

# Clean up the grid, and electrify almost everything

–  
A global-local View

Christian Breyer  
Professor for Solar Economy  
LUT University, Lappeenranta  
Akademischer Energieverein Leipzig e.V.  
Leipzig, May 6, 2019



Open your mind. LUT.  
Lappeenranta University of Technology

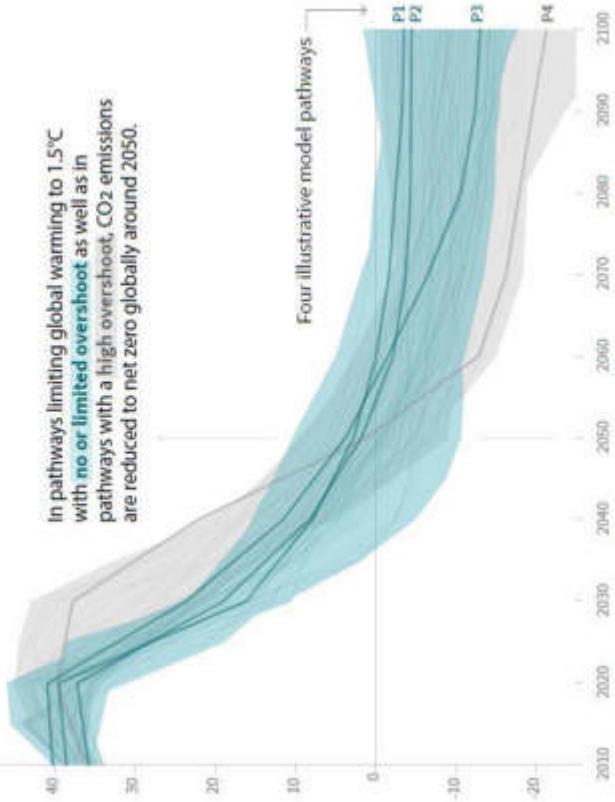


# Latest insights for a 1.5°C world



Global total net CO<sub>2</sub> emissions  
Billion tonnes of CO<sub>2</sub>/yr

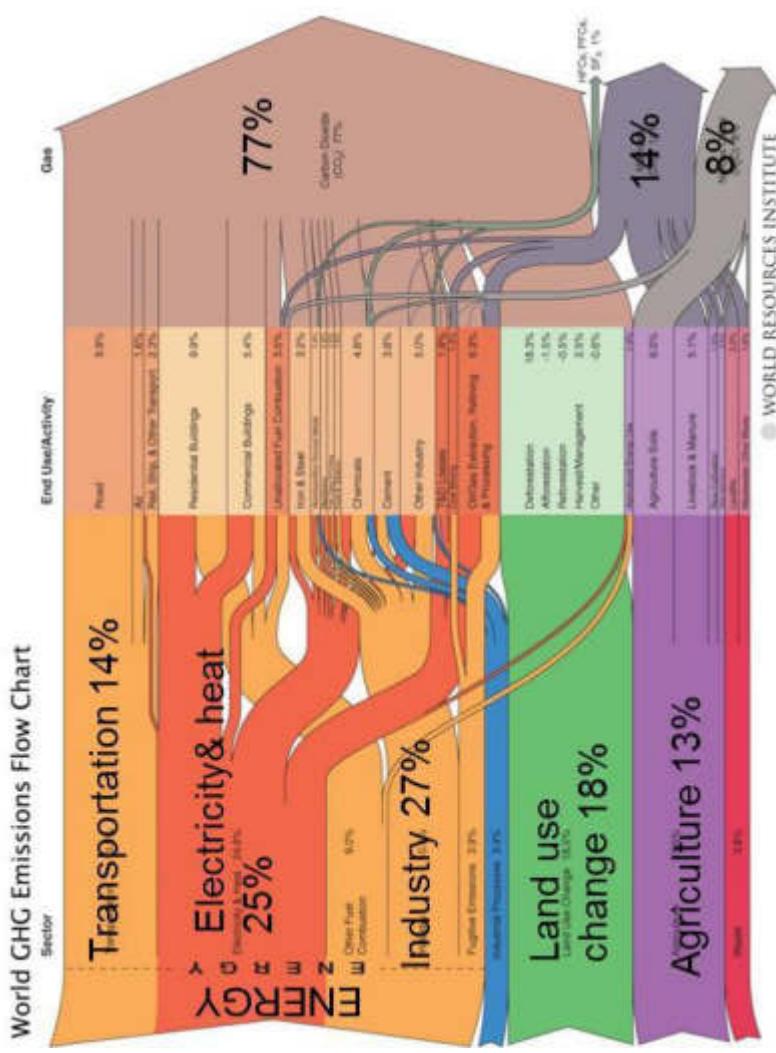
An IPCC special report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas mitigation pathways, of concern to protecting the global environment and climate system for current and future generations, and others to inform policy processes.



## Key insights:

- very fast defossilisation is needed in any case
- zero GHG emissions in 2050s in all relevant scenarios
- net-negative CO<sub>2</sub> emissions from 2050s onwards
- 100% RE referenced in the SR1.5 for the first time in IPCC history
- please be aware, a 1.5°C scenario still implies loss of most coastal cities in the world

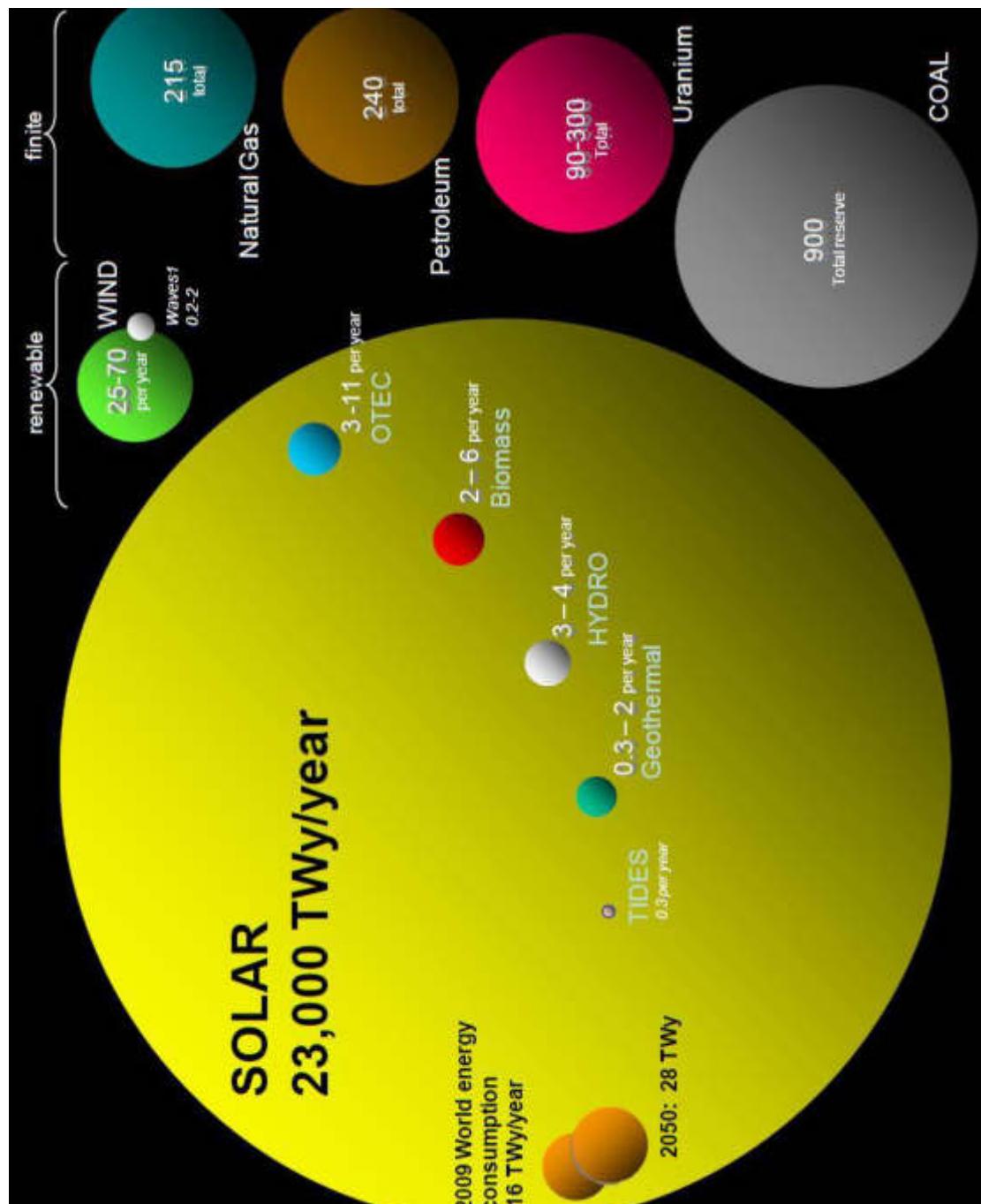
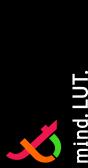
# Origin of GHG emissions



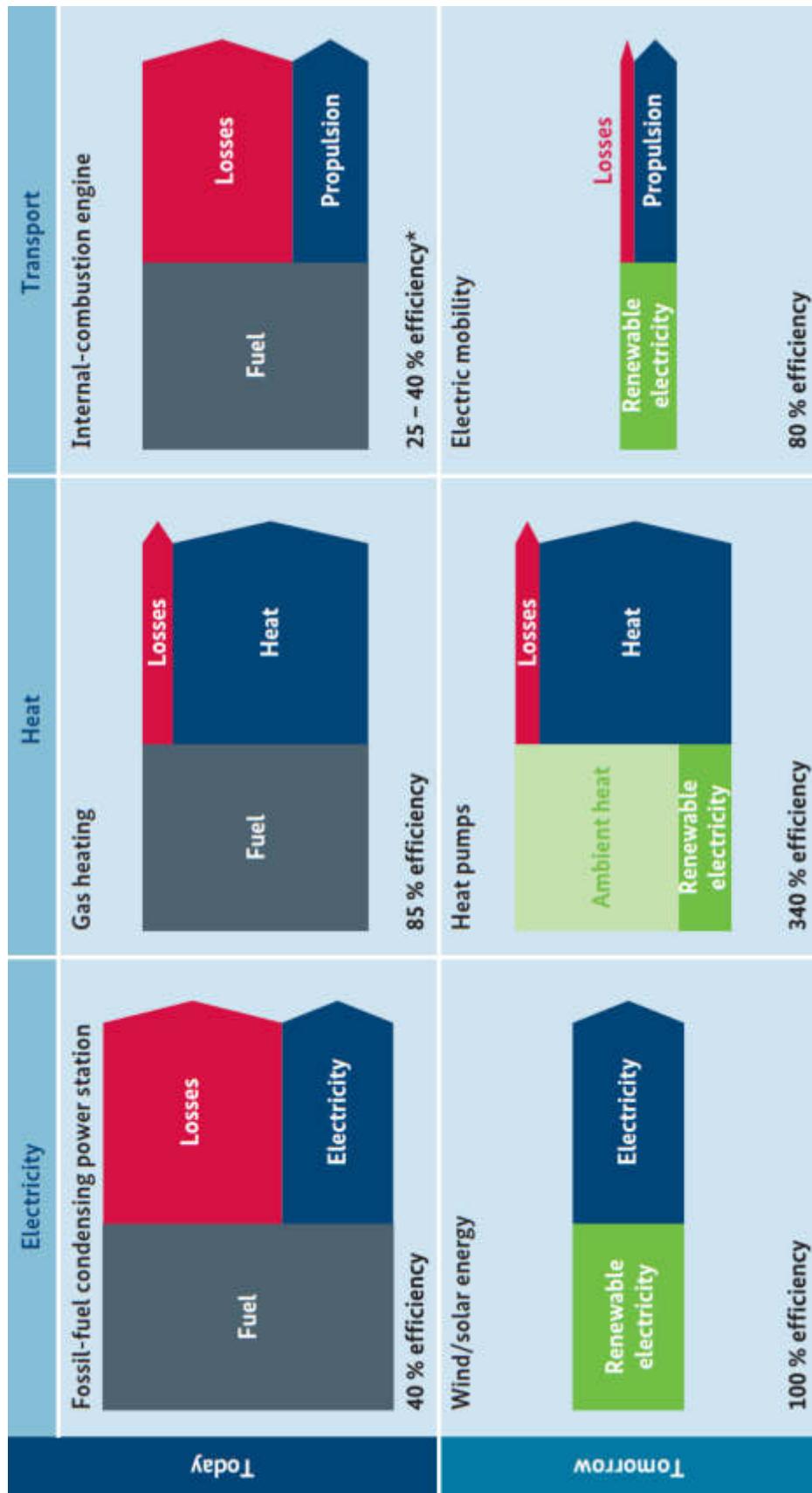
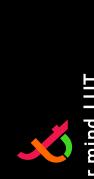
## Key insights:

- Net zero emissions is mandatory for ALL GHG emissions
- To achieve net zero for the agricultural sector and land use changes is outstanding difficult
- Consequence 1: all energy sectors (Power, Heat, Transportation, Industry) HAVE to go to zero
- Consequence 2: all usage of fossil coal, oil, gas needs to be stopped
- Scientific debate on 'negative emission technologies' is intensifying AND opportunity
  - Afforestation may have a strong impact as constraint AND opportunity

# Resources and Energy Demand



# Key rationale for electrification: Efficiency



\* The efficiency of internal-combustion engines in other applications (e.g. maritime transport, engine-driven power plants) can exceed 50 %.



**Nov 2016, COP-22, Marrakech:  
48 countries (Climate Vulnerable Forum) decided for a  
100% RE target**

**More Countries and States set 100% targets, e.g.:  
Denmark, Sweden, California, Spain, Hawaii, ...**

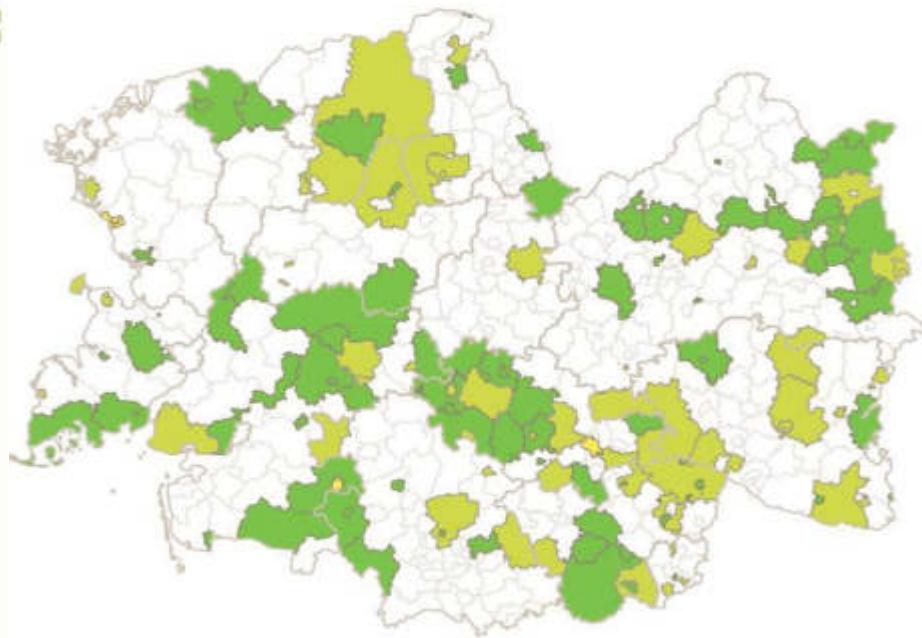
**Some Countries are already around 100%, e.g.:  
Norway, Costa Rica, Uruguay, Iceland, ...**

**Cities with 100% RE targets, e.g.:**

Barcelona, Masdar City, Munich, Masheireb, Downtown,  
Doha, Vancouver, San Francisco, Copenhagen, Sydney, ...

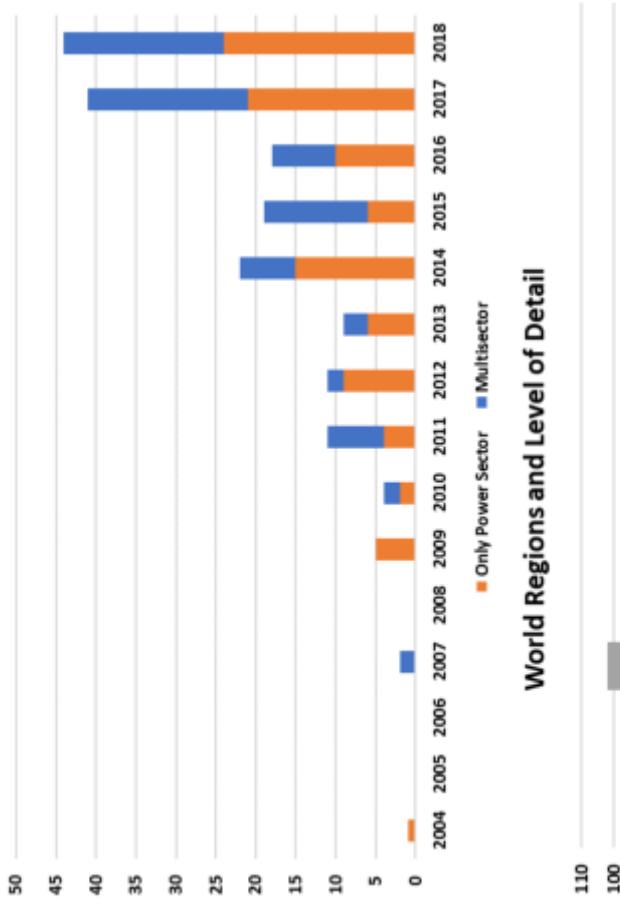
**Companies with 100% RE targets, e.g.:**

Google, Microsoft, Coca-Cola, IKEA, Wärtsilä, Walmart, ...

