

Modelling Stringent UK CO₂ Reduction: *The UKERC Academic Scenarios*

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UKERC Energy 2050 Project

- UKERC's **Energy Systems Modelling (ESM)** research activities are being undertaken within the Department of Geography at Kings College London (KCL), and the Cambridge Centre for Climate Change Mitigation Research (4CMR) at the University of Cambridge.
- There are four core modelling scenarios:**

The **"Reference" (REF)** scenario assumes that concrete policies and measures in place at the time of the 2007 Energy White Paper continue into the future.

The **"Ambition" (CAM)** scenario (is the reference low carbon scenario): 80% reduction in UK carbon emissions by 2050 relative to 1990, with an intermediate milestone of 26% in 2020.

The **"Resilience" (R)** scenario takes no account of the carbon reduction goal but assumes additional investment in infrastructure, demand reduction and supply diversity with a view to making the energy system more resilient to external shocks.

The **"Low Carbon Resilient" (LCR)** scenario combines the carbon and resilience goals.

UKERC Energy 2050 Project

- The UKERC recently released its first report in the UKERC Energy 2050 project series.
- The report focuses on a range of **low carbon scenarios** underpinned by energy systems analysis using the newly developed and updated UK MARKAL elastic demand (MED) model.
- It gives insights on a range of scenarios of future energy system evolution and the resultant technology pathways, sectoral trade-offs and economic implications.
- Policy discussion on the scenarios

The image shows the cover of a report from the UK Energy Research Centre (UKERC). The title is 'Pathways to a Low Carbon Economy: Energy systems modelling'. It is identified as 'UKERC Energy 2050 Working Paper 1' and dated 'November 2008: REF UKERC/WP/ESH/2008/001'. The authors listed are Gabriel Ameeragah, Neil Strachan, Paul Ekins, Ramachandran Kannan, and Nick Hughes. A prominent blue box contains the text 'The full report can be downloaded www.ukerc.ac.uk'. At the bottom, there is a small disclaimer: 'The core model development and analysis for this Research Report was conducted under the auspices of the UK Energy Research Centre (UKERC) which is funded by the Natural Environment Research Council, the Engineering and Physical Sciences Research Council and the Economic and Social Research Council.' The UKERC logo and name are at the top right, and the website 'www.kcl.ac.uk' is at the bottom right.

3

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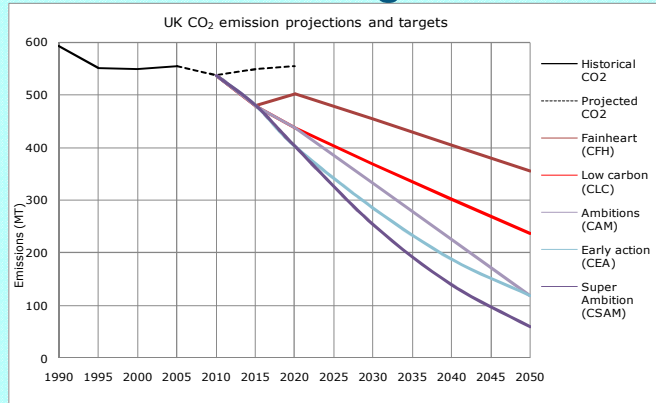
Assumptions & Calibration Notes

- Calibrated in its base year (2000) to DUKES data within 1% of actual resource supplies, energy consumption, electricity output, installed technology capacity and CO₂ emissions
- All existing policy measures are implemented (RO, energy efficiency commitment, climate change levy, etc)
- Other than EU-ETS (€20/t-CO₂) no carbon price is included
- Resource price in line with higher revisions from IEA, BERR
- 10% global discount rate and technology specific 'hurdle' rates on future transport technology and on building conservation and efficiency options are applied.
- The hurdle rates apply only to capital costs and thus effectively increases the investment barriers to these efficiency technology. Set at 15%, 20% and 25%. These hurdle rates represent information unavailability, non price determinants for purchases and market imperfections
- Elasticity values: taken from different literatures.

