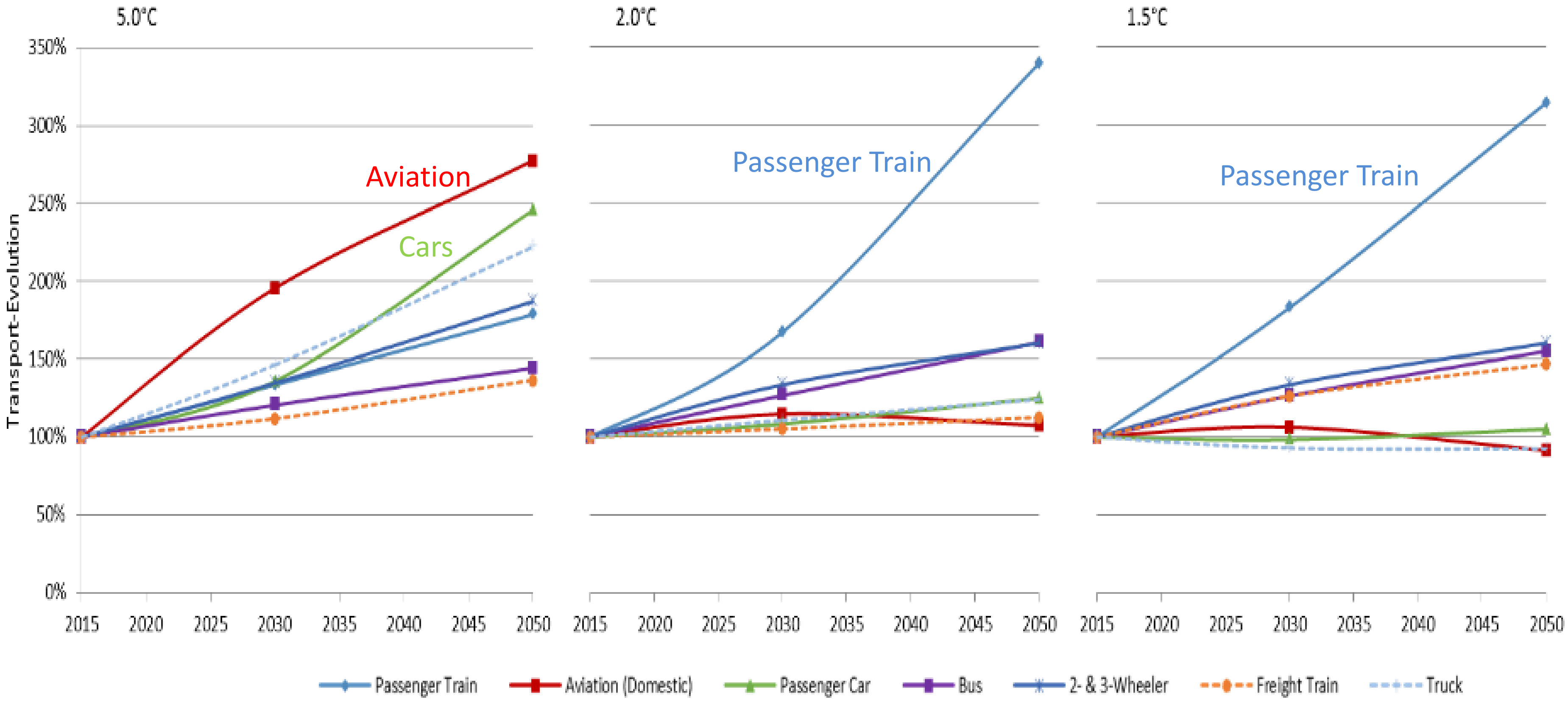
The 2.0°C Scenario:

- global energy-related CO_2 emission budget of around 590 Gt between 2015 and 2050.
- Energy efficiency and renewable energy driven
- Assumes continued rapid expansion of RE industry and electrification across all sectors

The 1.5°C Scenario:

- global energy-related CO2 emission budget of around 450 Gt, accumulated between 2015 and 2050
- requires immediate action to realize all available options.
- Technical benchmark scenario

Assumptions– Transport Model



Key Results

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Key Results
Global Renewable Energy Potential