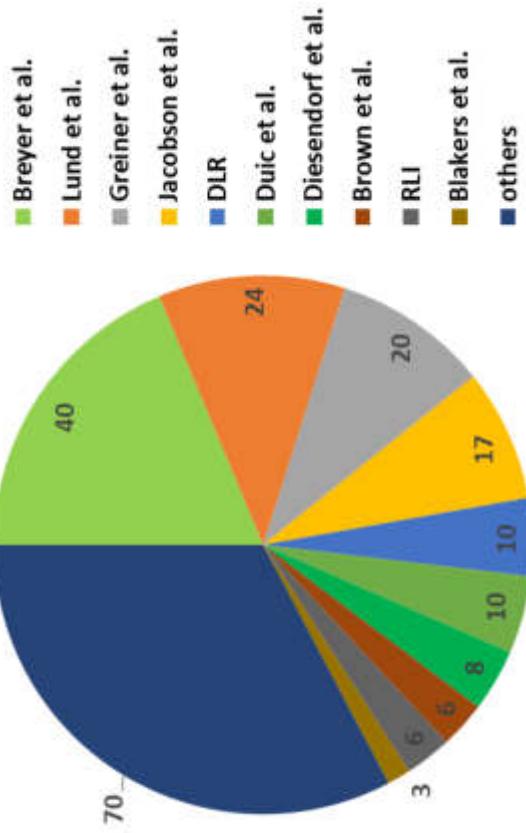


[www.100-ee.de/](http://www.100-ee.de/)

# 100% RE articles in recent years



Journal articles on 100% RE for regions



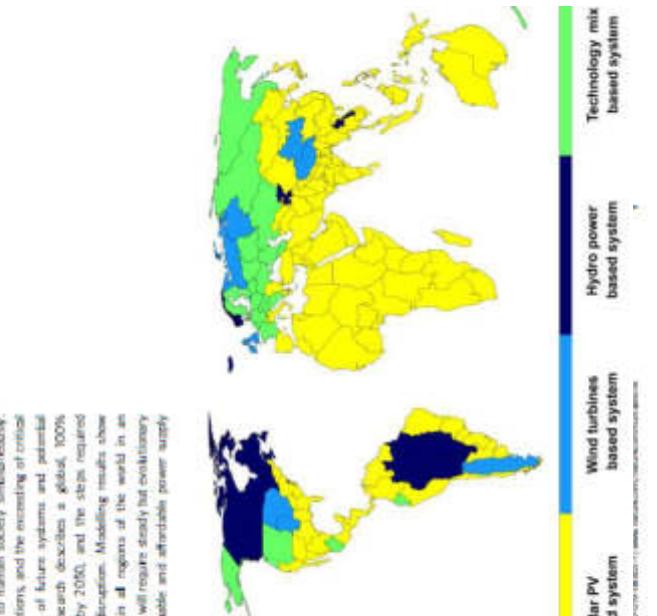
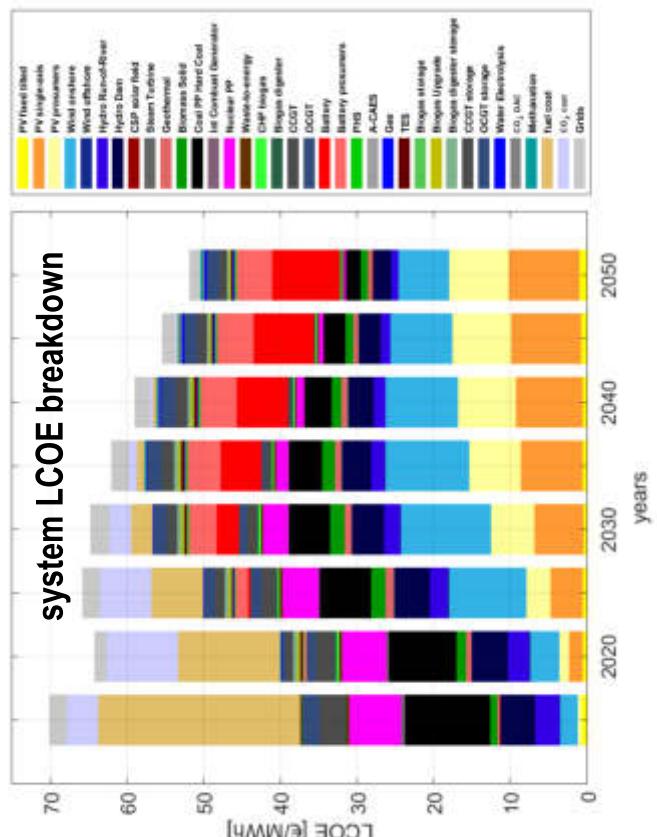
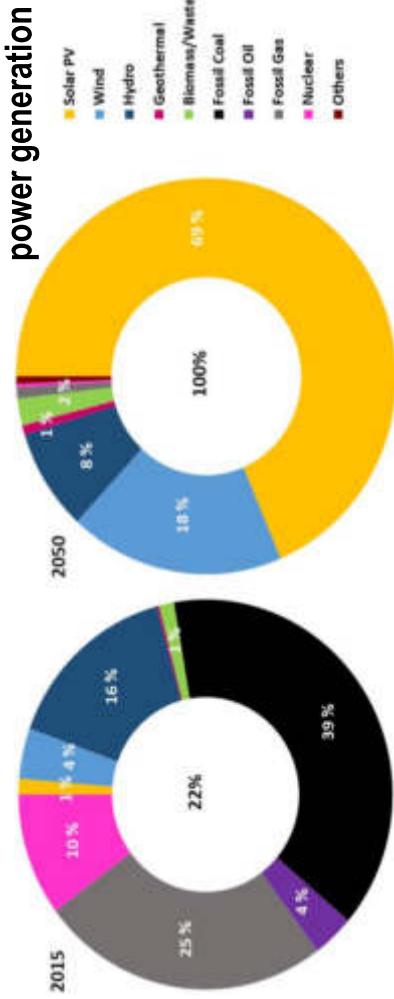
## Key insights:

- Research field exists since about 10 years
- Most publications are in hourly resolution
- More multisector publications
- Europe (FI, DK, DE) is hot spot of 100% RE research
- Gaps are in regional coverage and sectoral coverage (industry, NETs), temporal range (21st century)
- Community starts to get impact on neighbouring fields (e.g. IAMs, IPCC), but still ignored for major reports (IEA, IRENA, Shell & Co., most governments)

source: [Hansen, Breyer, Lund H., 2019. Energy, 175, 471-480](#)

Clean up the grid, and electrify almost everything – Global-local view  
Christian Breyer ► christian.breyer@lut.fi @ChristianOnRE

# 100% RE for Power Sector



## Area demand:

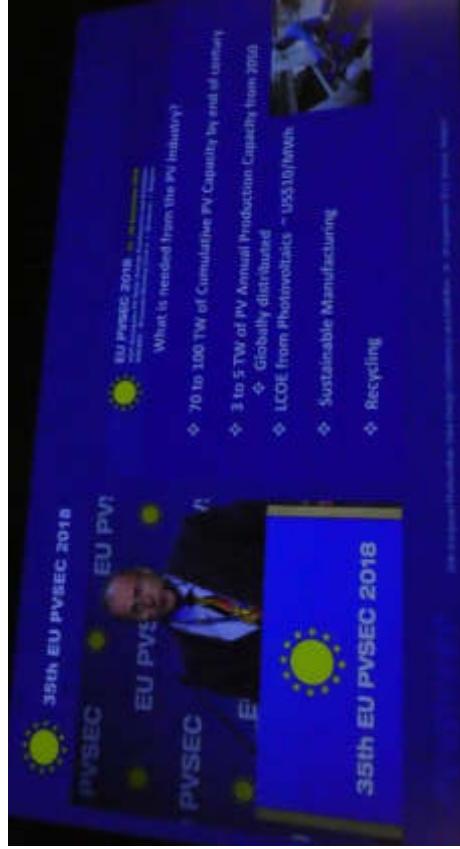
- Wind: 4% max per region; 0.3% of land area used
- Solar PV rooftop is zero impact area; ground-mounted is 0.14% of total global land area

Clean up the grid, and electrify almost everything – Global-local view  
Christian Breyer ► christian.breyer@lut.fi @ChristianOnRE

source: [Breyer et al., 2018., Progress in Photovoltaics, 26, 505-523;](#)  
[Bogdanov et al., 2019. Nature Communications, 10, 1077](#)

# How radical is this scenario?

Obviously the way forward for leaders of the PV community



- Martin Green, UNSW, Sydney, key developer of the currently used solar cell types and PV master mind
- Pierre Verlinden, former Chief Scientist of Trina Solar, CN, AU, BE
- Zhenguo Li, President of Longi, the PV world market leader and PV company with the largest R&D budget in the industry
- Jeremy Leggett, founder of Solarcentury, SolarAid
- NREL, AST, Fraunhofer ISE, ETIP PV, ITRPV
- Claude Turmes, Energy Minister Luxembourg

Clean up the grid, and electrify almost everything – Global-local view  
Christian Breyer ► christian.breyer@lut.fi

source: [speech of Zhenguo Li, President of Longi at BNEF conference, London, October 22, 2018 \(at 6:00\)](#)

# Society changes. [www.scientists4future.org](http://www.scientists4future.org)

Open your mind. LUT.  
Lappeenranta University of Technology

By Sam Morgan | [@SamMorgan1](#) | Mar 5, 2019 | [\(Reposted\)](#) | Mar 5, 2019

## Five EU countries call for 100% renewable energy by 2050

The European Union's 28 energy ministers had their first public debate on the European Commission's 2050 climate plan on Monday 4 March. But five member states decided the lack of a 100% renewable energy scenario among the EU executive's proposed options.

The Commission's 'Clean Planet for All' strategy, which detailed in November 2018, offers 28 countries eight different emission-cutting scenarios to make Europe's economy consistent with the

Climate change

"The beginning of great change: Greta Thunberg hails school climate strikes

The 16-year-old's lone protest last summer has morphed into a powerful global movement challenging politicians to act.

Taking part? Share your stories.



From Twitter

Tweets by [@GretaThunberg](#)

Christian Schwartek  
[@Schwartzek](#)  
Gespräch mit dem EU-Klima- und Umweltminister Christian Schwartek über die Zukunft des EU-Klimaschutzes. Er erläutert die Vorschläge der EU-Kommission für ein Klimapaket bis 2050 und wie sie die EU-Klimaziele erreichen können. Er betont, dass die EU-Klimaziele nicht ausreichen, um das Klima zu schützen. Er fordert eine verstärkte Beteiligung der Bevölkerung und der Wirtschaft an den Klimaschutzmaßnahmen.

From Twitter

Tweets by [@GretaThunberg](#)

Christian Schwartek  
[@Schwartzek](#)  
Gespräch mit dem EU-Klima- und Umweltminister Christian Schwartek über die Zukunft des EU-Klimaschutzes. Er erläutert die Vorschläge der EU-Kommission für ein Klimapaket bis 2050 und wie sie die EU-Klimaziele erreichen können. Er betont, dass die EU-Klimaziele nicht ausreichen, um das Klima zu schützen. Er fordert eine verstärkte Beteiligung der Bevölkerung und der Wirtschaft an den Klimaschutzmaßnahmen.



ARD\*

Greta Thunberg is hopeful the student climate strike on Friday can bring about positive changes as young people in more and more countries join the protest movement she started last summer as a lone campaigner outside the Swedish parliament.

ARD Home Nachrichten [tagesschau.de](#)

ARD\*

Greta Thunberg is hopeful the student climate strike on Friday can bring about positive changes as young people in more and more countries join the protest movement she started last summer as a lone campaigner outside the Swedish parliament.

ARD Home Nachrichten [tagesschau.de](#)



Scientists for Future

"Die junge Generation hat Recht"

Stand: 12.3.2019 9:44:01,001



Die Schüler, die jeden Freitag für das Klima auf die Straße gingen, bekommen Unterstützung aus der Wissenschaft: 12.000 "Scientists for Future" haben eine Petition gestartet.

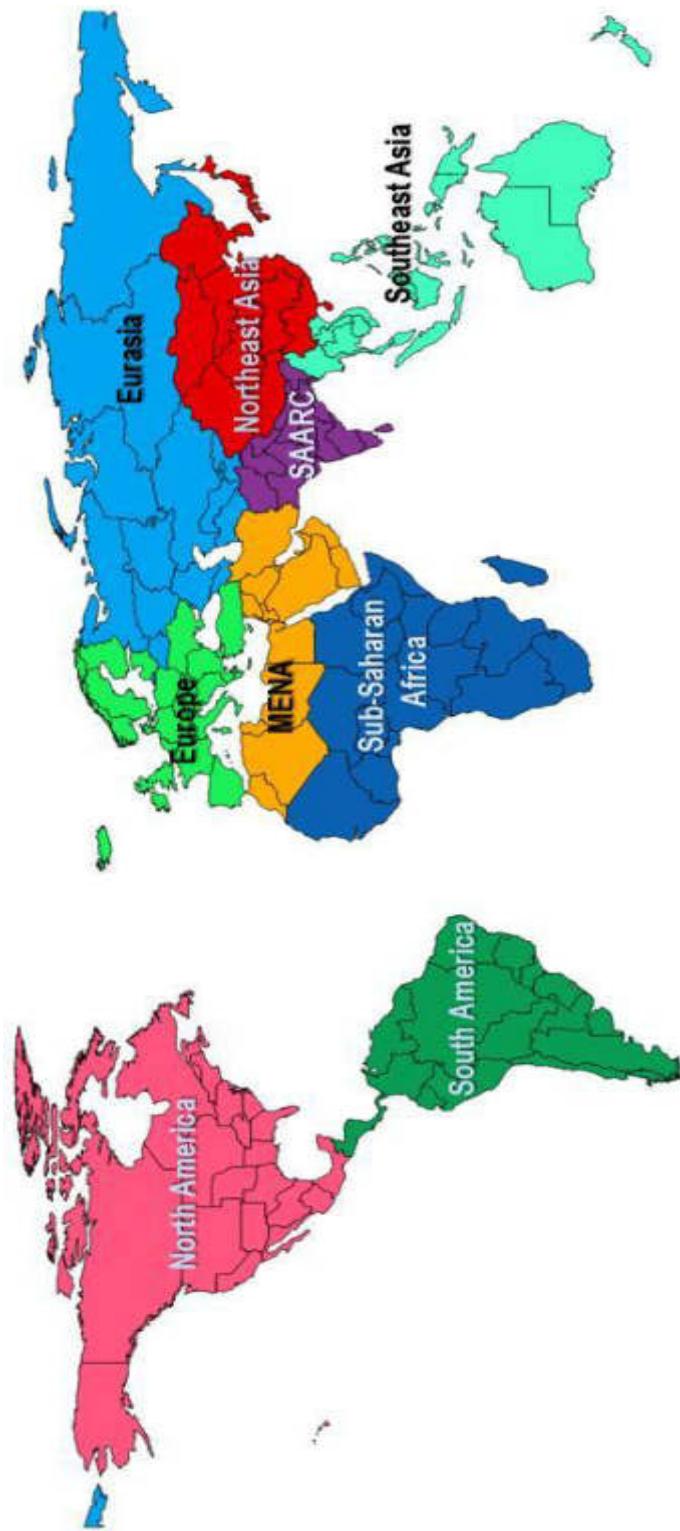
Von Christof Leyh (Weltamt), ARD-Hauptstadtstudio



KORRESPONDENT



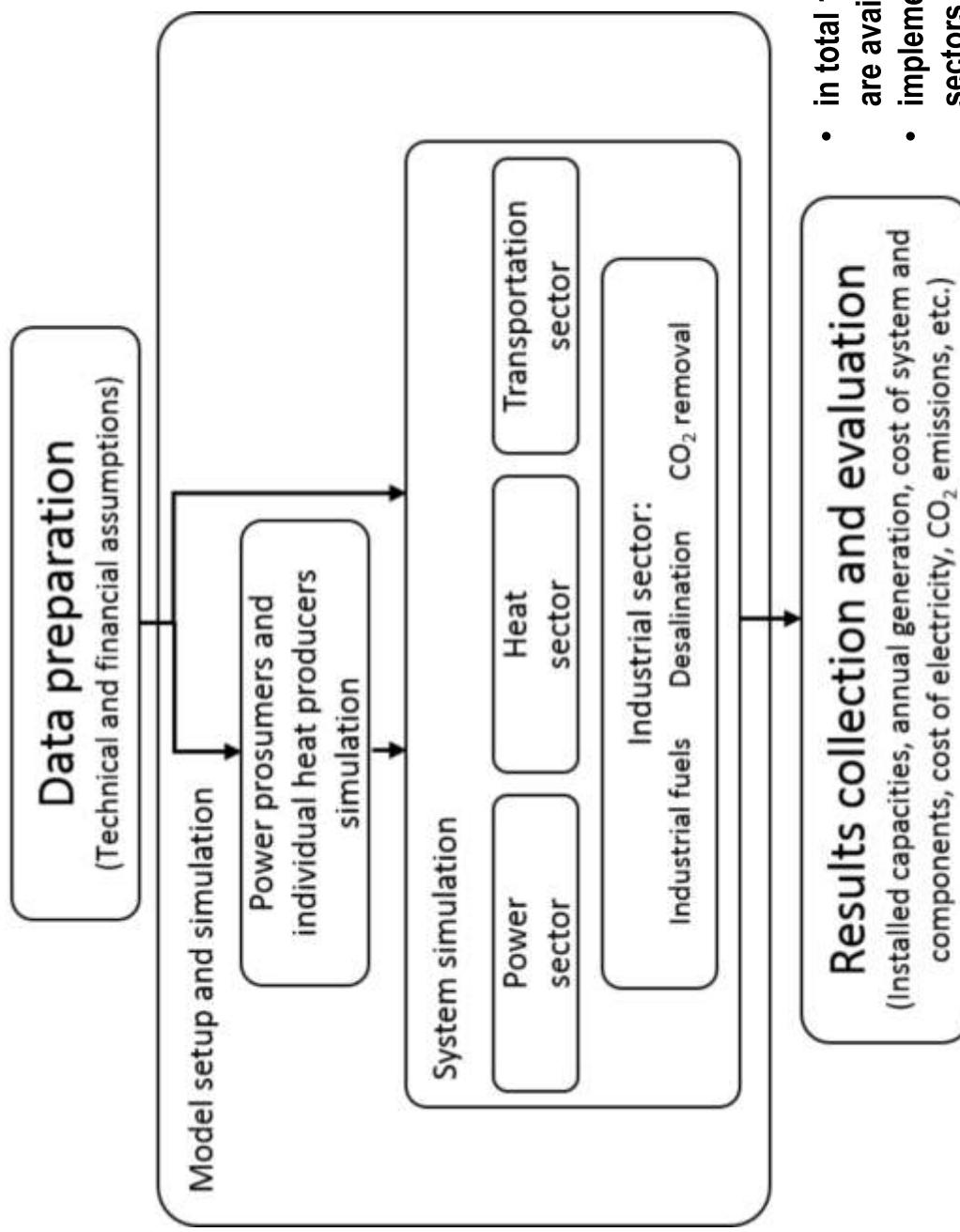
# Global Overview



- The world is structured into 9 major regions, which are further divided to 145 sub-regions
- Some sub-regions are comprised of more than one smaller (by population) country, while others represent parts of a larger country
- The sub-regions are interconnected by power lines within the same country
- The results shown are for the Power, Heat, Transport, Desalination sectors