4

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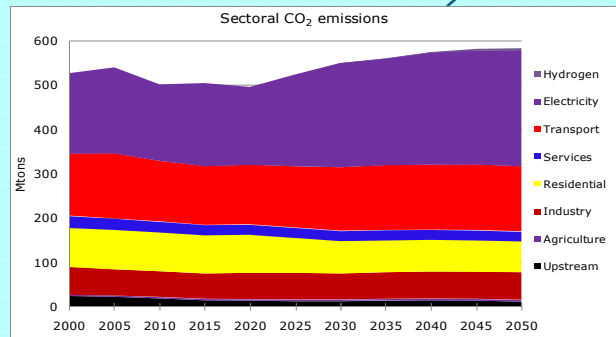
Carbon Targets and Scenarios



- 1. Base Reference (B): No constraint
- 2. Faint Heart (CFH): -15%; 40%
- 3. Low Carbon (CLC): -26% ; -60%
- 4. Ambition (CAM): -26% ; -80%
- 5. Super Ambition (CSAM): -32% ; -90%
- 6. Early Action (CEA): -32% ; -80%
- 7. Least cost path (CCP): -80% post 2050
- 8. Stability of final cost (CCSP): -80% post 2050

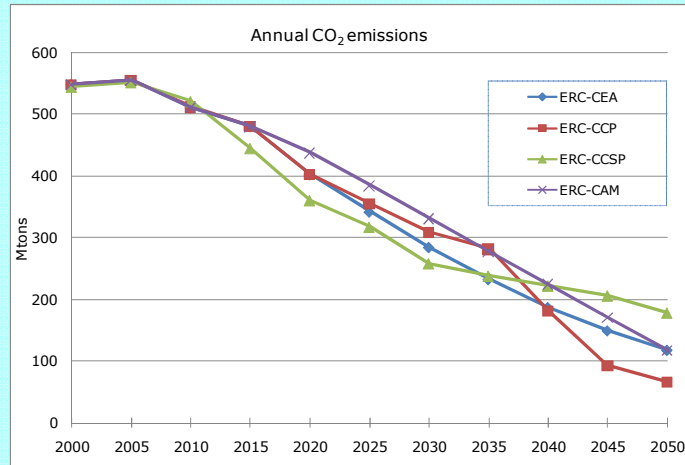
- One scenario with no CO₂ constraint
- Five scenarios with annual CO₂ constraints
 - Mitigation targets: 15-32% in 2020 and 40-90% in 2050.
- Two scenarios with cumulative CO₂ constraints (2010-2050)

Base Reference Case CO₂ Emissions



- If new policies/measures are not taken, base case CO₂ emissions in 2050 would be 584 MtCO₂: 6% higher than 2000 levels and 1% lower than 1990 levels.
- Existing policies and technologies would bring down emissions in 2020 to about 500 MtCO₂ - a 15% reduction (government target of -26% by 2020).
- Power sector is the largest contributor to CO₂ emissions followed by transport and residential sectors.

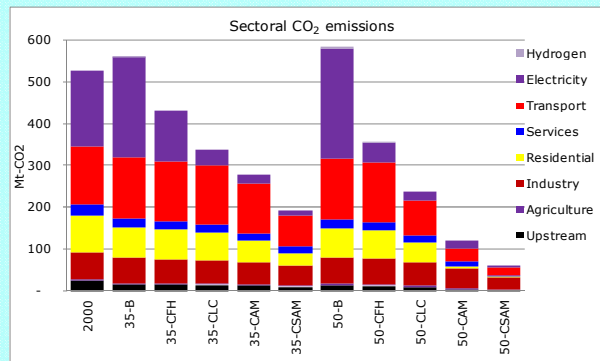
Cumulative Cases CO₂ Emissions



CCSP- Early action reducing 39% in 2020 and 70% in 2050

CCP- Later action reducing 32% in 2020 and about 90% in 2050

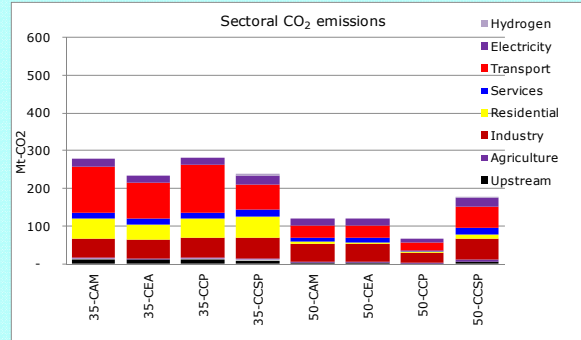
Decarbonisation



- Decarbonisation is foremost in the power sector till middle or end of the planning horizon. Then major efforts switch to the residential and/or transport sector.

- Transport and residential sectors are heavily decarbonised in the CSAM case in 2035.

Decarbonisation

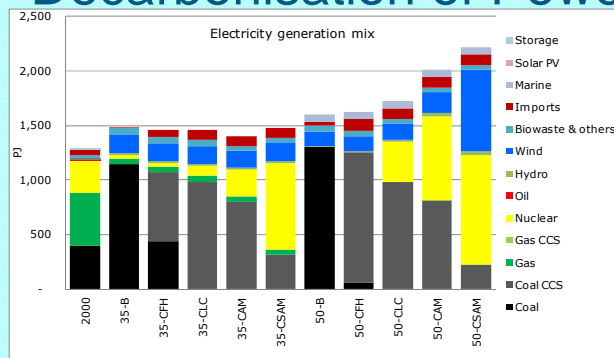


- A focus on earlier action means the transport sector works harder in the CEA and especially the CCSP runs as the lowest cost power sector zero-CO₂ technologies are not ready till 2030+.
- Service sector and upstream are also heavily decarbonised in the CCP case in addition to transport and industry sectors.