Region	Subregion	Solar: Potential availability for utility-scale installations	Solar: Space Potential	Onshore Wind: Potential availability for utility-scale installations	Onshore Wind: Space Potential
		[km^2]	[GW]	[km^2]	[GW]
OECD North America	Canada East	2 742 668	68 567	2 530 232	12 651
	Canada West	2 242 715	56 068	2 180 271	10 901
	Mexico	3 365 974	84 149	3 341 940	16 710
	USA -South East	269 650	6 741	254 976	1 275
	USA – North East	1 043 033	26 076	1 043 026	5 215
	USA – South West	1 847 162	46 179	1 840 980	9 205
	USA – North West	431 277	10 782	427 709	2 139
	USA - Alaska	1 152 288	28 807	1 091 698	5 458
Latin America	Caribbean	34 238	856	34 238	171
	Central America	17 529	438	17 603	88
	North Latin America	869 811	21 745	869 811	4 349
	Brazil	1 623 625	40 591	1 623 625	8 118
	Central South America	1 023 848	25 596	1 024 340	5 122
	Chile	693 990	17 350	693 990	3 470
	Argentina	1 651 168	41 279	1 651 168	8 256
	CSA -Uruguay	32 360	809	32 360	162
Europe	EU - Central	146 797	3 670	146 797	734
	EU - UK & Islands	22 406	560	22 406	112
	EU – Iberian Peninsula	15 608	390	15 608	78
	EU -Balkans + Greece	4 825	121	4 825	24
	EU - Baltic	32 090	802	32 090	160
	EU - Nordic	218 496	5 462	218 496	1 092
	Turkey	134 354	3 359	134 354	672
Middle East	East - Middle East	165 202	[illegible]	5 738	29
	North - Middle East	91 970	2 299	7 123	36
	Iraq	119 967	2 999	9 104	46
	Iran	586 595	14 665	57 965	290
	United Arab Emirates	530	13	530	3
	Israel	386	10	217	1
	Saudi Arabia	13 284	332	13 284	66
Africa	North - Africa	9 726 388	243 160	9 784 694	48 923
	East - Africa	6 378 561	159 464	6 980 497	34 902
	West - Africa	8 336 960	208 424	8 669 628	43 348
	Central - Africa	7 229 129	180 728	7 509 351	37 547
	Southern - Africa	3 269 644	81 741	3 547 591	17 738
	Rep. South Africa	1 626 528	40 663	1 650 471	8 252

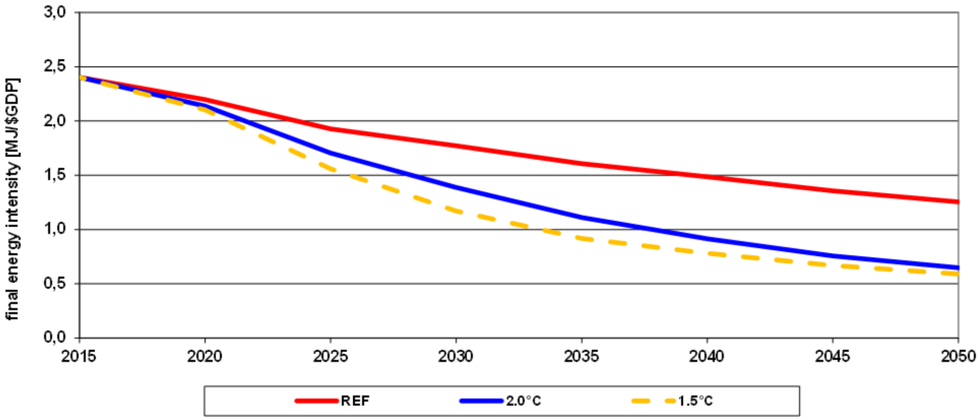
Energy Intensity:

Compared with the 5.0°C case based on the Current Policies Scenario of the IEA, the alternative scenarios follow more stringent efficiency levels.

The 1.5°C Scenario represents an even faster implementation of efficiency measures than the 2.0°C Scenario. The 1.5°C Scenario involves the decelerated growth of energy services in all regions, to avoid any further strong increase in fossil fuel use after 2020.

The global average intensity drops from 2.4 MJ/$GDP in 2015 to 1.25 MJ/$GDP in 2050 in the 5.0°C case compared with 0.65 MJ/$GDP in the 2.0°C Scenario and 0.59 MJ/$GDP in the 1.5°C Scenario.

The average final energy consumption decreases from 46.3 GJ/capita in 2015 to 28.4 GJ/capita in 2050 in the 2.0°C Scenario and to below 26 GJ/capita in the 1.5°C Scenario. In the 5.0°C case, it increases to 55 GJ/capita.

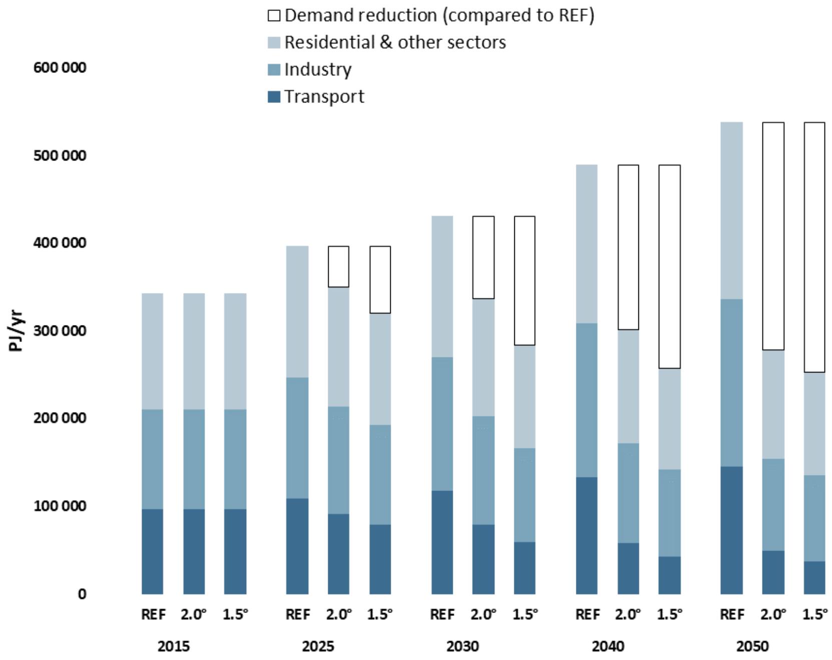


Key Results – Global and Regional Long-term Energy Pathways

Global: final energy demand by sector:

Combining the assumptions for population growth, GDP growth, and energy intensity produced the future development pathways for the global final energy demand develops as follows:

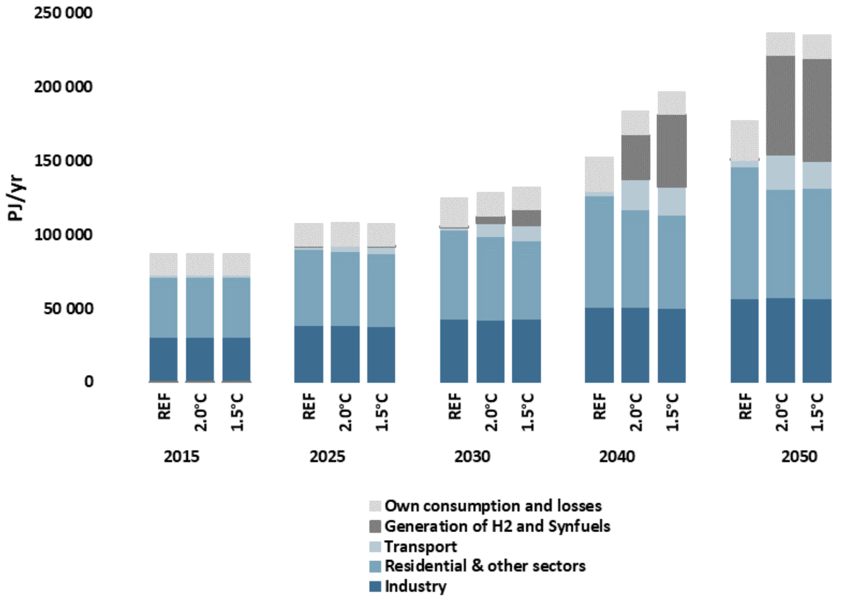
- 5.0°C Scenario, the total final energy demand will increase by 57% from 342 EJ/yr in 2015 to 537 EJ/yr in 2050.
- 2.0°C Scenario, the final energy demand will decrease by 19% compared with the current consumption and reach 278 EJ/yr by 2050.
- 1.5°C Scenario will reach 253 EJ, 26% below the 2015 demand. In the 1.5°C Scenario, the final energy demand in 2050 is 9% lower than in the 2.0°C Scenario.



Global: final electricity demand by sector:

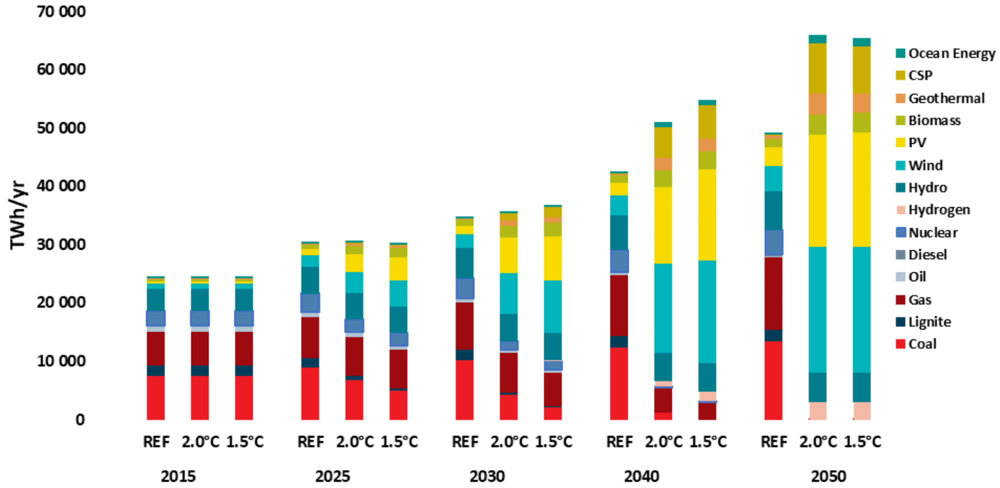
Electrification will lead to a significant increase in the electricity demand by 2050.

- 2.0°C Scenario: Electricity demand for heating will be about 12 600 TWh/yr due to electric heaters and heat pumps, and in the transport sector there will be an increase of about 23 400 TWh/yr due to increased electric mobility.
- The generation of hydrogen (for transport and high-temperature process heat) and the manufacture of synthetic fuels (mainly for transport) will add an additional power demand of 18 800 TWh/yr.
- The gross power demand rises from 24 300 TWh/yr in 2015 to 65 900 TWh/yr in 2050 in the 2.0°C Scenario, 34% higher than in the 5.0°C case.
- 1.5°C Scenario, the gross electricity demand will increase to a maximum of 65 300 TWh/yr in 2050.