# LUT Energy System Transition model

## Fundamentals: Data Flow

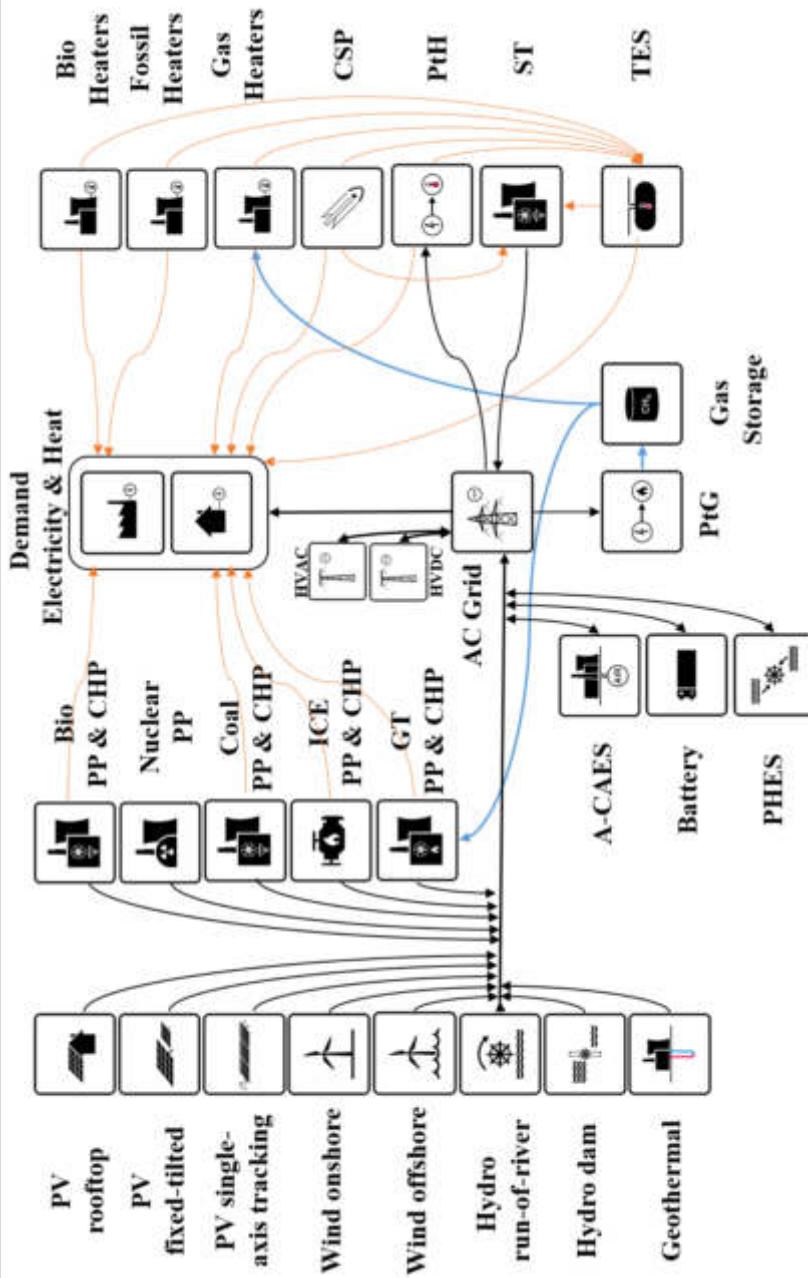


- in total 106 technology components are available for the model
- implemented in 2019: industrial sectors, off-grid, global trade, NETs



# LUT Energy System Transition model

## Power & Heat

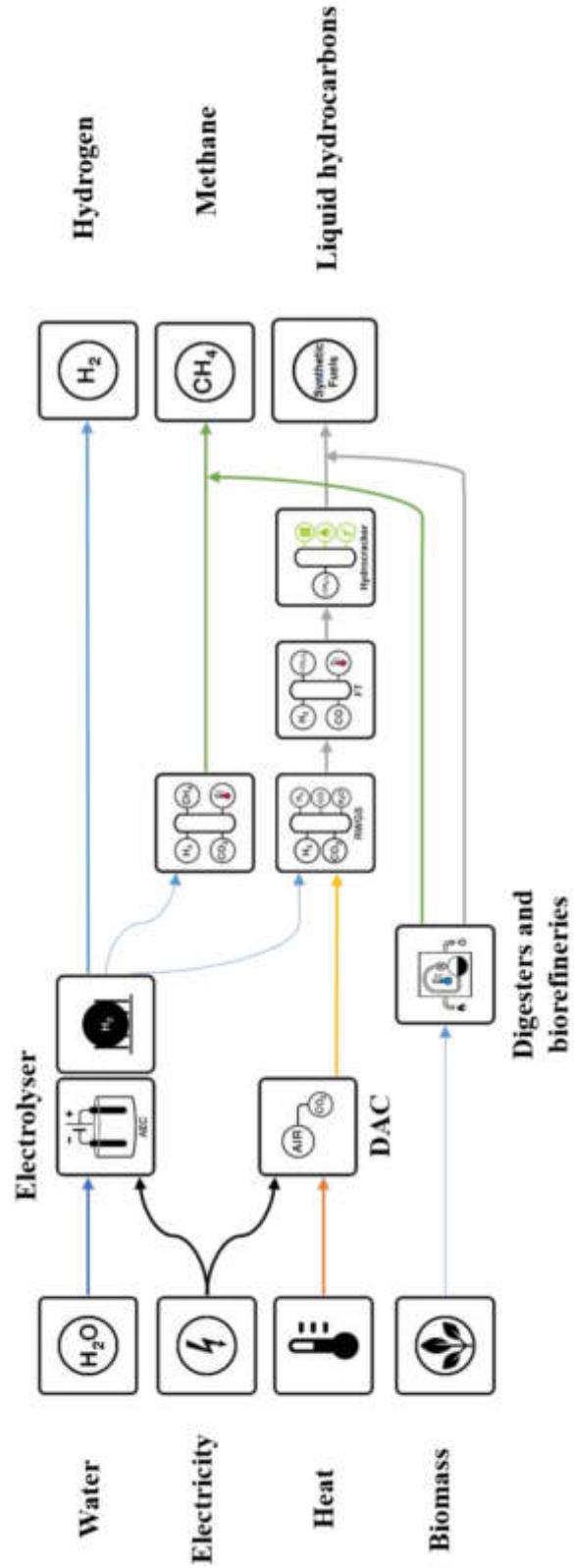
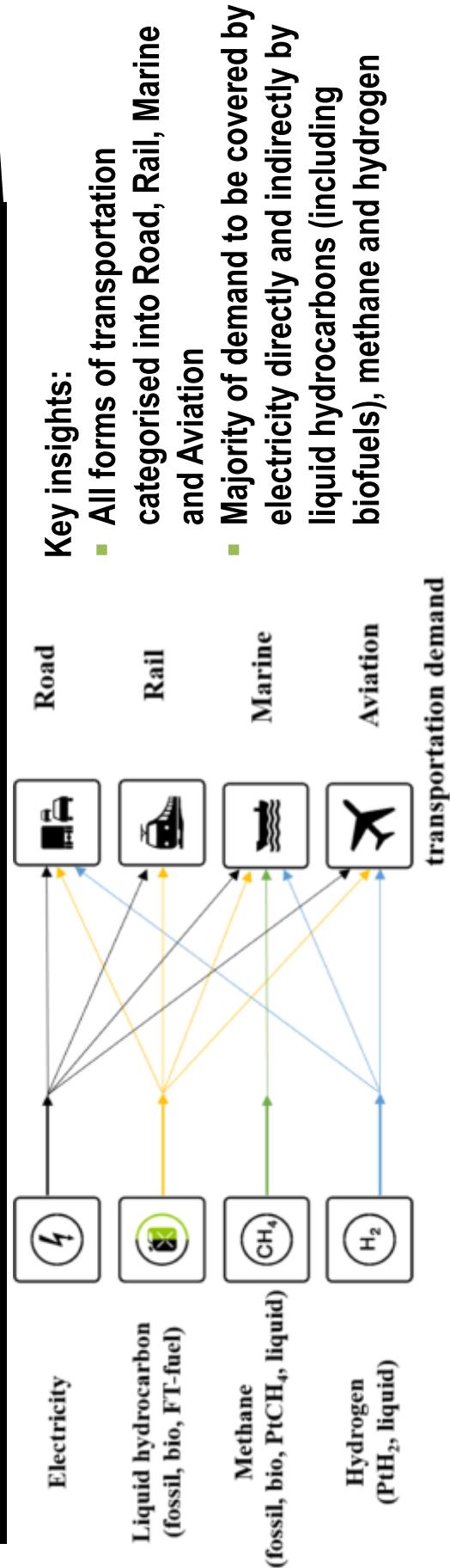


- The technologies applied for the energy system optimisation include those for electricity generation, heat generation, energy storage and electricity transmission
- The model is applied at full hourly resolution for an entire year
- The LUT model has been applied across all energy sectors



# LUT Energy System Transition model

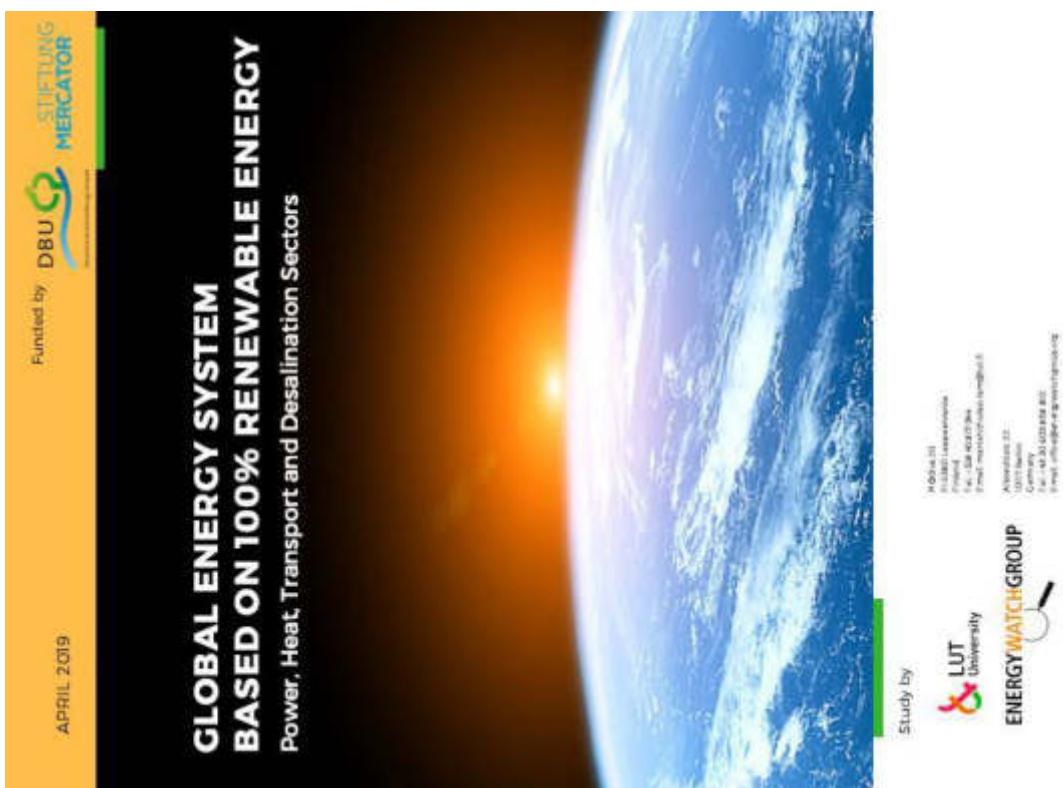
## Transport



ENERGYWATCHGROUP

Clean up the grid, and electrify almost everything – Global-local view  
 Christian Breyer ► christian.breyer@lut.fi

# Reports: Europe (COP24), Global (released April 12)



Both reports are available for download

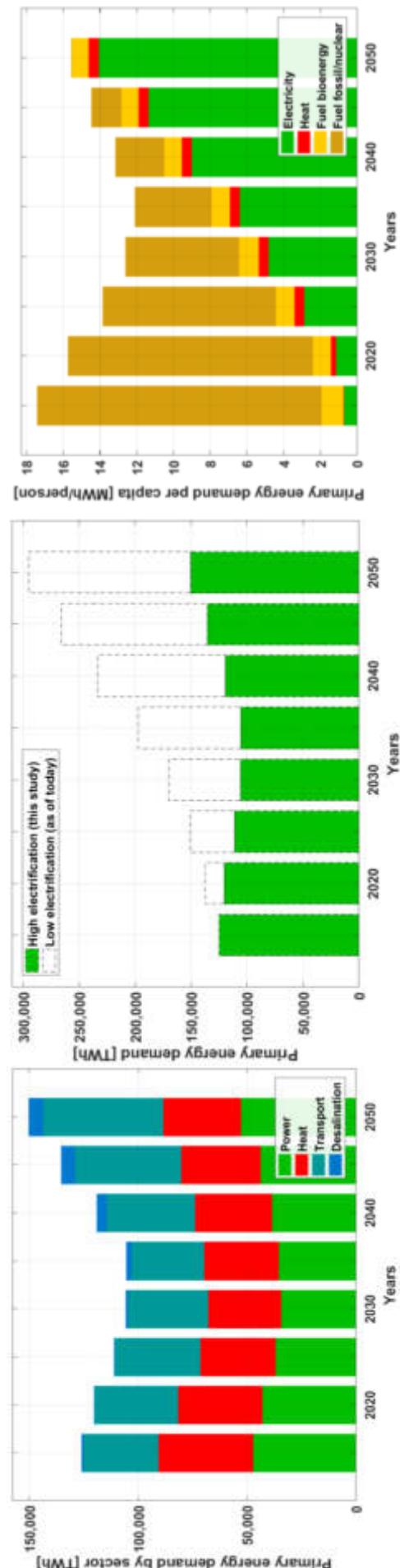
[www.energywatchgroup.org](http://www.energywatchgroup.org)



ENERGYWATCHGROUP  
MAGNETIC

Clean up the grid, and electrify almost everything – Global-local view  
Christian Breyer ► christian.breyer@lut.fi

# Long-term Energy Demand

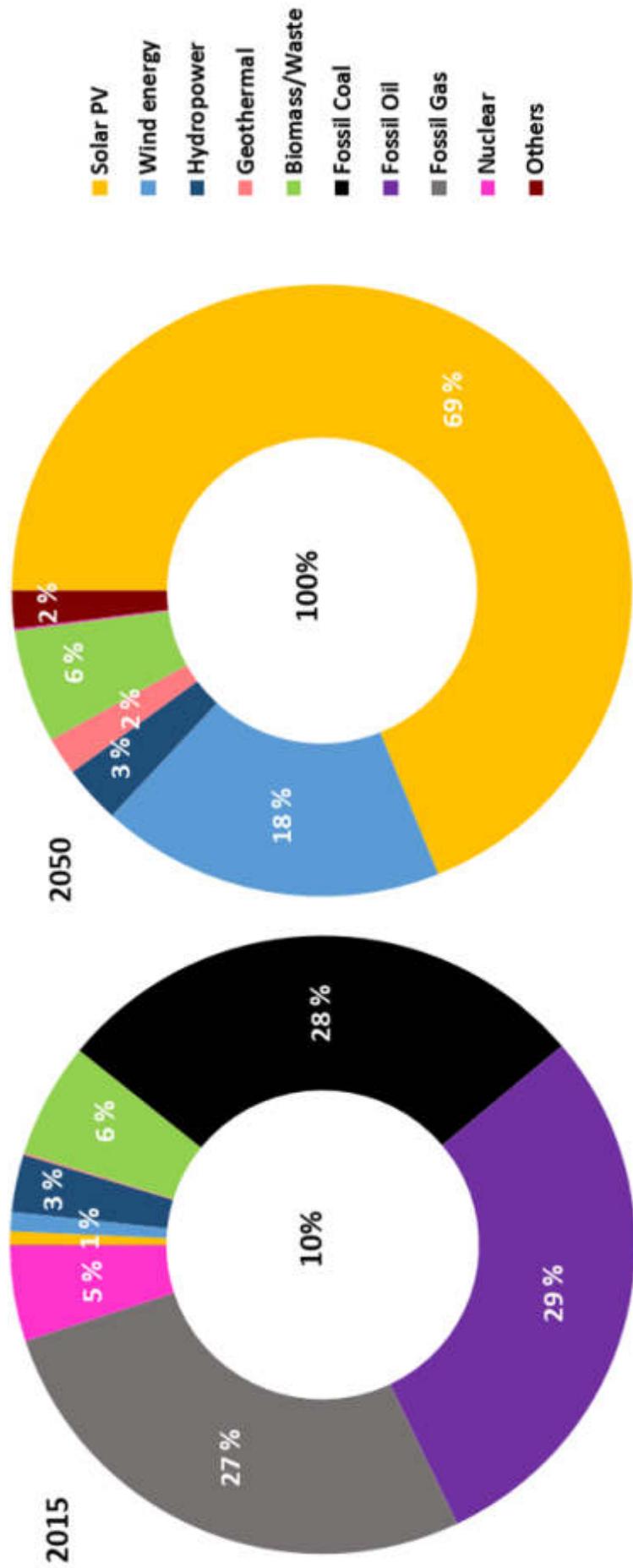


## Key insights:

- A global compound average annual growth rate of about 1.0% in final energy demand drives the transition. This is composed by final energy demand growth for power and heat, desalinated water demand and transportation demand linked to powertrain assumptions. This leads to a comprehensive electrification, which massively increases overall energy efficiency, to an even higher growth rate in provided energy services.
- This results in an average annual growth rate of about 0.5% in total primary energy demand (TPED).
- World population is expected to grow from 7.2 to 9.7 billion, while the average per capita PED decreases from around 17 MWh/person in 2015 to 12 MWh/person by 2035 and increases up to around 15 MWh/person by 2050.
- TPED decreases from almost 130,000 TWh in 2015 to around 105,000 TWh by 2035 and increases up to 150,000 TWh by 2050 in this study (which assumes high electrification).
- In comparison, current practices (low electrification) would result in a TPED of nearly 300,000 TWh by 2050.
- The massive gain in energy efficiency is primarily due to a high level of electrification of more than 90% in 2050, saving nearly 150,000 TWh compared to the continuation of current practices (low electrification).