9

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Decarbonisation of Power Sector



- In 2035, electricity generation decreases in line with the successive targets CFH, CLC and CAM (not in CSAM).

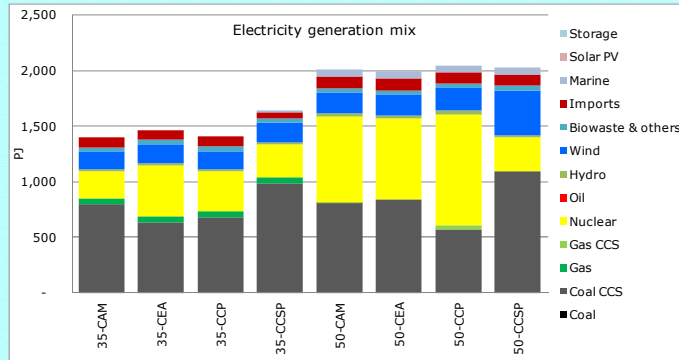
- In 2050, electricity generation increases in line with the successive targets

- Over 90% of the electricity is generated from the high carbon content coal in B.
- Decarbonisation of the power sector means replacing coal by low carbon coal-CCS technology and/or switching to zero carbon nuclear and/or wind technology/resources
- Decarbonisation of the power sector begins with the deployment of **carbon capture and storage (CCS)** for coal plants in 2020-2025 in all mitigation scenarios.
- When the target is increased, **nuclear is selected instead of CCS** to meet the carbon target in CAM and Nuclear+wind in CSAM. It is due to the residual emissions in CCS

10

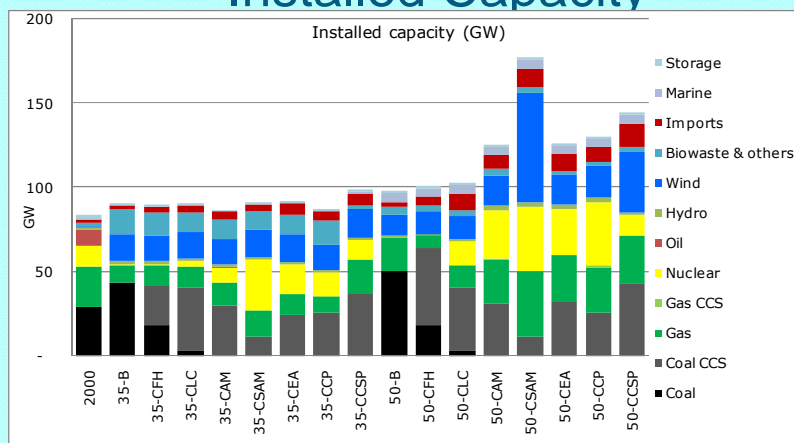
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Decarbonisation of Power Sector



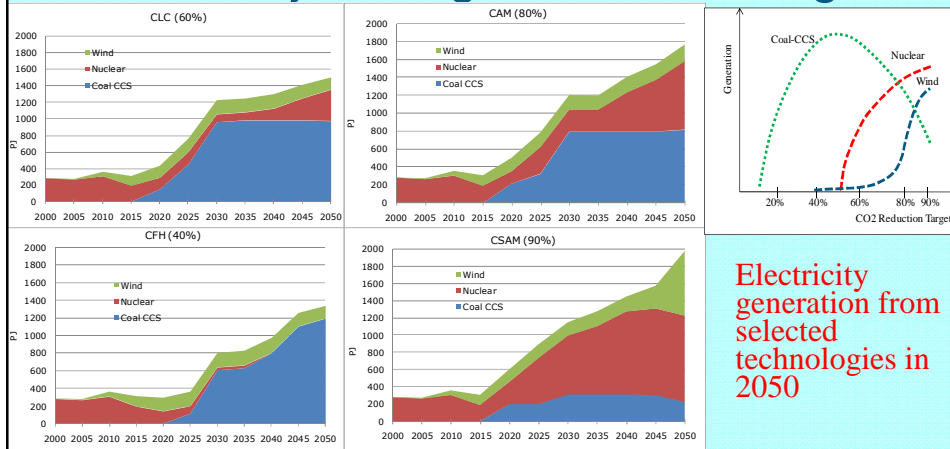
- When the target is increased, nuclear is selected instead of CCS to meet the carbon target in CAM, CEA and CCP while wind is selected in CCSP instead of nuclear.