Key Results – Global and Regional Long-term Energy Pathways

Global: Electricity Generation and Capacity:



in GW		2015	2025	2030	2040	2050
Hydro	5.0°C	1 202	1 420	1 558	1 757	1 951
	2.0°C	1 202	1 386	1 416	1 473	1 525
	1.5°C	1 202	1 385	1 415	1 471	1 523
Biomass	5.0°C	112	165	195	235	290
	2.0°C	112	301	436	617	770
	1.5°C	112	350	498	656	798
Wind	5.0°C	413	880	1 069	1 395	1 790
	2.0°C	413	1 582	2 901	5 809	7 851
	1.5°C	413	1 912	3 673	6 645	7 753
Geothermal	5.0°C	14	20	26	41	62
	2.0°C	14	49	125	348	557
	1.5°C	14	53	147	356	525
PV	5.0°C	225	785	1 031	1 422	2 017
	2.0°C	225	2 194	4 158	8 343	12 306
	1.5°C	225	2 829	5 133	10 017	12 684
CSP	5.0°C	4	13	20	39	64
	2.0°C	4	69	361	1 346	2 062
	1.5°C	4	92	474	1 540	1 990
Ocean	5.0°C	0	1	3	9	22
	2.0°C	0	22	82	307	512
	1.5°C	0	22	80	295	450
Total	5.0°C	1 971	3 285	3 902	4 899	6 195
	2.0°C	1 971	5 604	9 478	18 243	25 583
	1.5°C	1 971	6 644	11 420	20 980	25 723

Key Results – Global and Regional Long-term Energy Pathways

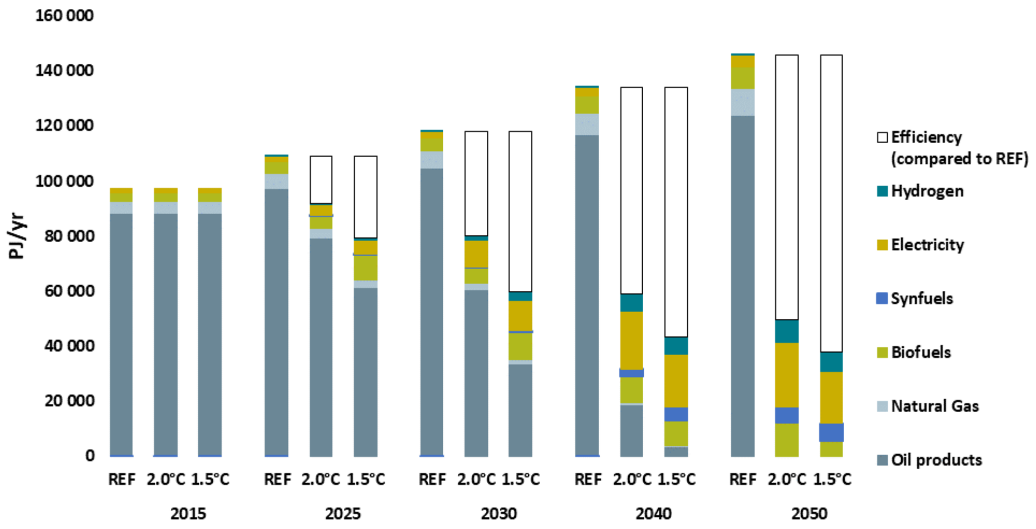
Global: Electricity Generation – Investment Costs versus Fuel Cost Savings:

ACCUMULATED INVESTMENT COSTS difference 5.0C minus 1.5C		2015-2020	2021-2030	2031-2040	2041-2050	2015-2050	2015 - 2050 average per year
conventional (fossil + nuclear	billion $	323.7	1,238.7	1,460.2	1,926.3	4,949.0	126.9
renewables (incl. CHP)	billion $	-432.5	-10,906.4	-12,467.2	-11,874.0	-35,680.1	-914.9
total	billion $	-108.8	-9,667.7	-11,007.0	-9,947.7	-30,731.1	-788.0
ACCUMULATED FUEL COST SAVINGS							
savings cumulative 1.5C versus 5.0C							
fuel oil	billion $	50.1	497.1	852.7	972.7	2,372.6	60.8
gas	billion $	93.2	967.4	2,887.9	6,709.9	10,658.4	273.3
hard coal	billion $	182.1	1,929.2	4,066.0	5,712.1	11,889.4	304.9
lignite	billion $	34.0	461.5	683.1	881.6	2,060.2	52.8
nuclear energy	billion $	6.5	215.9	600.4	954.6	1,777.4	45.6
total	billion $	365.9	4,071.1	9,090.1	15,230.9	28,758.0	737.4

Key Results – Global and Regional Long-term Energy Pathways

Global: Energy Supply – Transport:

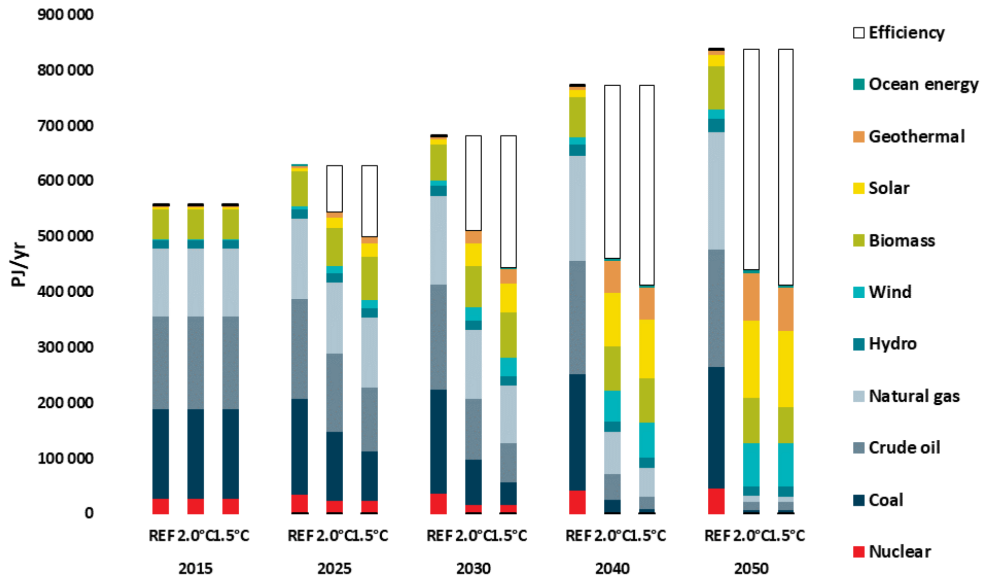
- 5.0°C Scenario: 50% increase of transport energy demand by 2050.
- 2.0°C Scenario, assumed technical, structural, and behavioural changes will reduce the energy demand by 66% (96 000 PJ/yr) by 2050 compared with the 5.0°C Scenario. A
- 1.5°C Scenario: Additional modal shifts, technology switches, and a reduction in the transport demand reduce energy demand further - 74% (or 108 000 PJ/yr) in 2050 compared with the 5.0°C case.
- 2.0°C Scenario: Electricity share 12% by 2030 and 47% in 2050. In 2050 8 430 PJ/yr of hydrogen will be used in the transport sector, as a complementary renewable option.
- Biofuel use is limited in 2.0°C and 1.5°C Scenarios to a maximum of around 12 000 PJ/yr / 10 000 PJ/yr.



Key Results – Global and Regional Long-term Energy Pathways

<u>Global: Primary Energy Supply:</u>

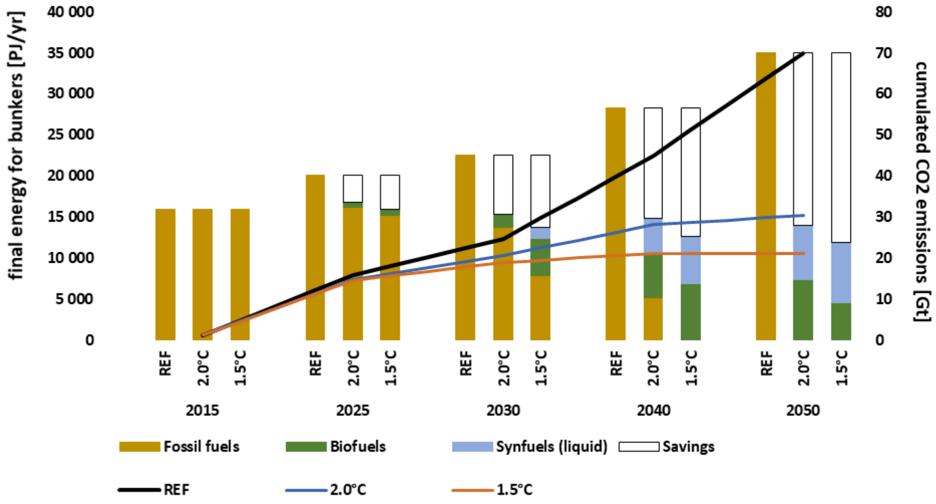
- 5.0°C: 837 EJ in 2050
- 2.0°C Scenario: 439 EJ/yr in 2050 (-21%)
  - -48% compared to 5.0°C Scenario
- 1.5°C Scenario: 412 EJ in 2050
- Both the 2.0°C and 1.5°C Scenarios aim to rapidly phase-out coal and oil.
- Renewable energy share:
- 2.0°C Scenario: 35% (2030); 92% (2050) (= non-energy use)1.5°C Scenario: 40% (2030) 100% (2050
- Nuclear energy will be phased -out in both the 2.0°C and 1.5°C Scenarios Around 2040.



Key Results – Global and Regional Long-term Energy Pathways

Global: Bunker Fuel Supply:

- Bunker fuels: Fuel supply for international aviation and
- Their use and related emissions are not usually directly allocated to the regional energy balances.
- 2015: Annual bunker fuels consumption 16 000 PJ/a,
    - Aviation: 7 400 PJ/a + Shipping: 8 600 PJ/a
- 2009 – 2015: Increase of bunker fuel consumption by 13%.
- 2015 CO_2 emissions from bunker fuels: 1.3 Gt
    - approx. 4% of global energy-related CO2 emissions.
- Bunker fuels are replaced by biofuels or synthetic liquid fuels (RE produced); Hydrogen not used.
- Renewable synthetic fuel production for bunker fuels:
    - Africa, the Middle East, and Australia



Global: Energy-related CO_2:

5.0°C Scenario:

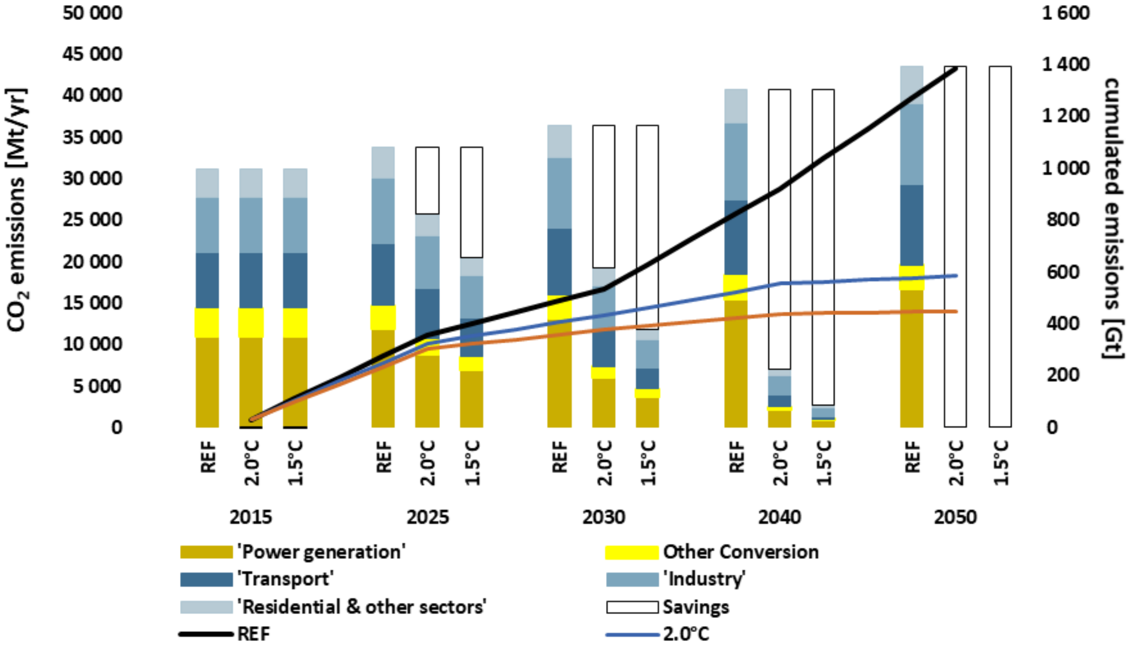
- 43.5 Gt CO_2 /year in 2050 (+40%)

2.0°C Scenario:

- 7.07 Gt CO_2 /year in 2040, zero in 2050
- 587 Gt CO_2 (2015–2050)

1.5°C Scenario:

- 2.65 Gt CO_2 /year in 2040 t, zero in 2050
- 450 Gt CO_2 (2015-2050.



Key Results – Global and Regional Power Sector Analysis

Global: Power Generation Structure

- Variable Renewables increase from around 5% to 65%
- Dispatchable Fossil decrease from around 60% to 7%
- The role of variable and fossil fuel based generation will swap
- There will be no power plants dedicated to supply for base-load after

Power Generation Structure in 10 world regions		2.0°C			1.5°C		
World		Variable Renewables	Dispatch Renewables	Dispatch Fossil	Variable Renewables	Dispatch Renewables	Dispatch Fossil
OECD North America	2015	7%	35%	58%	7%	41%	52%
	2030	48%	30%	23%	59%	27%	15%
	2050	68%	19%	13%	68%	21%	11%
Latin America	2015	3%	63%	34%	3%	62%	35%
	2030	24%	51%	25%	36%	61%	3%
	2050	39%	45%	16%	40%	46%	13%
Europe	2015	15%	47%	38%	15%	47%	38%
	2030	44%	44%	12%	51%	39%	10%
	2050	67%	28%	4%	69%	27%	4%
Middle East	2015	0%	12%	88%	0%	13%	87%
	2030	51%	19%	31%	56%	18%	27%
	2050	81%	19%	0%	70%	16%	13%
Africa	2015	2%	26%	73%	2%	17%	81%
	2030	47%	21%	32%	52%	13%	35%
	2050	73%	27%	0%	64%	15%	21%
Eurasia	2015	1%	35%	63%	1%	35%	63%
	2030	36%	43%	21%	40%	46%	14%
	2050	69%	23%	7%	65%	25%	10%
Non-OECD Asia	2015	1%	35%	64%	1%	35%	64%
	2030	26%	35%	39%	36%	34%	30%
	2050	52%	28%	19%	55%	28%	17%
India	2015	4%	32%	64%	4%	32%	64%
	2030	45%	26%	29%	60%	21%	19%
	2050	72%	27%	1%	58%	26%	16%
China	2015	6%	35%	59%	6%	21%	73%
	2030	30%	24%	46%	39%	30%	31%
	2050	49%	47%	5%	49%	42%	9%
OECD Pacific	2015	4%	34%	61%	4%	34%	61%
	2030	40%	31%	30%	45%	29%	27%
	2050	71%	26%	2%	64%	22%	14%
Global average	2015	4%	35%	60%	4%	34%	62%
	2030	39%	32%	29%	47%	32%	21%
	2050	64%	29%	7%	60%	27%	13%

Note: Variable renewable generation shares in long term energy pathways and power sector analysis differ due to different calculation methods. The power sector analysis results are based on the sum of up to eight sub-regional simulations, while the long term energy pathway is based on the regional average generation excluding variations in solar and wind resources within that region.