# Total Primary Energy Demand Shares

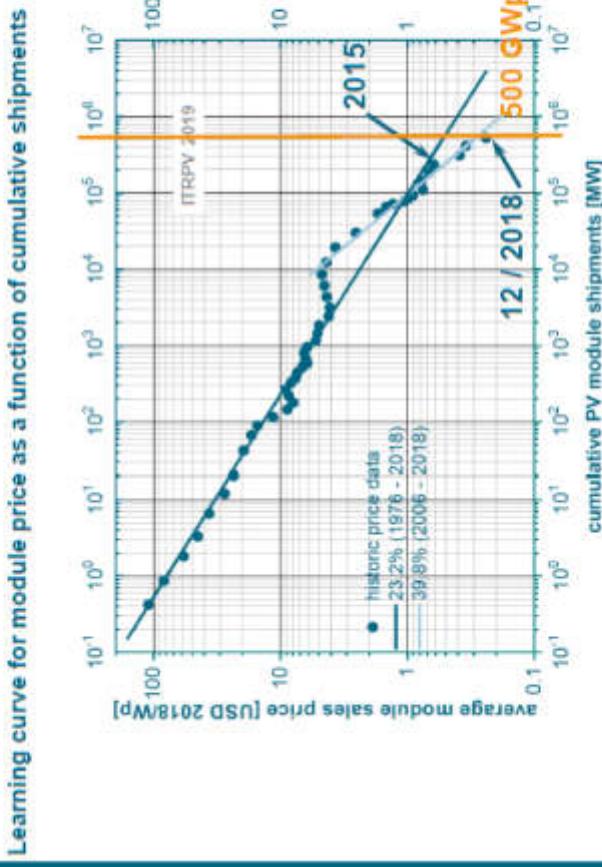


## Key insights:

- TPED shifts from being dominated by coal, oil and gas in 2015 towards solar PV and wind energy by 2050
- Renewable sources of energy contribute just 22% of TPED in 2015, while in 2050 they supply 100% of TPED
- Solar PV drastically shifts from less than 1% in 2015 to around 69% of primary energy supply by 2050, as it becomes the least cost energy supply source

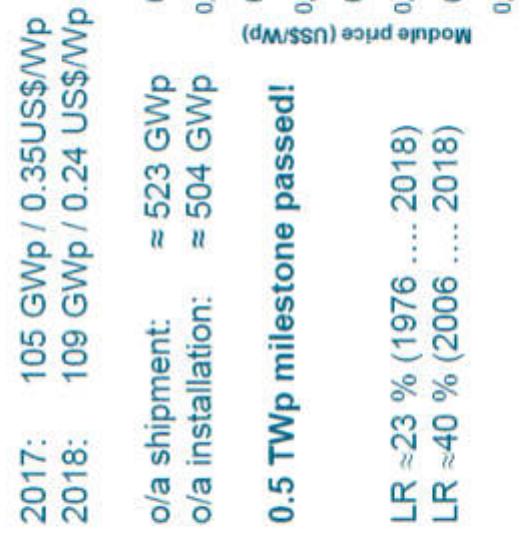
# Steep cost decline of PV

## PV learning curve



Shipments /avg. price at years end:

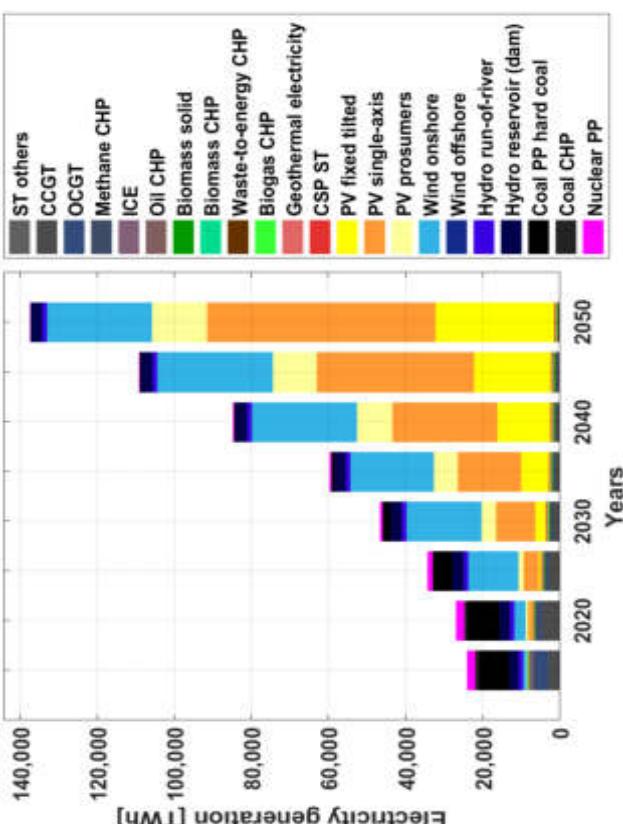
ITRPV



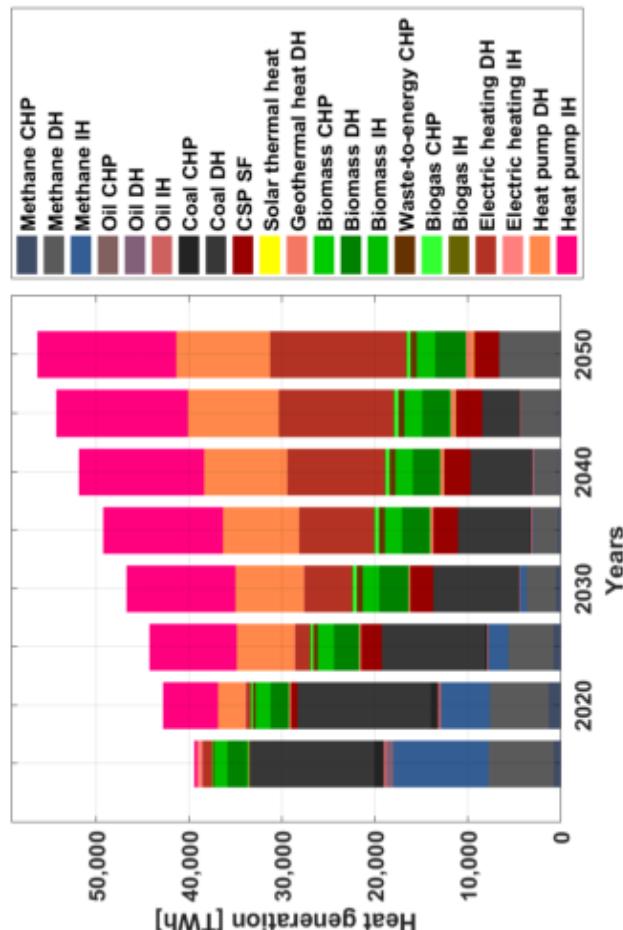
→ Stable volume shipped with huge price deterioration

# Energy Supply

## Electricity Generation



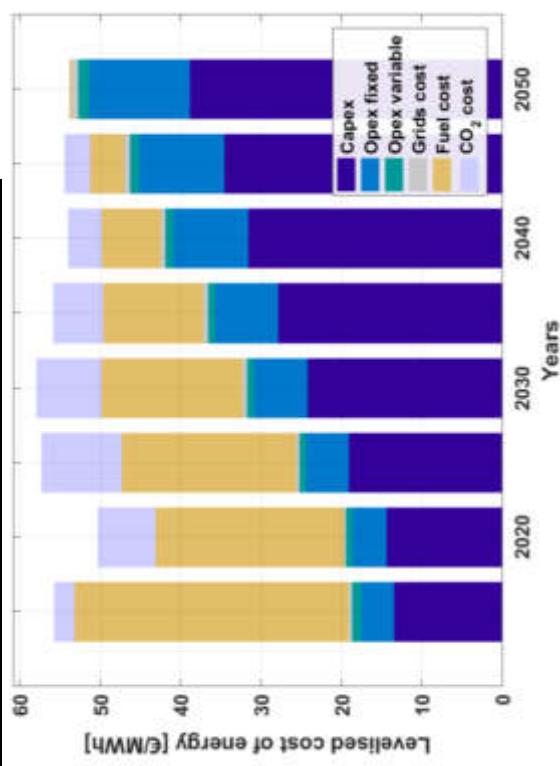
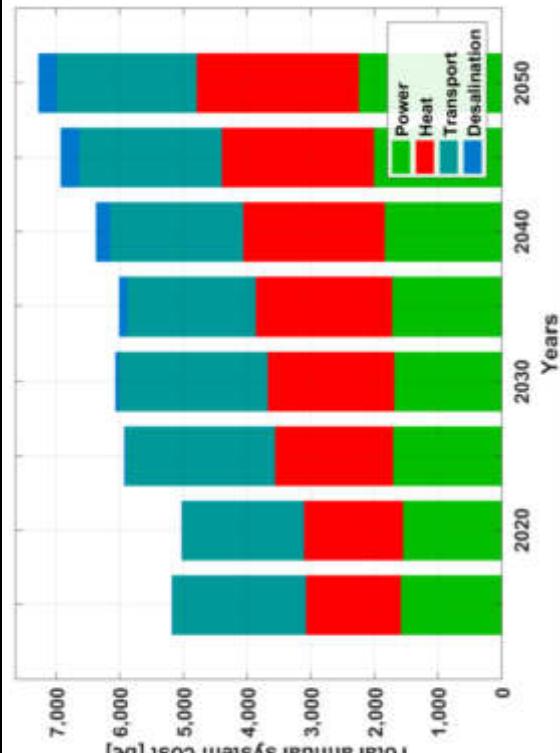
## Heat Generation



### Key insights:

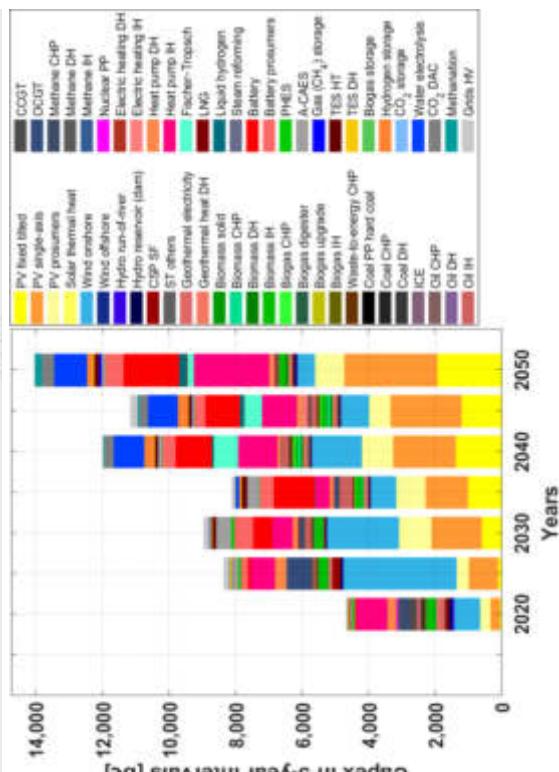
- Electricity generation is comprised of demand for all sectors (power, heat, transport, desalination)
- Solar PV supply increases from 32% in 2030 to about 73% in 2050 becoming the main energy source
- Wind energy increases to 43% by 2030 and steadily declines to about 20% till 2050
- Heat pumps play a significant role in the heat sector with a share of over 40% of heat generation by 2050 coming from heat pumps on district and individual levels with some shares of non-fossil gas and biomass based heating
- Gas-based heating decreases through the transition from above 40% in 2015 to around 11% by 2050

# Energy System Cost



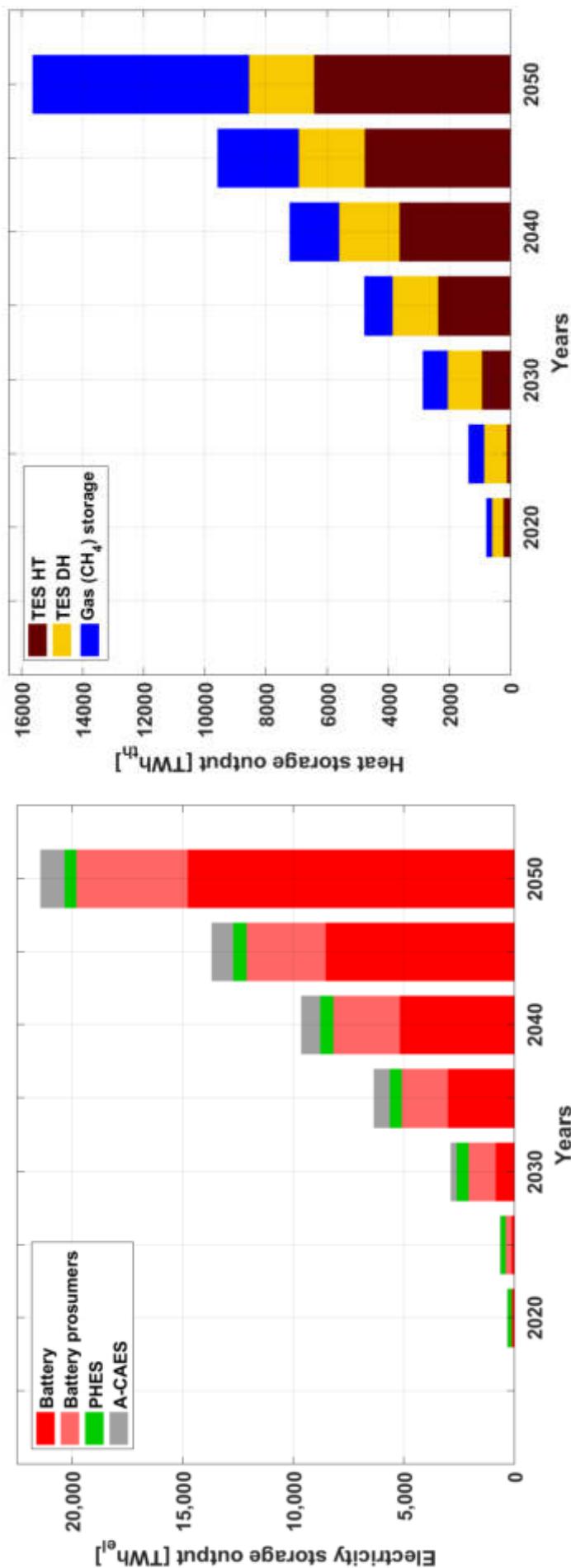
## Key insights:

- The total annual costs are in the range of 5100-7200 b€ through the transition period and well distributed across the 3 major sectors of Power, Heat and Transport
  - LCOE remains around 50-57 €/MWh and is increasingly dominated by capital costs as fuel costs lose importance through the transition period, which could mean increased self-reliance by 2050
  - Costs are well spread across a range of technologies with major investments for PV, wind, batteries, heat pumps and synthetic fuel conversion up to 2050
  - The cumulative investment costs are about 67,200 b€