Installed Capacity



- Since contribution of wind to peak load is limited, selection of wind needs large amount of gas plants as reserve capacity

Three major mitigation technologies



Electricity generation from selected technologies in 2050

- When the target is increased, there is a shift from Coal-CCS to Nuclear to Wind

13

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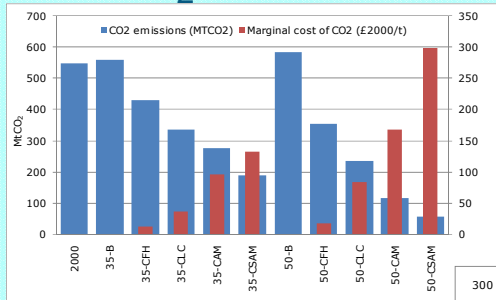
Decarbonisation of End-use Sectors

- The residential sector is decarbonised by **shifting to electricity** (from gas) as well as technology switching from boilers to **heat pumps** for space heating and hot water heating.
- The transport sector is decarbonised by **fuel switching**: hybrid, hybrid plug-in (diesel and petrol), ethanol, hydrogen and battery operated vehicles.
- The service sector is decarbonised by shifting to electricity and to biomass (in the CCP case).
- Besides efficiency and fuel switching (and technology shifting), the elasticity (**demand reduction**) also plays a major role in reducing CO₂ emissions by reducing energy service demand (5% - 25% by scenario and by ESD)

14

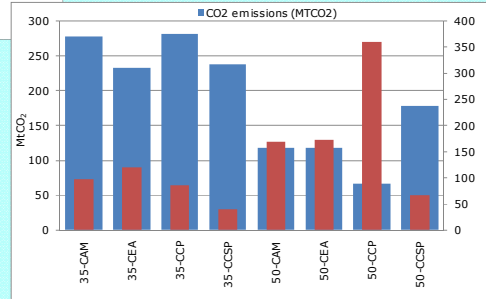
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CO₂ Emissions & Marginal Costs



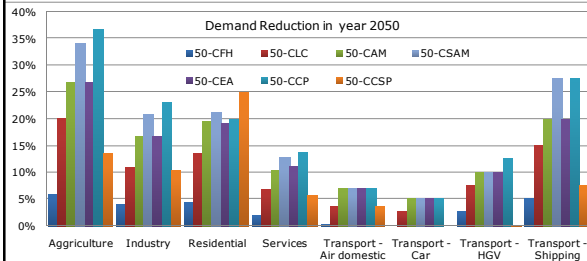
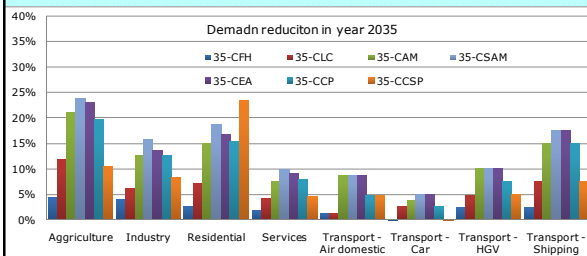
- Rising CO₂ marginal costs with target stringency

- As expected CEA gives higher early costs
- CCP gives 90% CO₂ reduction with very high marginal cost



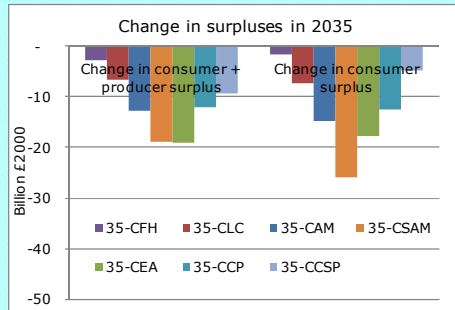
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Demand reductions



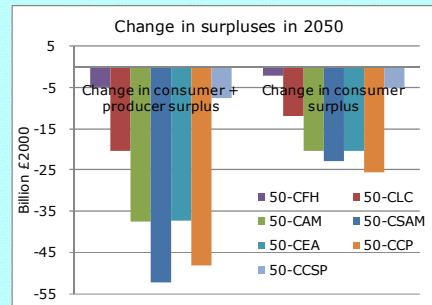
- Demand reduction level is relatively high in 2050 than in 2035 as the CO₂ reduction level is relatively high in 2050 under all scenarios.
- Agriculture, industry, residential and international shipping have higher demand reductions than that of air, car and HGV (heavy good vehicles) in transport sectors.
- There is a social welfare loss due to demand reduction