Key Results – Global and Regional Power Sector Analysis

Global: Power Generation Structure

- **Limited dispatchable fossil and nuclear power plants**:
  - Coal, Lignite, and Nuclear power plants with limited ability to respond to changes in demand.
  - Power systems dominated by renewable energy usually contain high proportions of variable generation require quick reaction times (to ramp up and down). Limited dispatchable power plants cannot deliver these services and are therefore being phased-out.
- **Limited dispatchable renewable systems** :
  - CSP plants with integrated storage and co-generation systems with renewable fuels (including geothermal heat).
  - No second or minute reserve possible (yet), but can still be used as dispatch power plants for 'day ahead' planning.
- **Dispatchable fossil fuel power plants**
  - Gas power plants that have very quick reaction times and therefore provide valid power system services.
- **Dispatchable renewable power plants**
  - Hydropower plants (although they are dependent on the climatic conditions in the region where the plant is used),
  - Biogas power plants, and former gas power plants converted to hydrogen and/or synthetic fuel.
  - This technology group is responsible for most of the required load-balancing services and is vital for the stability of the power system, as storage systems, interconnections, and, if possible, demand-side management.
- **Variable renewables:**
  - Solar PV plants, onshore and offshore wind farms, and ocean energy generators. Ocean energy plants—tidal energy plants—is very predictable.

Key Results – Global and Regional Power Sector Analysis

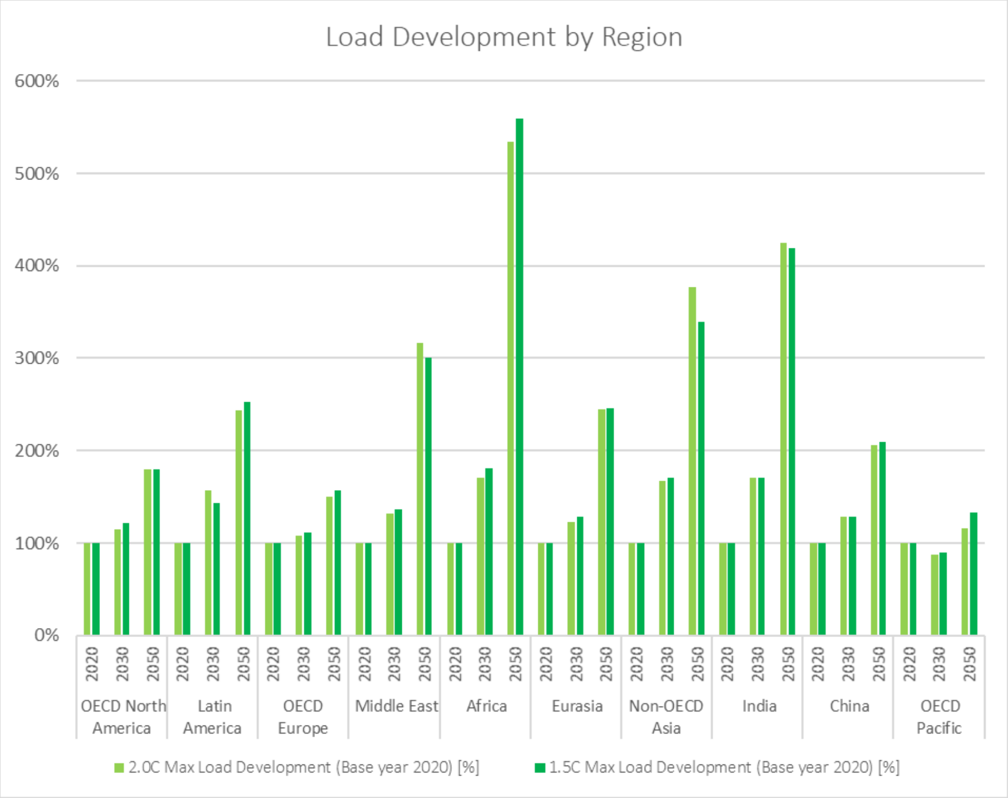
Global: Load Development by Region - 2.0°C and 1.5°C Scenario

Africa:

- + 534% by 2050
  - Favourable economic development
  - Increased access to energy services by households.

OECD Pacific:

- - 87% by 2030
  - Efficiency measures across all sectors
- 116% increase by 2050
  - Electric mobility
  - Increased Electrification of the process heat supply especially in the industry sector.