# Sectoral Outlook

## Power & Heat – Storage Output



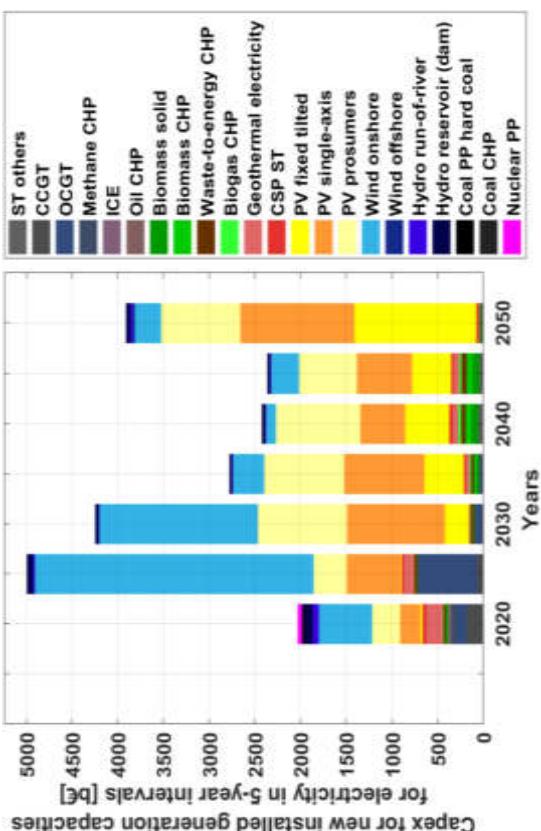
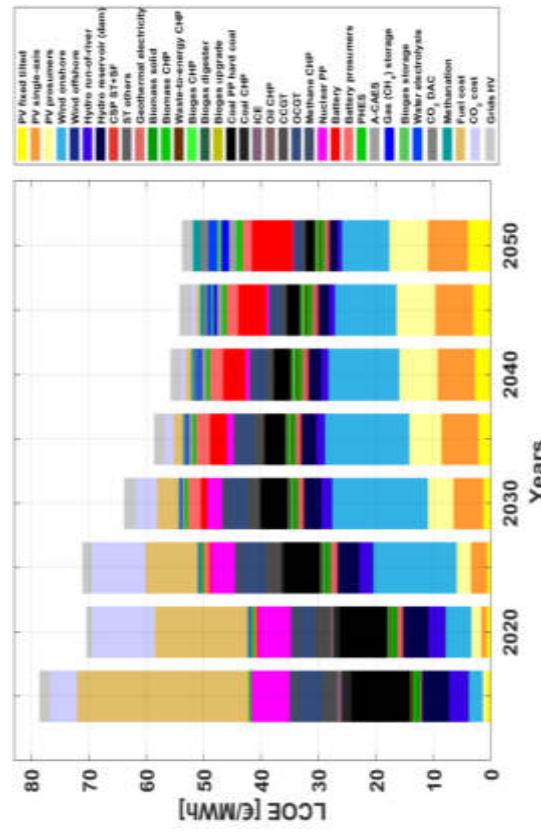
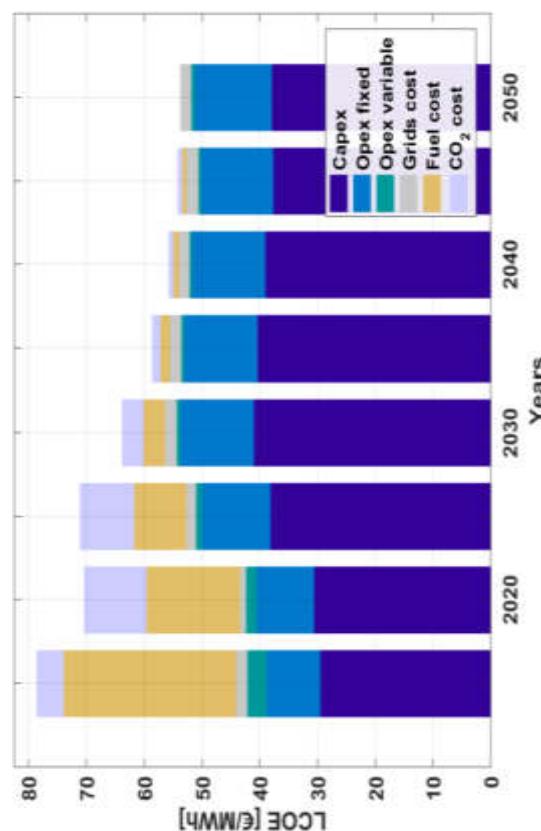
### Key insights:

- Utility-scale and prosumer batteries contribute a major share of the electricity storage output with nearly 92% by 2050
- Pumped hydro energy storage and compressed air energy storage contribute through the transition
- Thermal energy storage emerges as the most relevant heat storage technology with about 61% of heat storage output by 2050
- Gas storage contributes around 39% of the heat storage output in 2050 covering predominantly seasonal demand, which was covered by fossil gas before 2050



# Sectoral Outlook

## Power – Costs and Investments



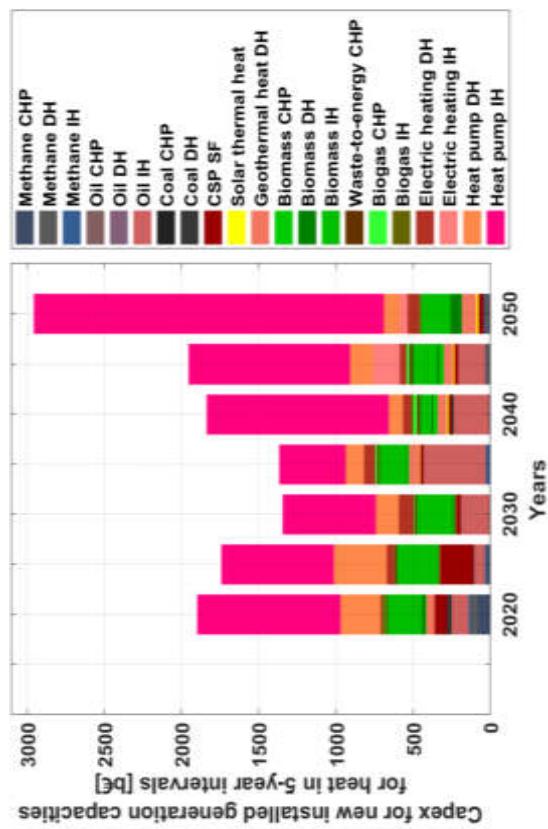
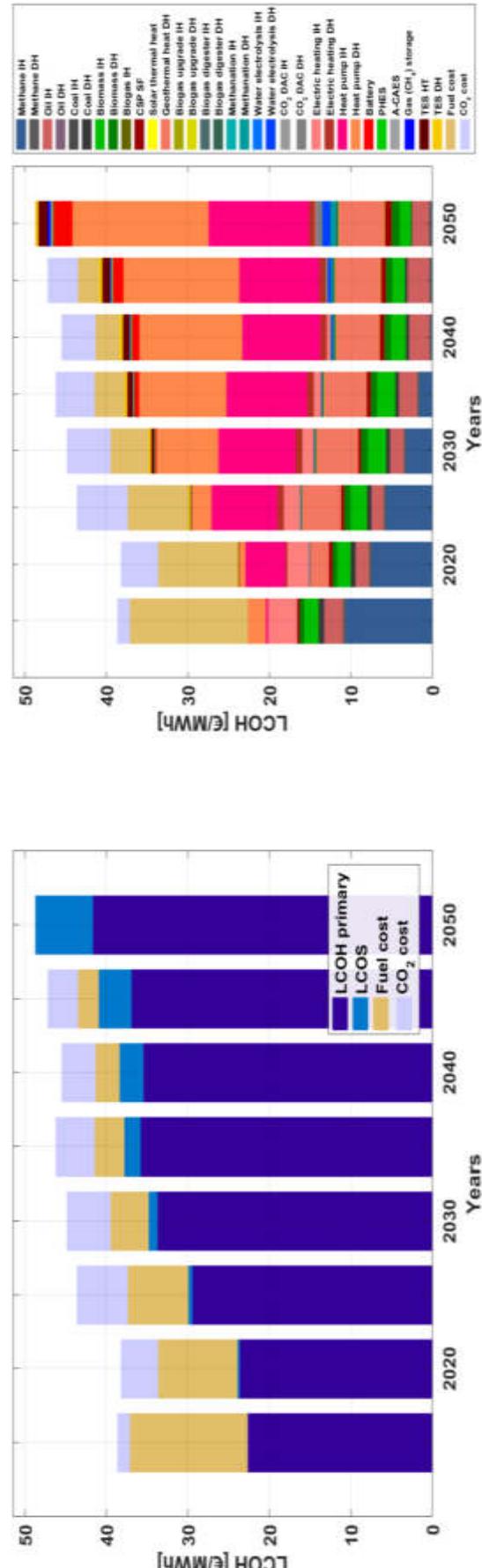
### Key insights:

- LCOE of the power sector decreases substantially from around 78 €/MWh in 2015 to around 54 €/MWh by 2050
- LCOE is predominantly comprised of capex as fuel costs decline through the transition
- Investments are well spread across a range of technologies with major share in solar PV, wind and batteries up to 2050
- In 2025, 2030 and 2050 major extra investments are needed for substituting phased-out fossil plants

## **Sectoral Outlook**

### **Heat - Costs and Investments**

## Heat - Costs and Investments

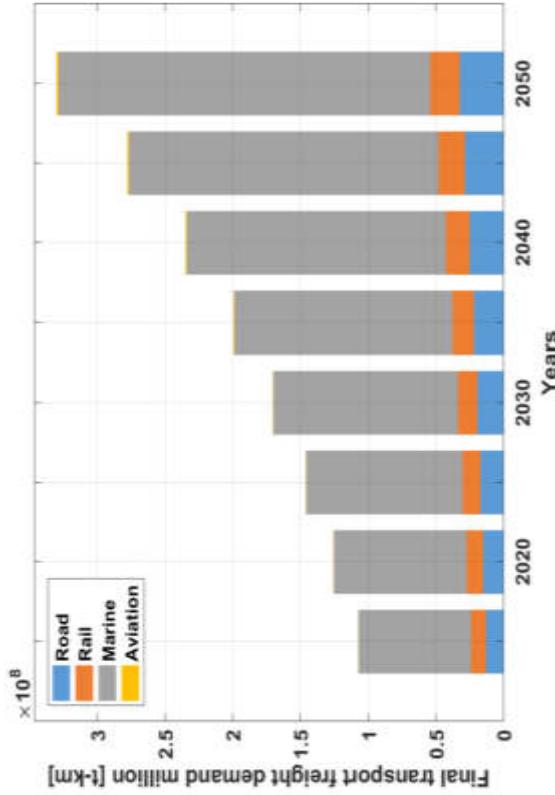
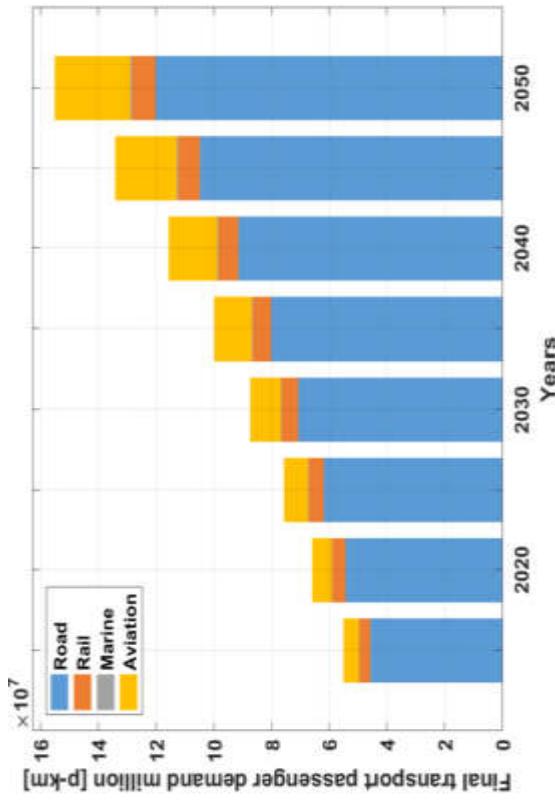


## **Key insights:**

- LCOH of the heat sector increases from around 39 €/MWh in 2015 to around 48 €/MWh by 2050
  - LCOH is predominantly comprised of capex as fuel costs decline through the transition
  - Investments are mainly in heat pumps and some shares in biomass heating up to 2050 and a steep increase in heat pump investments in 2050, replacing the remaining fossil-based heating systems

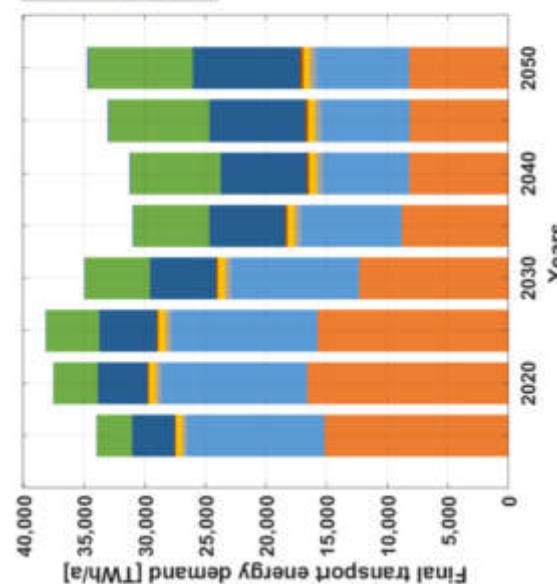
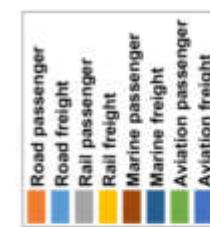
# Sectoral Outlook

## Transport – Demand



### Key insights:

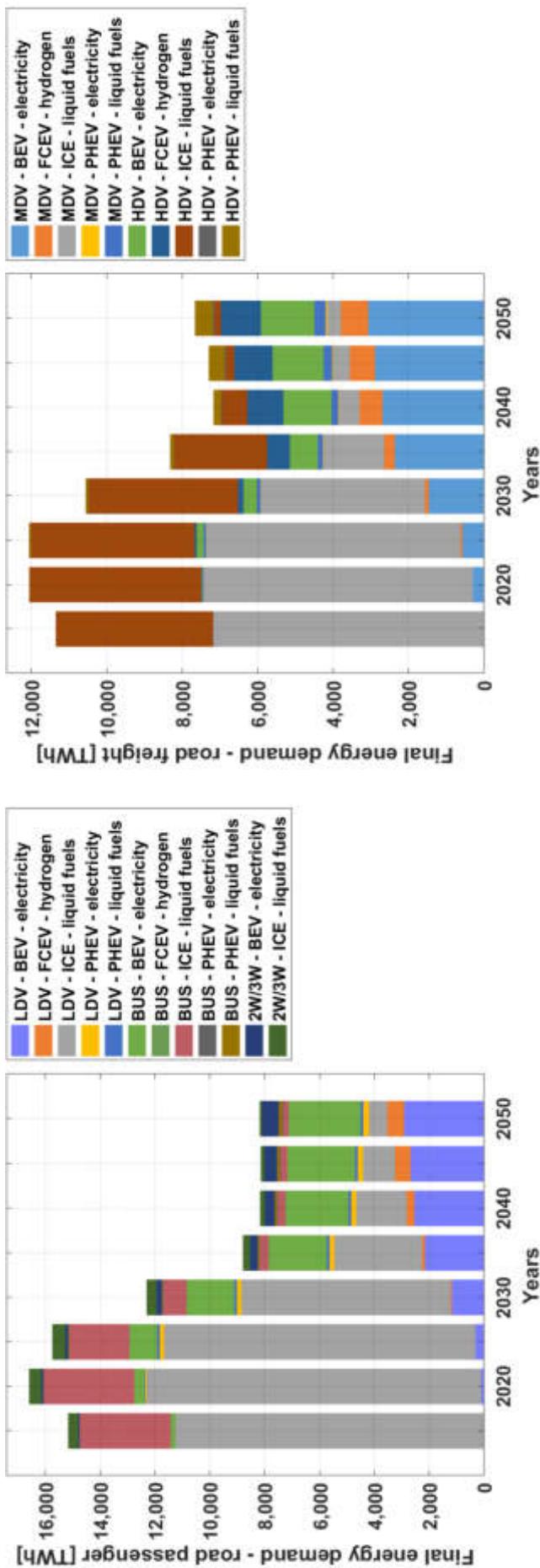
- The final transport passenger demand increases from around 50.8 million p-km to around 150.8 million p-km
- The final transport freight demand also increases from around 110 million t-km to around 330 million t-km
- Whereas, the final energy demand for overall transport increases slightly from 34,000 TWh/a in 2015 to 35,000 TWh/a by 2050, enabled by high efficiency of electric vehicles
- Marine freight is aligned to the scenario with a drastic decline in fuels transportation during the transition