Welfare Change



- Overall, In 2035, welfare losses are mainly for consumers

- In 2050, at larger CO₂ reduction level, producers and consumers share the losses



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Conclusions

- Carbon Ambition scenarios offer insights on technology, resources and demand pathways, as well as resultant costs
- Power sector decarbonisation occurs early and is critical**
 - Uncertainties in optimal technology mix (**CCS vs. nuclear vs. wind**)
 - Important interactions with **transport** (plug-in vehicles) and **buildings** (boilers and heat pumps)
- End-use sectors contribute significantly to later period decarbonisation
- Higher target levels (CFH to CLC to CSAM), produce deeper array of mitigation options (likely with more uncertainty)
- CEA and CCSP requires early action
 - Alternate sectors (**transport**), alternate resources (**wind, bio-fuels**)
- Very wide range of economic impacts
 - CO₂ marginal costs in 2050 from £20 - £360/tCO₂
 - Welfare costs in 2050 from £B5.0 - £B52.0

Comments and iteration

		Modelling focus	Energy 2050 WG
Gabrial	gabrial.anandarajah@kcl.ac.uk	LC scenarios; ATD; Transport	Policy and Technology
Neil	neil.strachan@kcl.ac.uk	Model variants; Resources; Processes	Demand
Kannan	r.kannan@kcl.ac.uk	Core model; Electricity; Buildings	Markets & Security
Nick	nicholas.hughes@kcl.ac.uk	Scenarios	Technology & Supply

THANK YOU

Modelling Reports

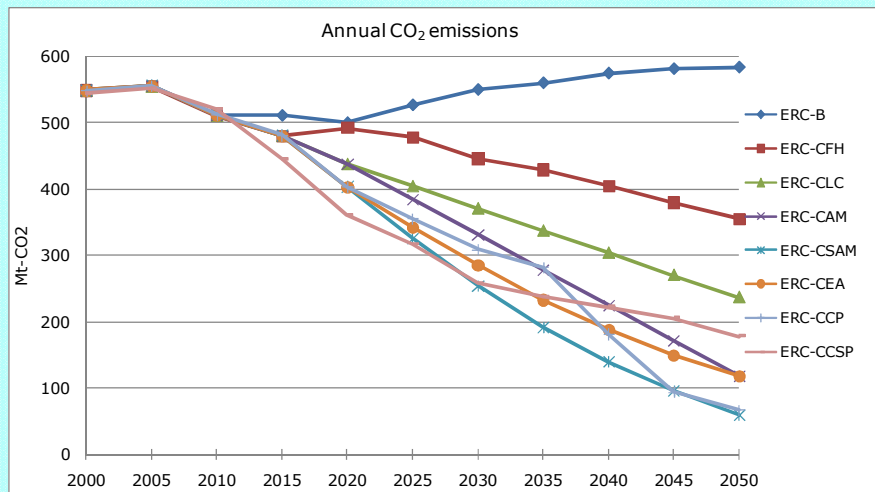
	Report title	Lead working group	Lead model	Support model
1a	Pathways to a low carbon economy: Energy systems modelling	Policy	MED	
1b	Pathways to a low carbon economy: Macro-econometric modelling	Policy	E3MG	MED
2	Technology's contribution to a low carbon economy	Supply	MED	E3MG
3	The UK and long-term global energy markets	Markets and security	E3MG	MED
4	Building a resilient UK energy economy	Markets and security	CGEN, WASP	E3MG
5	Sustainable energy lifestyles and behaviour	Demand	MED	Demand
6	The environment and sustainable energy	Supply	MED	
7	A decentralized energy system			Demand, CGEN, WASP
8	Synthesis report			

Scenarios

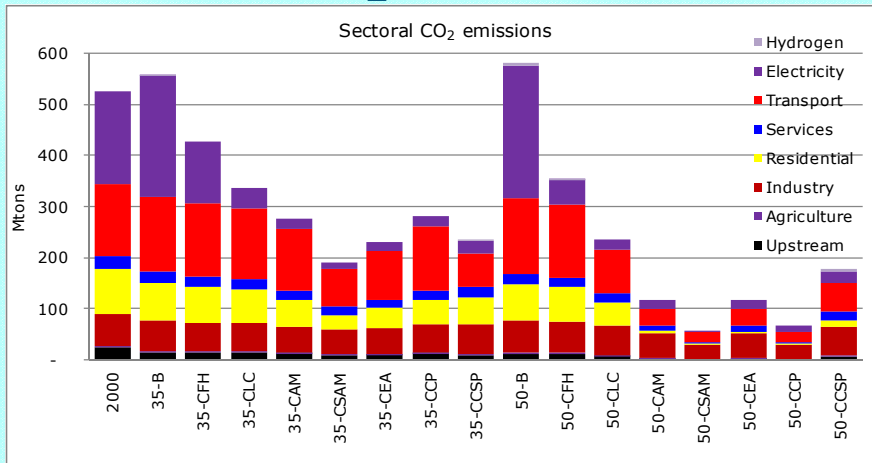
Scenario	Scenario name	Annual targets	Cumulative targets	Notes
B	Base reference	-	-	Also run by E3MG
CFH	Faint heart	-15% by 2020 -40% by 2050	-	Also run by E3MG
CLC	Low carbon reference	-26% by 2020 -60% by 2050	-	Also run by E3MG
CAM	Ambition	-26% by 2020 -80% by 2050	-	Also run by E3MG
CEA	Early action	-32% by 2020 -80% by 2050	-	Also run by E3MG
CCP	Least cost path	-80% post 2050	cumulative emissions budget (2010-2050) similar to CEA	10% discount rate
CCSP	Socially optimal least cost path	-80% post 2050	cumulative emissions budget (2010-2050) similar to CEA	3.5% discount rate