Key Results – Global and Regional Power Sector Analysis

Global: Estimated Investment in Battery and Pumped Hydro Storage

- Pumped Hydro market stable around $4 billion annually from 2021 till 2050
- Batteries sharp increase from $4.5 billion to $15 billion in 2030 and $65 billion in 2050

Esitmated Storage investment costs In $ billion	2015-2020	Average annual	2021-2030	Average annual	2031-2040	Average annual	2041-2050	Average annual	2015-2050	Average annual
Storage										
Battery	4.8	0.967	44.5	4.4	148.1	14.8	655.8	65.6	853.3	24.4
Hydro Pumpstorage	0	0	38.7	3.9	42.7	4.3	47.2	4.7	128.6	3.7
Total	4.8	0.967	83.2	8.3	190.8	19.1	703.0	70.3	981.9	28.1

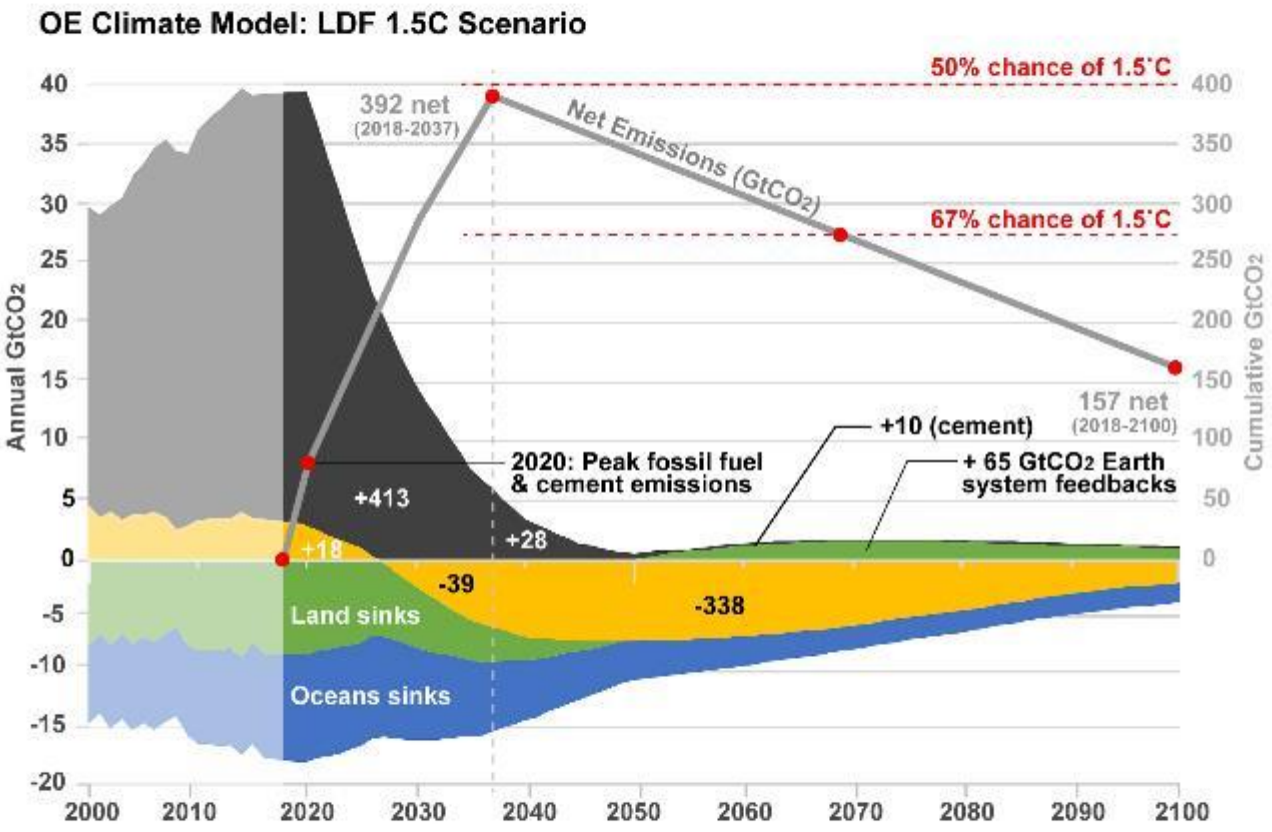
Summary: Required fossil fuel resources under the 2.0°C and 1.5°C trajectories

- 2.0°C Scenario : Global fossil fuel extraction industry must reduce production at a rate of 2% per annum
- 1.5°C Scenario: Minus 3% per annum
- International measures required to organize the economic and social transitions in the producing countries,
- Communities and workers need to be involved.

- The idea of a 'just transition' is well documented in the international literature. According to the International Labour Organization (ILO 2015), the concept was first mentioned in the 1990s, when North American unions began developing the concept of just transition.

The Paris Climate Agreement 2015, during the 21st session of the Conference of the Parties (COP 21) "*decided to continue and improve the forum on the impact of the implementation of response measures (hereinafter referred to as the improved forum), and adopted the work programme, comprising two areas: (1) economic diversification and transformation; and (2) just transition of the workforce, and the creation of decent work and quality jobs*"

(UNFCCC-JT 2016).


OE Climate Model: LDF 1.5C Scenario
50% chance of 1.5˚C
67% chance of 1.5˚C
392 net
(2018-2037)
Net Emissions (GtCO2)
157 net
(2018-2100)
2020: Peak fossil fuel
& cement emissions
+10 (cement)
+ 65 GtCO2 Earth
system feedbacks
+413
+18
+28
-39
-338
Land sinks
Oceans sinks
Annual GtCO2
Cumulative GtCO2
40
35
30
25
20
15
10
5
0
-5
-10
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Achieving the Paris Climate Agreement Goals

Global and Regional 100% Renewable Energy Scenarios with Non-energy GHG Pathways for +1.5°C and +2°C

Editors: **Teske**, Sven (Ed.)

Presents robustly modeled scenarios to achieve 100% renewable energy by 2050

Thank you

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