ENERGYWATCHGROUP  
ENERGYWATCHGROUP

# Sectoral Outlook

## Transport – Road Demand

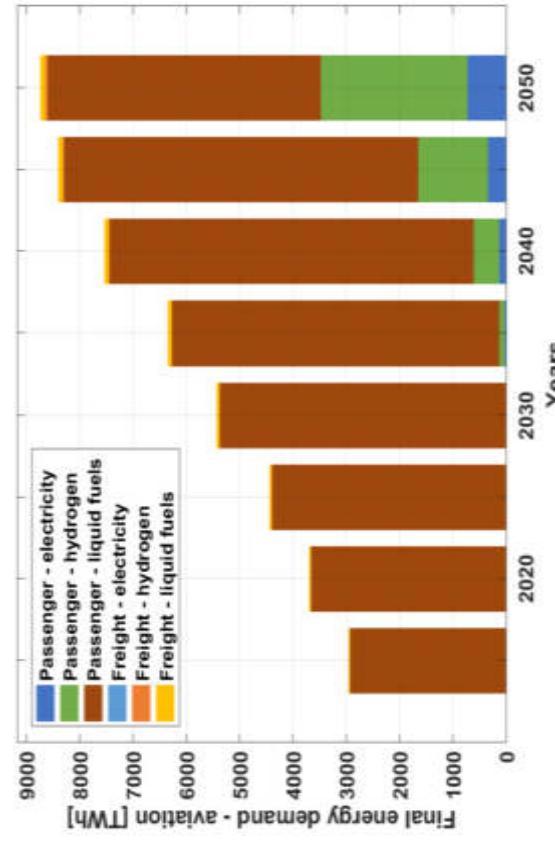
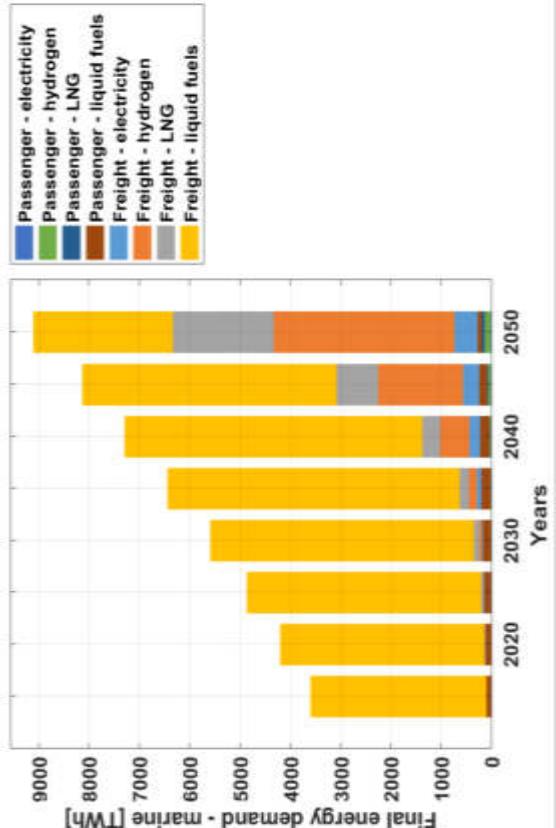
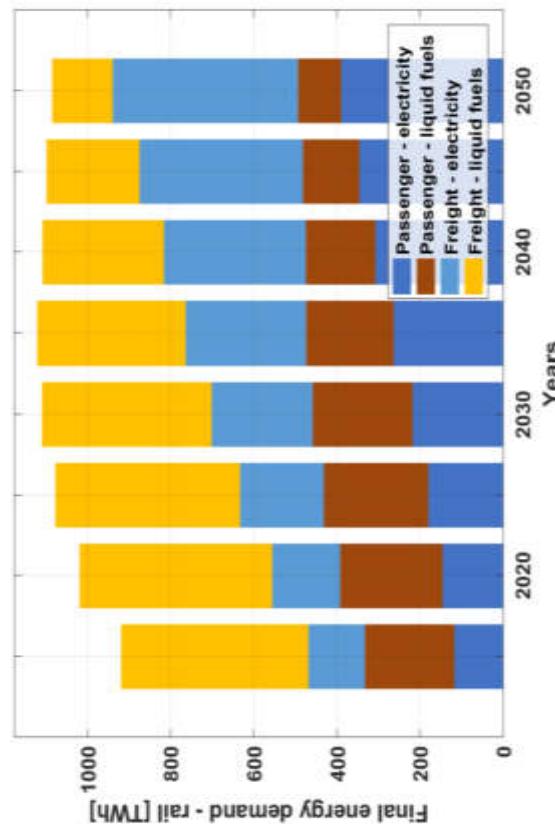


### Key insights:

- The final energy demand for road passengers decreases significantly from around 14,500 TWh in 2015 to just around 8000 TWh by 2050
- The final energy demand for road freight decreases substantially from around 11,500 TWh in 2015 to around 7700 TWh by 2050
- The significant decrease in final energy demand for overall road transport is primarily driven by the massive electrification

# Sectoral Outlook

## Transport – Rail, Marine and Aviation Demand

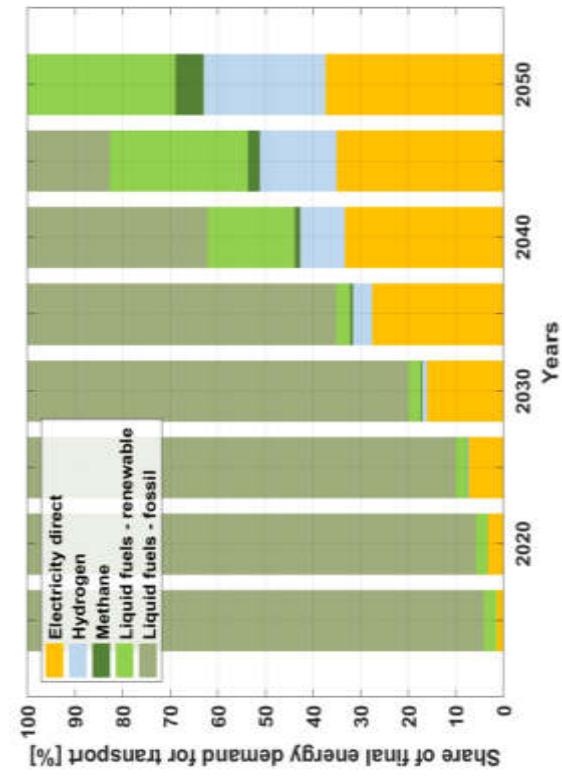
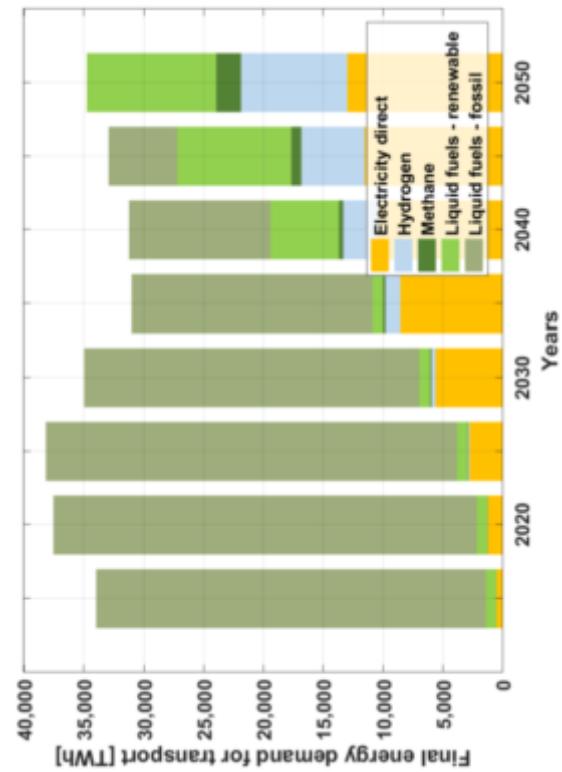


### Key insights:

- The final energy demand for rail transport increases from around 860 TWh in 2015 to around 1100 TWh by 2050
- The final energy demand for marine transport increases steadily from around 3600 TWh in 2015 to around 9000 TWh by 2050
- The final energy demand for aviation transport increases significantly from nearly 3000 TWh in 2015 to around 8800 TWh by 2050

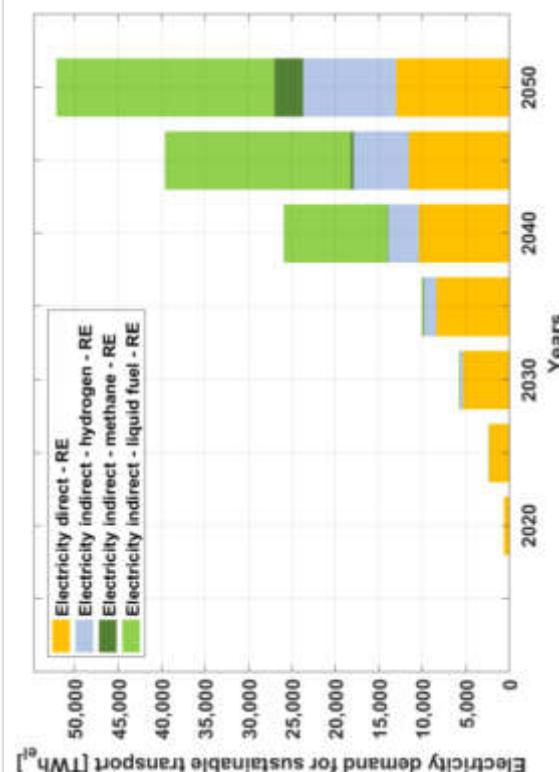
# Sectoral Outlook

## Transport – Defossilisation and Electrification



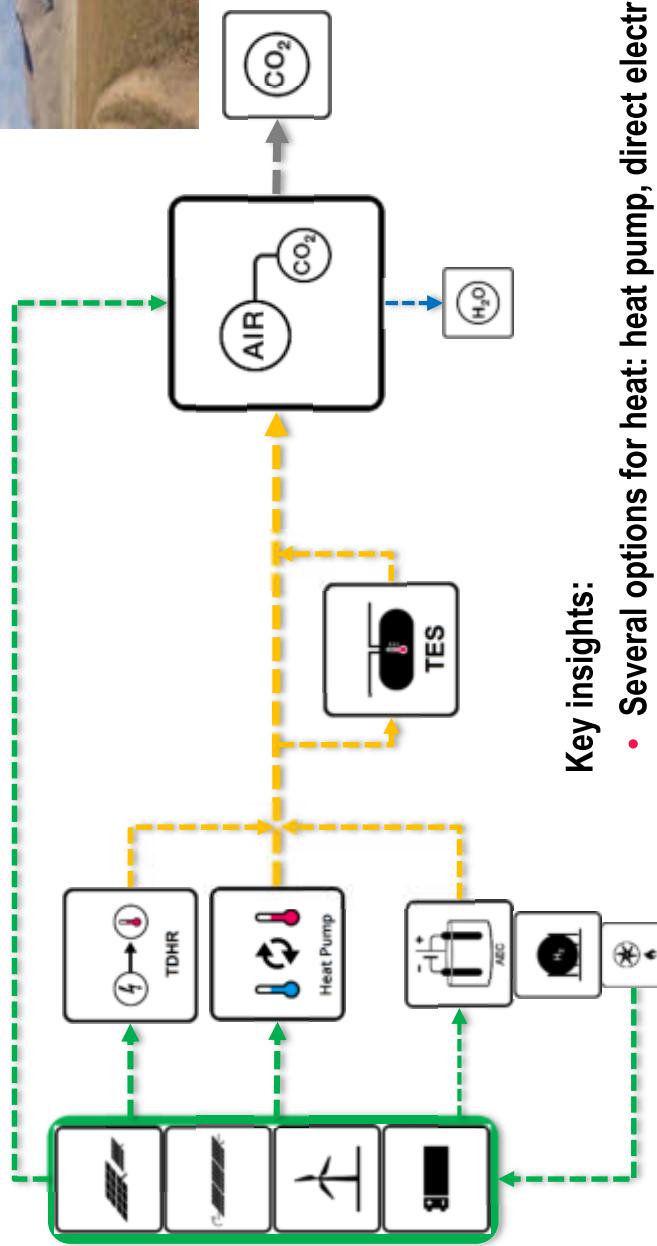
### Key insights:

- Fossil fuel consumption in transport is observed to decline through the transition from about 97% in 2015 to zero by 2050
- Liquid fuels produced by renewable electricity contribute around 31% of the final energy demand in 2050
- Hydrogen constitutes more than 26% of final energy demand in 2050
- Electrification of the transport sector creates an electricity demand of around 50,000 TWh<sub>el</sub> by 2050
- Massive demand for liquid fuels kicks in from 2040 onwards up to 2050



# Methodology

## RE-PtCO<sub>2</sub> Value Chain



### Key insights:

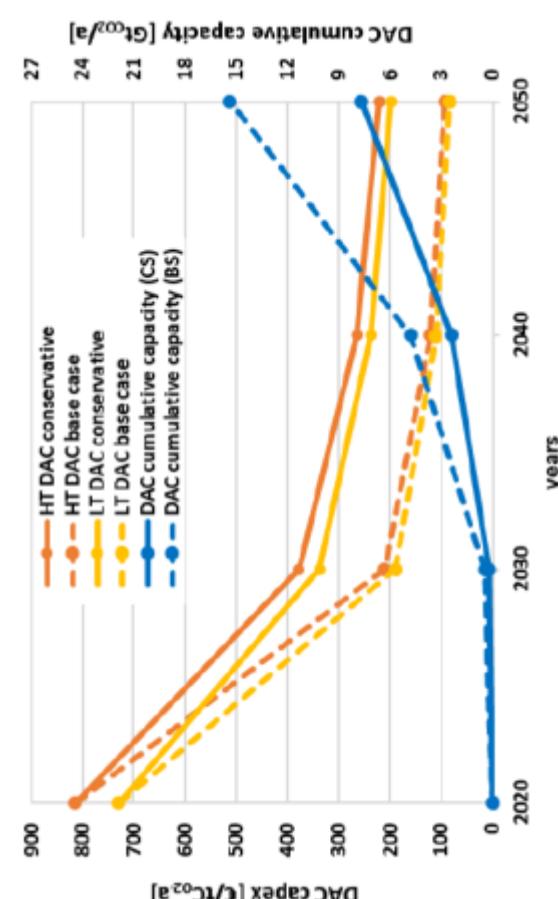
- Several options for heat: heat pump, direct electric heating or waste heat
- PtH<sub>2</sub>-fP as a second option for balancing electricity generation and consumption

• Dashed lines represent fluctuating flows  
• Continuous lines represent steady flows

Clean up the grid, and electrify almost everything – Global-local view  
Christian Breyer ► christian.breyer@lut.fi @ChristianOnRE

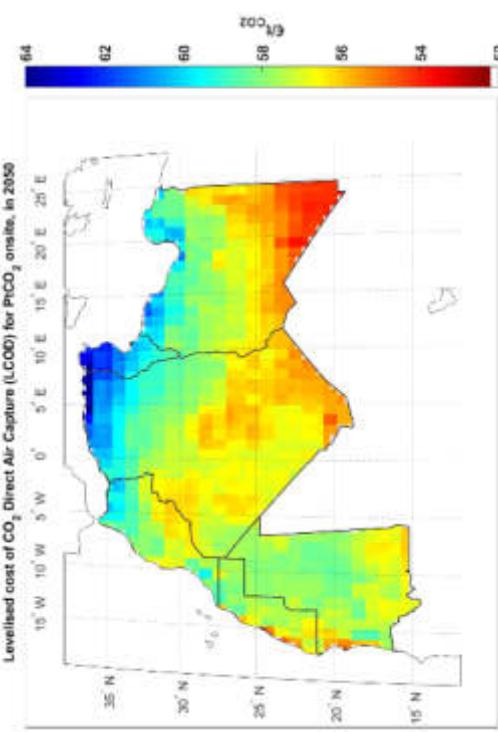
# LUT Energy System Model

## Financial Assumptions: CO<sub>2</sub> DAC



Sector	power-to-gas	unit	2020	2030	2040	2050
power	waste-to-energy	MtCO <sub>2</sub> /a	3	7	142	363
	sewage plant	MtCO <sub>2</sub> /a	0	-17	-99	-163
	road (cars/bus/trucks)	MtCO <sub>2</sub> /a	0	n/a	n/a	n/a
transport	rail	MtCO <sub>2</sub> /a	0	218	1309	1101
	marine	MtCO <sub>2</sub> /a	0	7	66	82
	aviation	MtCO <sub>2</sub> /a	0	56	962	1667
industry	chemical industry	MtCO <sub>2</sub> /a	0	54	964	1543
	pulp and paper	MtCO <sub>2</sub> /a	0	220	1054	2753
	cement mills (limestone)	MtCO <sub>2</sub> /a	0	-8	-52	-95
	others	MtCO <sub>2</sub> /a	0	-69	-425	-607
CO <sub>2</sub> DAC, energy system		MtCO <sub>2</sub> /a	0	n/a	n/a	n/a
CO <sub>2</sub> removal		MtCO <sub>2</sub> captured/a	3.0	470	3922	6642
other Negative Emission Technologies		MtCO <sub>2</sub> captured/a	0	0	10000	100000
CO <sub>2</sub> DAC, CO <sub>2</sub> removal		MtCO <sub>2</sub> /a	0	0	200	2000
CO <sub>2</sub> DAC, total		MtCO <sub>2</sub> /a	3	470	8766	8760

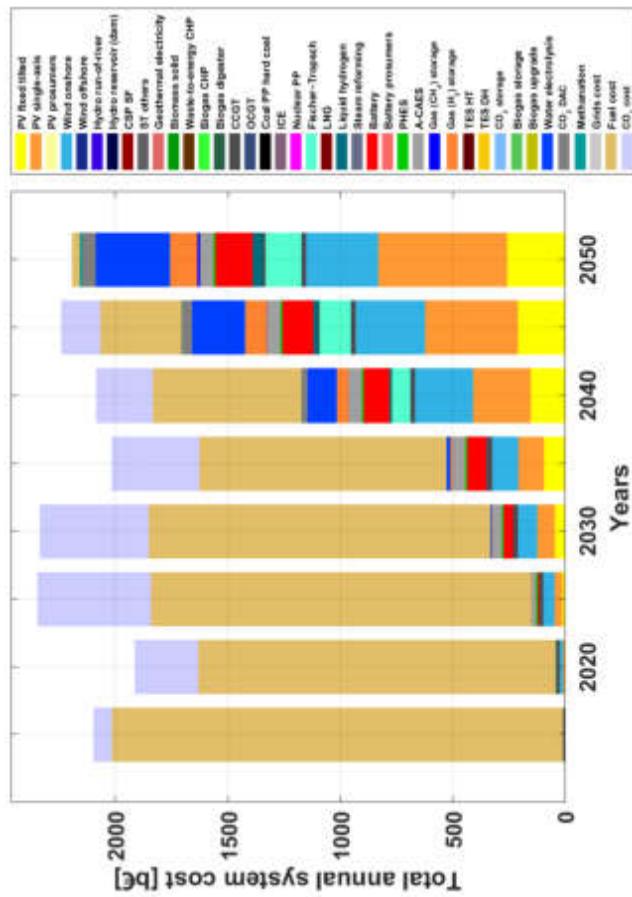
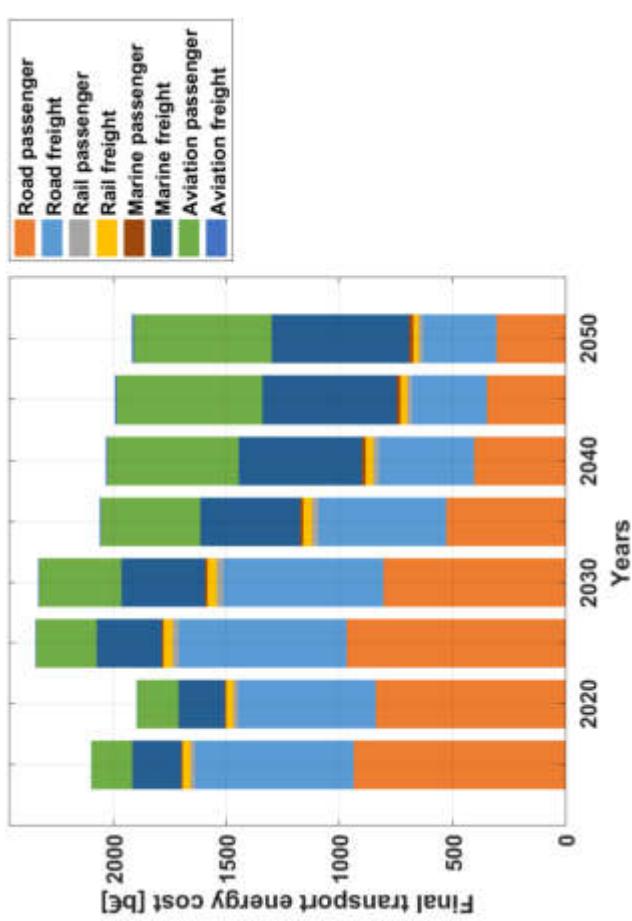
- Key insights:**
- DAC capex decline is driven by learning rate (10-15%) and capacity demand
  - Half of DAC capacity demand can be expected from the energy system
  - Half of DAC capacity demand can be expected from CDR
  - DAC business will become most likely a triple digit billion industry by 2050