CCSP employs a social discount rate of 3.5%

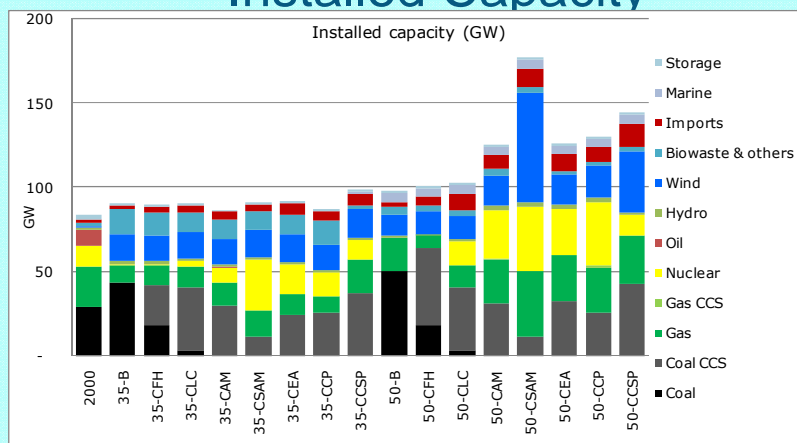
CO₂ Emissions: Low Carbon Scenarios



Sectoral CO₂ emissions

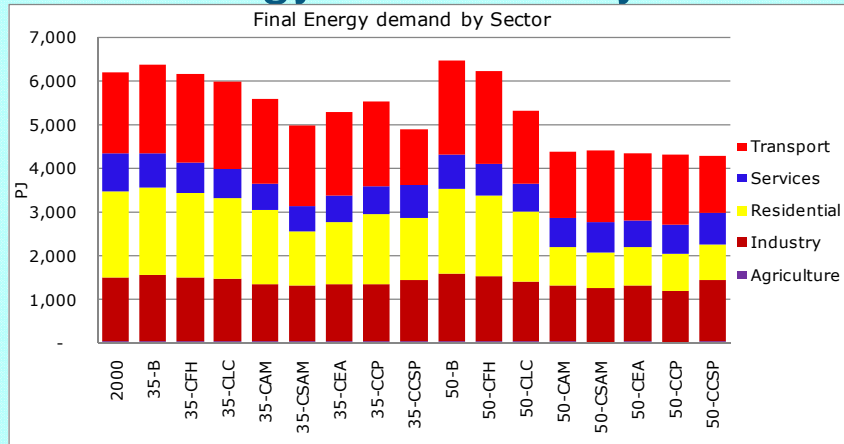


Installed Capacity



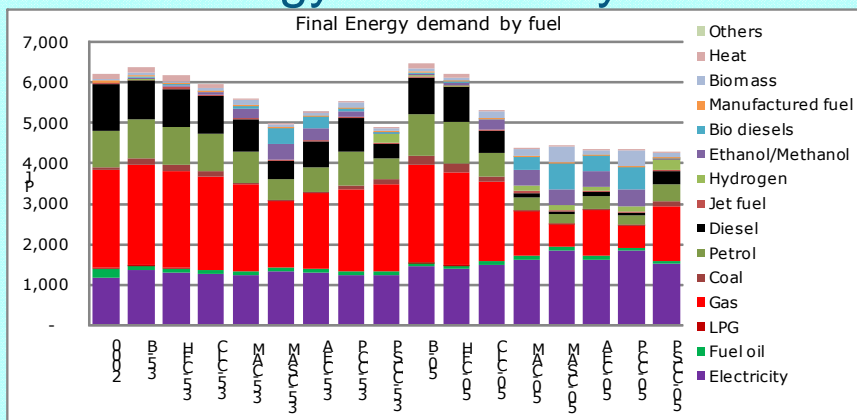
- Since contribution of wind to peak load is limited, selection of wind needs large amount of gas plants as reserve capacity
- Import electricity is also selected for reserve
- Bio-waste and others include land fill gas and sewage gas plants

Final Energy demand by Sector



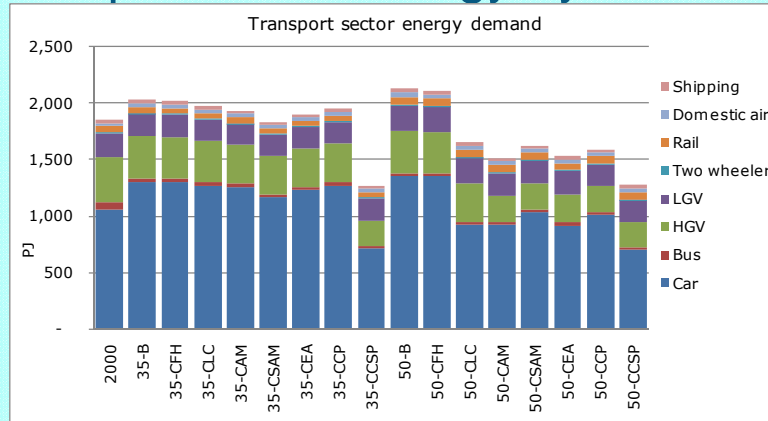
- Large reduction for residential sector energy demand in the mitigation scenarios.
- In CCSP, large reduction is observed in transport sector too as it shifts to electric and hydrogen (HGV and LGV) vehicles.

Final Energy Demand by Fuel



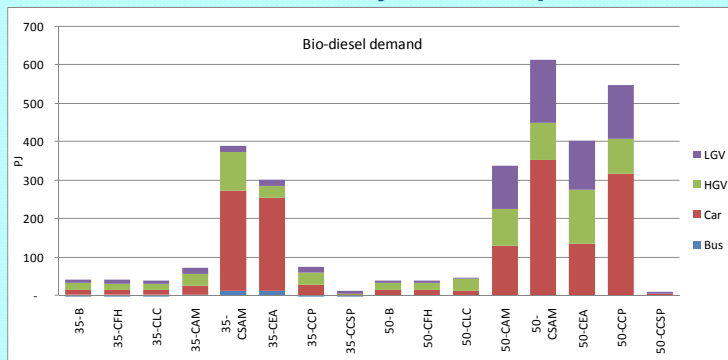
- Gas is mainly used in residential and service sectors mainly for space heating and main contributor to emissions of the respective sectors
- Transport sector is decarbonised by electric (hybrid plug in) and bio-fuel vehicles in CAM, CSAM, CEA and CCP.
- In CCSP, it is electric and hydrogen (HGV) vehicles.
- Hybrid plug-in vehicles use the wind electricity to charge the battery during the off-peak time.
- Hydrogen is produced from electrolysis

Transport Final Energy by Mode



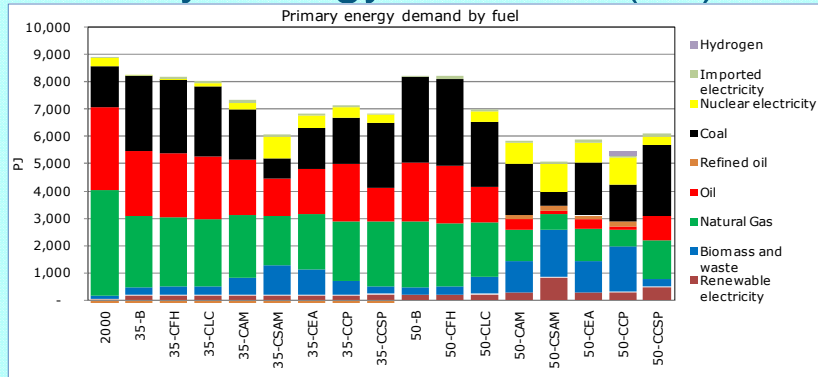
- Car plays a major role in transport sector energy demand followed by HGV
- Electric and hydrogen vehicles reduce the energy demand in CCSP
- Biomass doesn't play any role to reduce energy demand in CEA, CAM, CSAM and CCP as their efficiency is similar to petrol and diesel vehicles.