Clean up the grid, and electrify almost everything – Global-local view source: [Fasihi M., et al., 2019. Journal of Cleaner Production, 224, 957-980; Breyer et al., 2019. Mitigation and Adaptation Strategies for Global Change, online](#)

# Sectoral Outlook

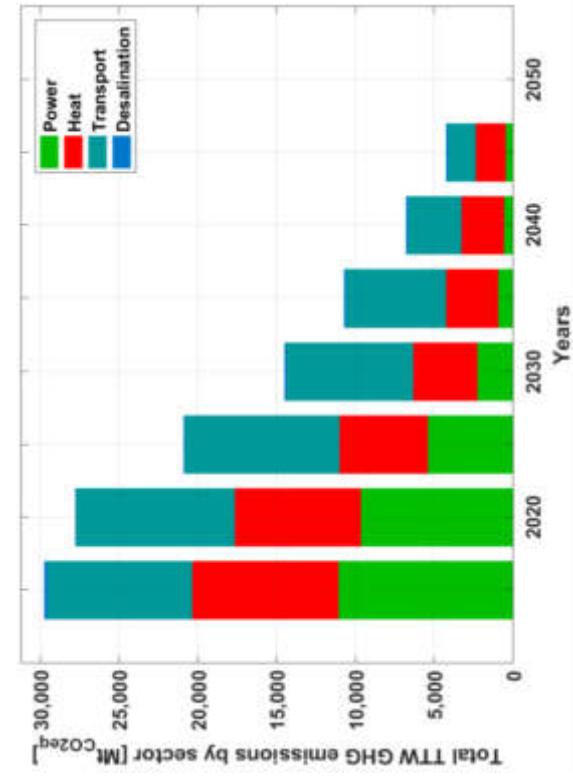
## Transport – Annual Energy Costs



### Key insights:

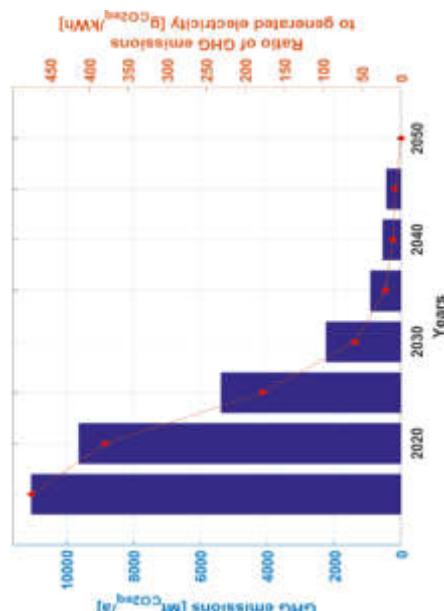
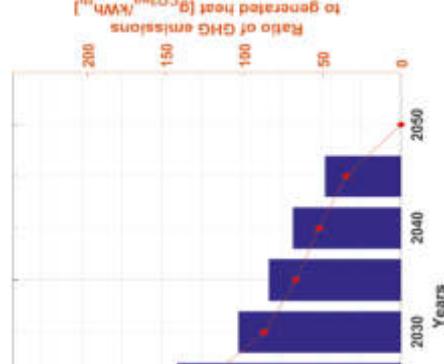
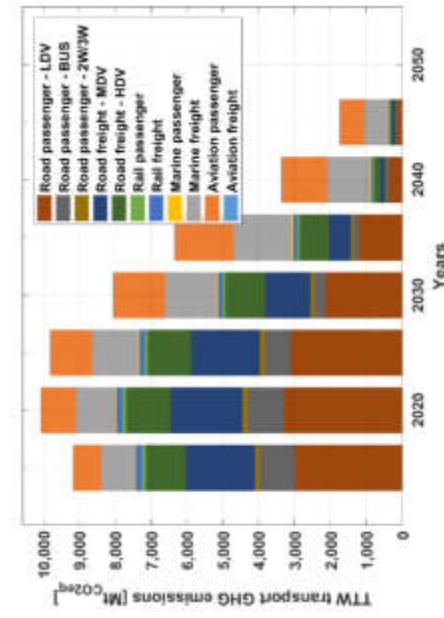
- The total annual energy costs for transport are in the range of 1900-2190 b€ through the transition period with a slight increase from around 2090 b€ in 2015 to about 2190 b€ by 2050
- Road transport forms a major share of the costs in the initial years up to 2030, beyond which the aviation mode dominates the share of costs as cost in the road mode declines through the transition up to 2050
- Rail and marine mode costs remain more steady through the transition
- Annual system costs transit from being heavily dominated by fuel costs in 2015 to a very diverse share of costs across various technologies for electricity, synthetic fuels and sustainable biofuel production by 2050
- FT units produce naphtha as by-product, which is included in overall system costs but not in transport cost

# GHG Emissions Reduction



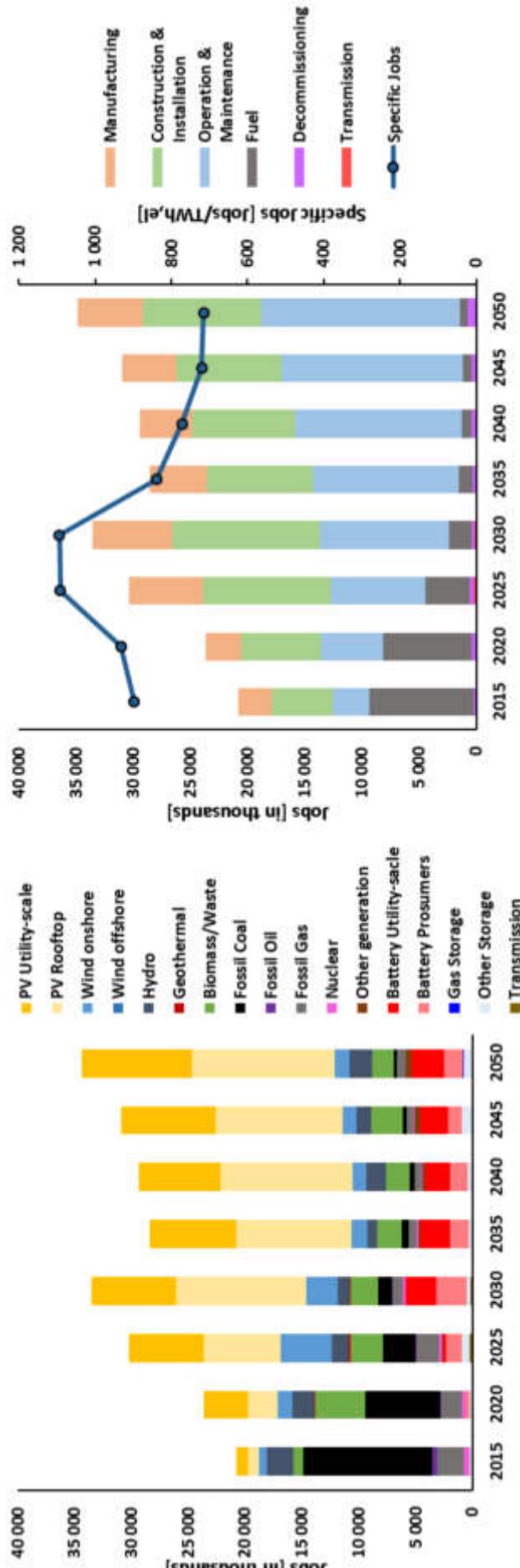
## Key insights:

- GHG emissions can be reduced from around 30,000 MtCO<sub>2</sub>eq in 2015 to zero by 2050 across all energy sectors
- The remaining cumulative GHG emissions comprise around 422 GtCO<sub>2</sub>eq from 2018 to 2050.
- The presented 100% RE scenario for the global energy sector is compatible with the Paris Agreement for 1.5°C Deep decarbonisation of the power and heat sectors is possible by 2030, while the transport sector is lagging and a massive decline of emissions is possible beyond 2030 up to 2050



ENERGYWATCHGROUP  
ENERGYWATCHGROUP

# Job Prospects – Power Sector

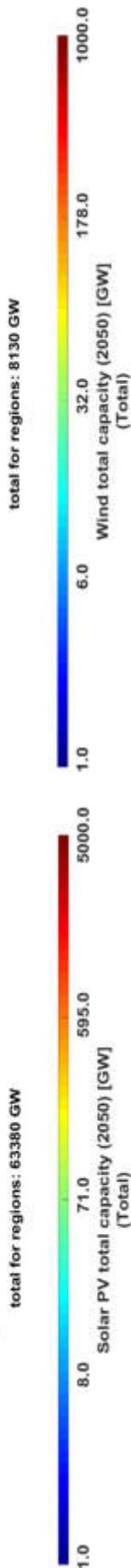
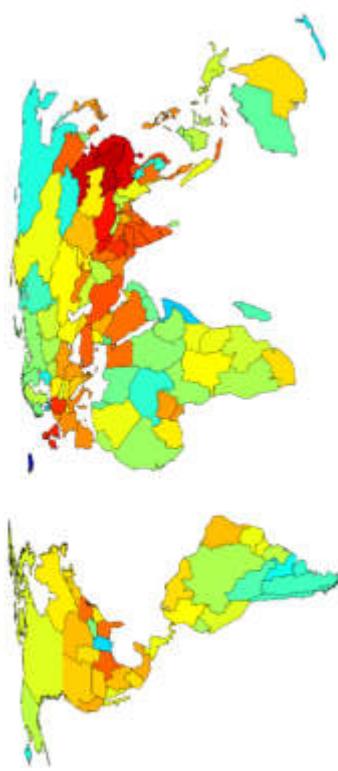


## Key insights:

- Total direct energy jobs are set to increase with the initial ramp up of installations from about 20 million in 2015 to around 34 million by 2025. After a decline in 2030, they are observed to steadily rise to around 35 million by 2050
- Solar PV emerges as the prime job creator in most regions of the world with over 22 million jobs by 2050
- Operation and maintenance jobs continue to grow through the transition period and become the major job segment by 2050 with 50% of total jobs
- Fuel related jobs are set to decline from 44% of total jobs in 2015 to just around 2% of total jobs by 2050, as fossil fuels and nuclear power capacities decline through the transition

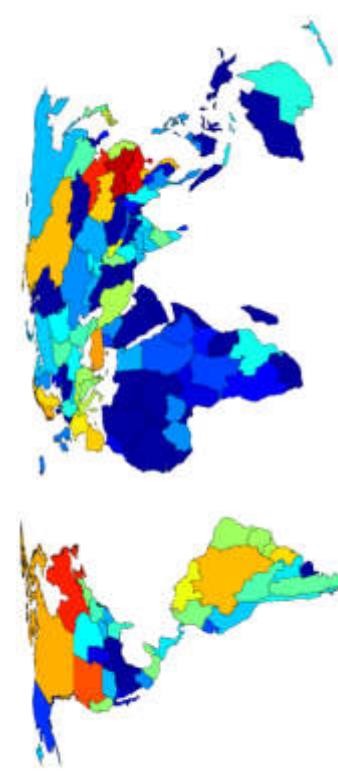


# Major RE Capacities in 2050

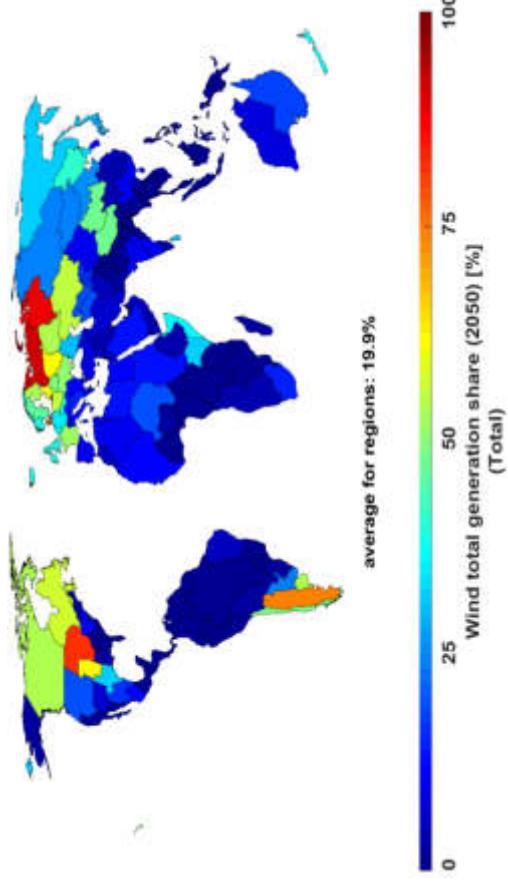
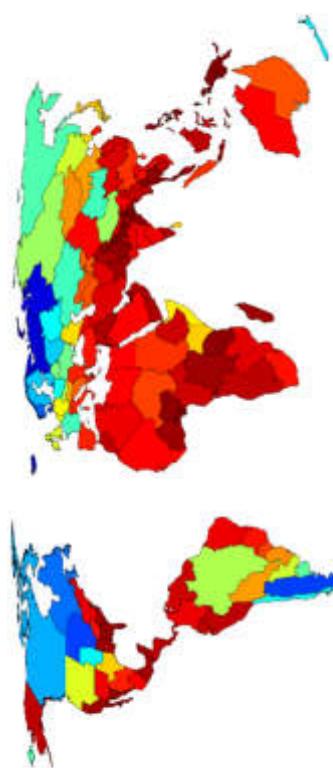


## Key insights:

- Latitudes of 45° N and higher show a strong seasonality effect, i.e. parts of North America, Europe and Eurasia; this implies a strong wind demand
- The effect of excellent other RE resources can be observed for instance in Russia (excellent wind, and hydropower in Siberia and Far East), Brazil (excellent hydropower), Laos (excellent hydropower) or Sumatra in Indonesia (excellent geothermal energy)
- Installed capacities in 2050 for all sectors
  - Solar PV: 63380 GW
  - Wind energy: 8130 GW
  - Hydropower: 1168 GW

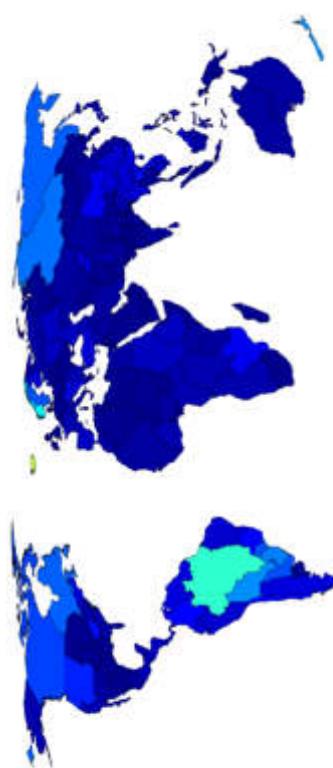


# Major RE Supply Shares in 2050

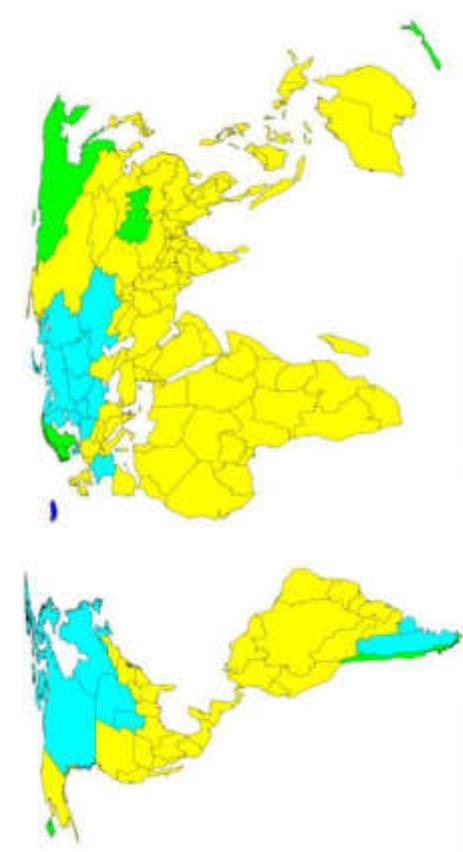
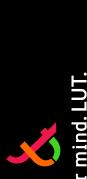


## Key insights:

- Countries in the Sun Belt would be almost fully dominated by solar PV
- Regions of strong seasons and excellent wind show lower PV values, as well as a few of the regions with hydropower and geothermal potential supply shares in 2050 for all sectors
- Solar PV at about 76% as the least cost source
- Wind energy at about 20%
- Hydropower at about 3%

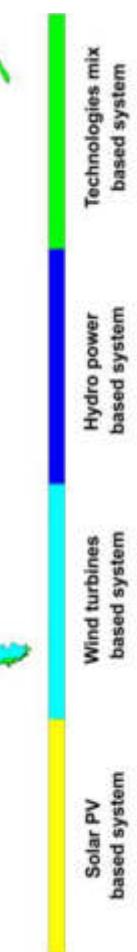


# Regional Variation in 2050



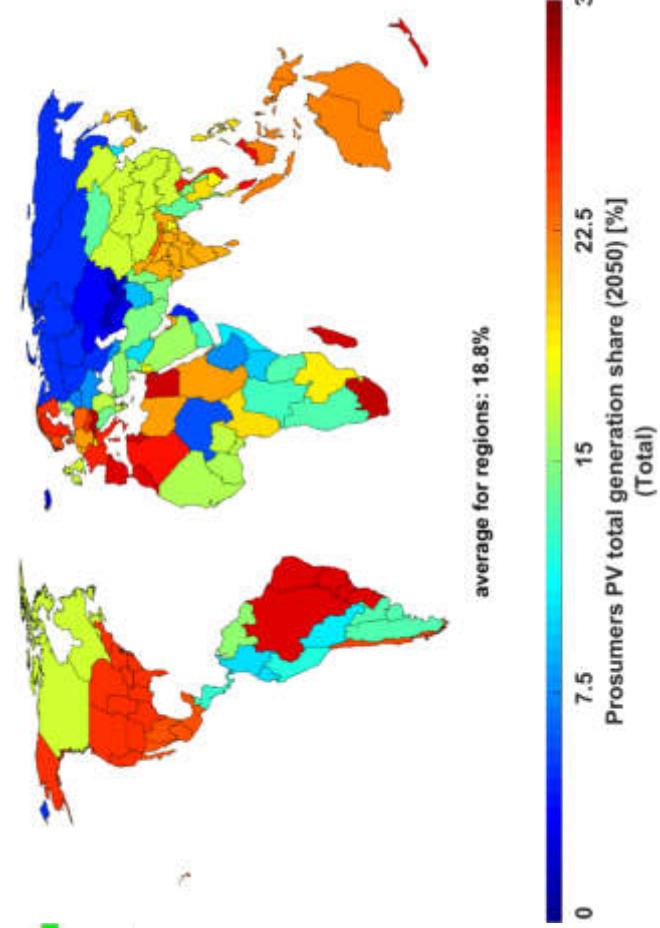
## Key insights:

- Solar PV dominates most of the regions around the world and particularly in the Sun Belt
- Wind energy drives systems in the Northern and Southern hemispheres with excellent wind conditions and lacking seasonal solar energy
- Some regions are further complemented with hydropower to form a mixed system



## Key insights:

- PV prosumers play a significant role in the global energy transition with an average share of almost 19% of electricity generation
- The shares vary quite drastically across the different regions of the world, which are influenced mainly by local retail electricity prices



Clean up the grid, and electrify almost everything  
Christian Breyer ► christian.breyer@lut.fi

additional residential PV prosumer study in expanded method:  
Keiner D., et al., 2019, Cost optimal self-consumption of PV Prosumers with stationary batteries, heat pumps, thermal energy storage and electric vehicles across the world up to 2050, Solar Energy, 185, 406-423

# Comparison to IEA – Annual Production of PV

## Outlook and summary - PV today and in future

Different calculated scenarios in 10<sup>th</sup> edition:

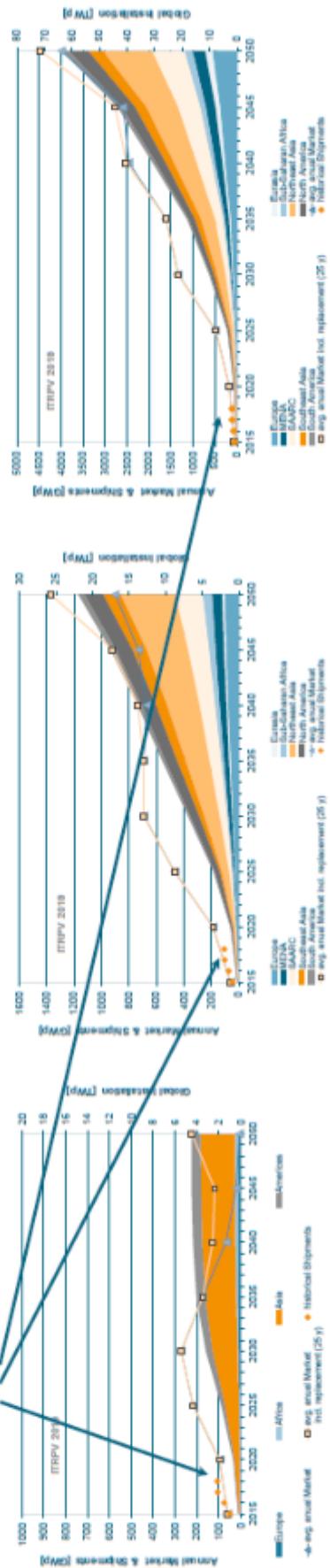
**IEA**  
low: 4.5 TWhp / 7 PWh (16% global electricity)

market peak: 3000+GWhp / 2030

**Breyer ("Electricity")**

high: 22 TWhp/ 38 PWh (69% global electricity)  
market peak: 1,400+GWp /2050

→ Shipments 2018 were close to approaches!



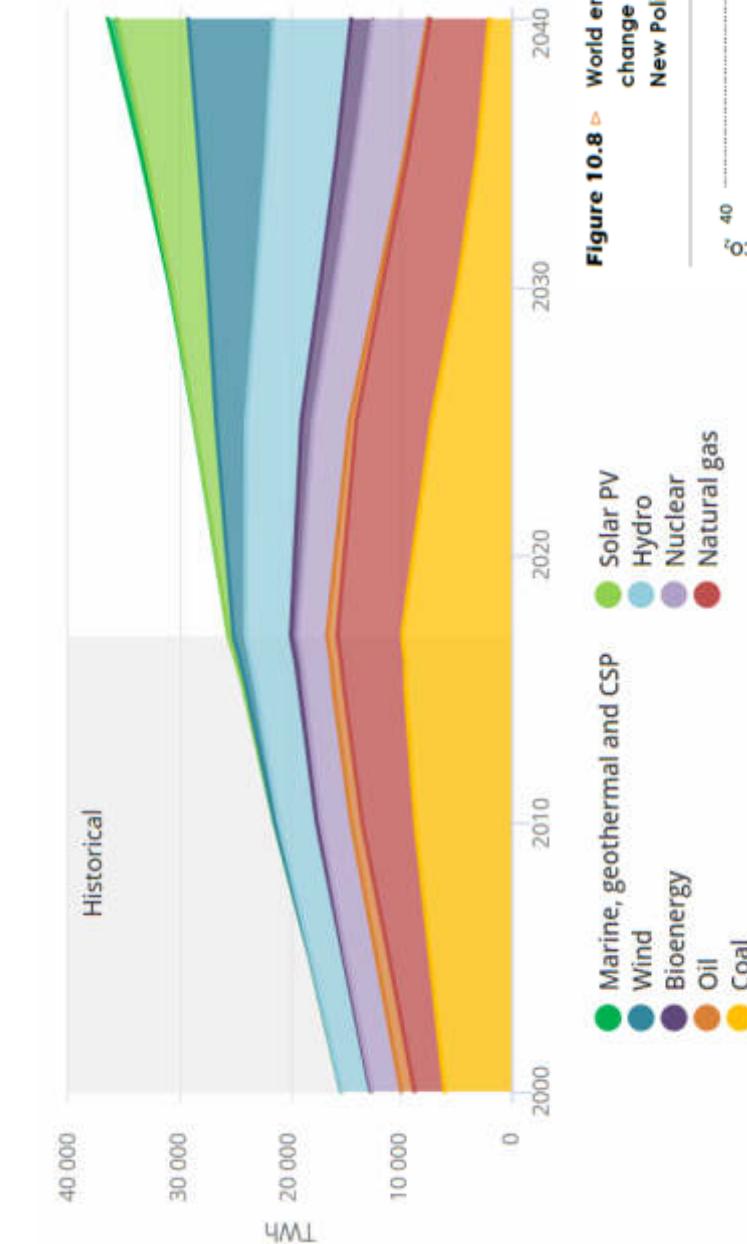
**ITRPV finding:**

- PV learning continues and progresses but market will remain volatile
- Several 100GW markets are ahead, and can be served based on todays PV technologies
- Further effort is required to meet 2030+ / xTWhp market requirements!

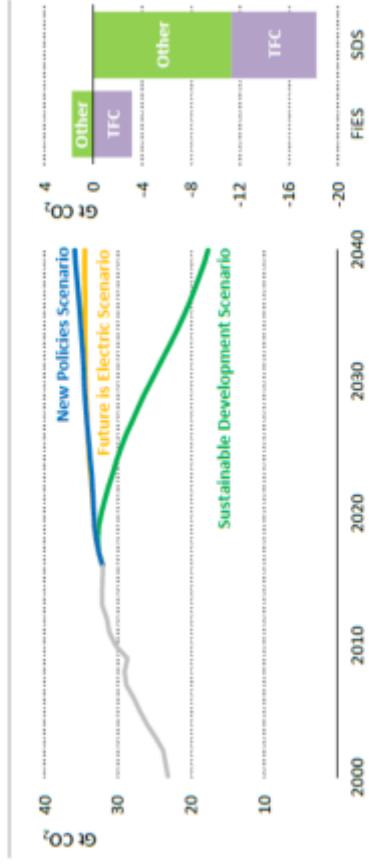
## ITRPV provides a guideline to handle the technology challenges



# WEO 2018 - SDS



**Figure 10.8** □ World energy-related CO<sub>2</sub> emissions by scenario (left) and change in CO<sub>2</sub> emissions by sector in 2040 relative to the New Policies Scenario (right)



Electrification alone is not sufficient to put the world on track to meet climate goals;  
it requires a more comprehensive energy system strategy

## Comments on electricity generation mix

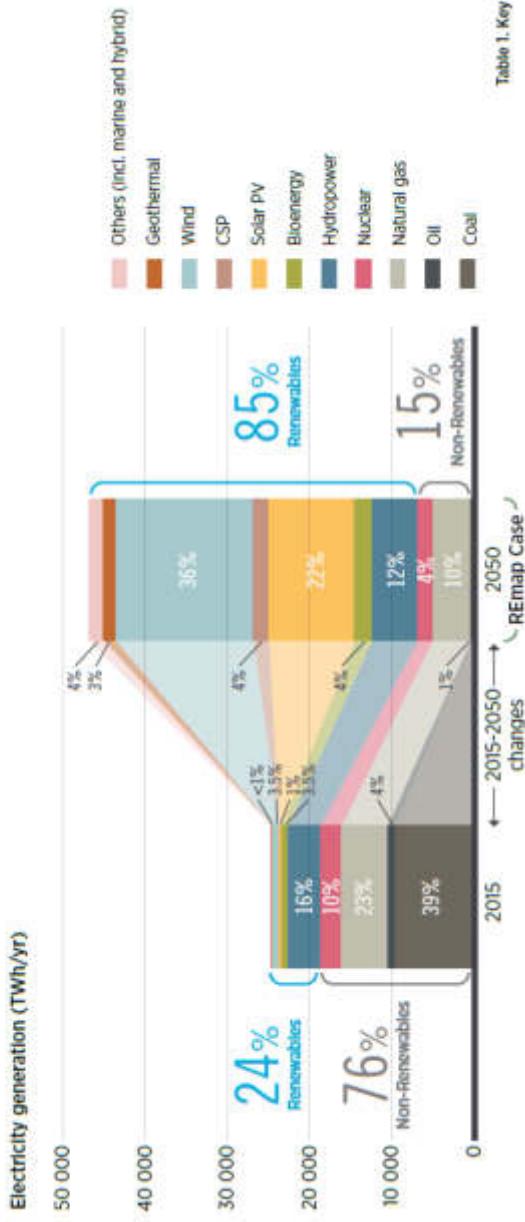
- 66% renewables
  - 20% fossil
  - 13% nuclear
- assuming about 90% growth (2017 ► 2040) in  
nuclear generation
- 4.2 TW of installed PV capacity in 2040

Clean up the grid, and electrify almost everything – Global-local view  
Christian Breyer ► christian.breyer@lut.fi @ChristianOnRE

# IRENA REMap 2050

Open your mind. LUT.  
Lappeenranta University of Technology

Figure 15. The rising importance of solar and wind energy in the power sector  
Breakdown of electricity generation, by source (TWh/yr)



## GLOBAL ENERGY TRANSFORMATION



Table 1. Key indicators relevant to the energy transition in selected countries (REmap Case)

	CHINA	EU	INDIA	USA
Share of renewable energy in primary energy supply	5%	69%	13%	75%
Share of renewable energy in final energy use	7%	17%	10%	9%
Electricity use in final energy consumption	19%	54%	18%	20%
Share of renewable energy in power	26%	94%	29%	14%

## Key insights:

- 85% RE on global average and 92-94% in India/China/EU leading the development
- RE in primary energy supply can reach 70-75% for all sectors
- Neither nuclear nor fossil CCS as major option
- Positive economics and stimulus for job creation

Clean up the grid, and electrify almost everything – Global-local view  
Christian Breyer ► christian.breyer@lut.fi @ChristianOnRE

# Key assumptions: WEO SDS, Remap, LUT/EWG

		WEO SDS	REmap	LUT/EWG	comments
Solar PV	2020 €/kW	1159	n/a	580	SDS and REMAP have only 2 and 1 PV option(s), respectively
	2030 €/kW	857	n/a	390	LUT/EWG offers 3 rooftop, 2 ground mounted options
	2040 €/kW	730	n/a	300	SDS ends in 2040, thus no values for 2050
	2050 €/kW	n/a	n/a	246	no SDS values disclosed, therefore from 450 S from 2016
Batteries	2020 €/kWh	n/a	n/a	300	PV power plant investment cost in 2019: 350-450 €/kW
	2030 €/kWh	n/a	n/a	150	LUT/EWG PV cost assumptions taken from ETIP PV (2017)
	2040 €/kWh	n/a	n/a	100	exchanger rate: 1.2 USD/€
	2050 €/kWh	n/a	n/a	75	LUT/EWG wind assumptions inline with NREL, Lazard, BNEF wind onshore in India/ China around 700-800 €/kW and less
Wind onshore	2020 €/kW	1402	n/a	1150	
	2030 €/kW	1330	n/a	1000	
	2040 €/kW	1300	n/a	940	
	2050 €/kW	n/a	n/a	900	

## General comment

- Disclosure of assumptions is in general poor, for WEO (2018 numbers not accessible), IRENA, but also IPCC scenarios
- Modelling community has to take transparency more seriously
- Many other assumptions play a role, therefore only the 3 most important core technologies have been selected on this slide
- Methods: WEO and Remap are still done in annual energy balancing method, whereas LUT/EWG is done in full hourly resolution for capturing the nature of VRE and flexibility options (storage, grids, demand response, supply response, sector coupling)

# Summary – Energy Transition

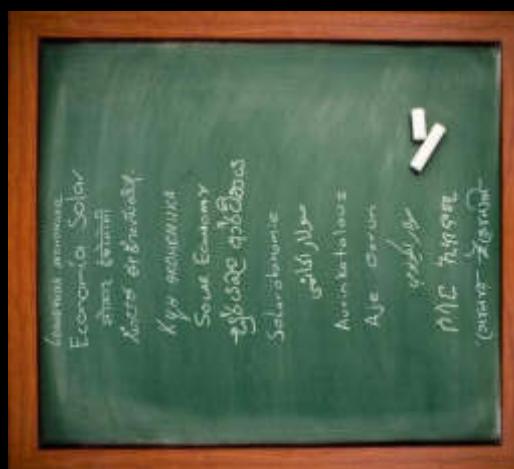
- A 100% RE can be reached globally and zero GHG emission by 2050, with solar PV and wind emerging as the new workhorses of the future energy system
- LCOE obtained for a fully sustainable energy system remains stable at around 53 €/MWh by 2050
- Solar PV emerges as the most prominent electricity supply source with around 73% of the total electricity supply on global average by 2050, complemented by wind energy, hydropower and bioenergy
- Batteries emerge as the key storage technology with 92% of total electricity storage output
- GHG emissions can be reduced from around 30 GtCO<sub>2eq</sub> in 2015 to zero by 2050 across all energy sectors, with remaining cumulative GHG emissions of around 422 GtCO<sub>2eq</sub> from 2018 to 2050
- Owing to the low-cost electricity driven by solar PV and wind, an electrification-of-almost-everything strategy is possible globally by coupling the low-cost renewable-led electricity generation to the transport, heat, desalination and power sectors.
- A 100% RE system is more efficient and cost competitive than a fossil based option and is compatible with the Paris Agreement – the presented scenario supports the 1.5°C target

**Thank you for your attention ...  
... and to the team!**



**NEO  
CARBON  
ENERGY**

TRUST IN RENEWABLE.



all publications at: [www.researchgate.net/profile/Christian\\_Breyer](http://www.researchgate.net/profile/Christian_Breyer)  
new publications also announced via Twitter: @ChristianOnRE



Open your mind. LUT.  
Lappeenranta University of Technology