Biodiesel Demand by Transport Mode



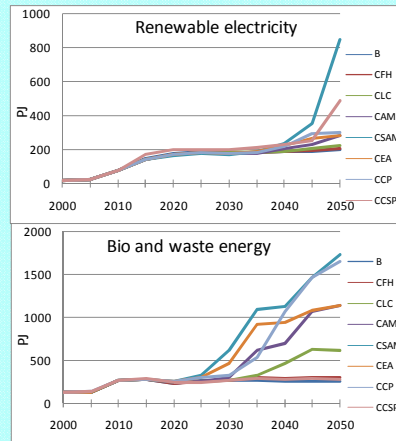
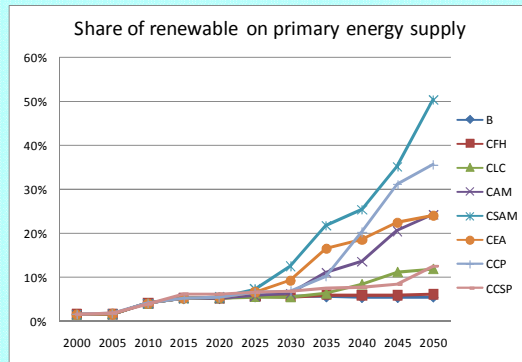
- Car and goods vehicles consume almost all the bio-diesel in transport sector
- As all the buses are battery based in the Base reference case itself during the latter part of the planning horizon, there is no demand for bio-diesel for buses in 2050.

Primary Energy Demand (PJ)



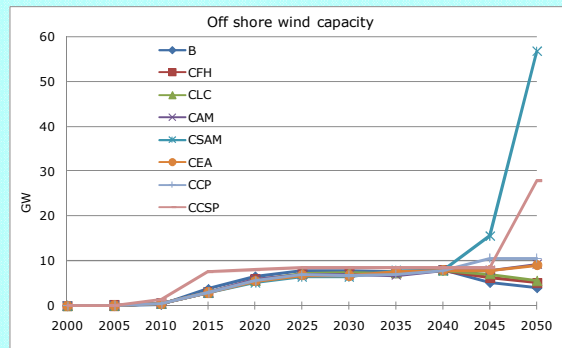
- Since the carbon target is mainly met by coal-CCS in CFH, primary energy demand is not changed much in CFH.
- Selection of nuclear and wind bring down the primary energy demand in CAM, CSAM, CEA, CCP and CCSP.
- Higher demand for biomass is observed in CAM, CEA and CCP. It is mainly used in transport and service sectors

Renewable Energy



- Since bio-energy is relatively high in absolute term as compared to the renewable electricity, the share of renewable on total primary energy is following the path of bio and waste energy.
- Share of renewable is below the EU target in 2020.

Offshore Wind and Marine

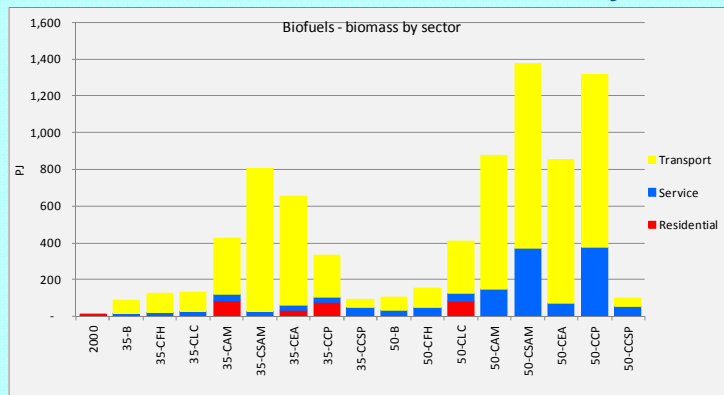


- On shore wind is almost selected to its full capacity in the Base reference case itself. Therefore, wind capacity added in the mitigation scenarios are from **offshore**.
- **3 GW and 5 GW** capacities of marine plants have also been selected in 2045 and 2050 respectively generating electricity equivalent to **36 PJ and 64 PJ** in respective years in all scenarios.

31

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Demand for Bio-fuels/biomass by sector

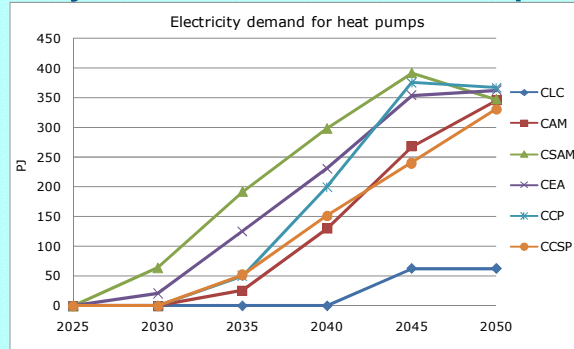


- Demand for bio-fuel is high in CAM, CSAM, CEA and CCP and it is mainly used in transport sector and services sector

32

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Electricity demand for heat pumps

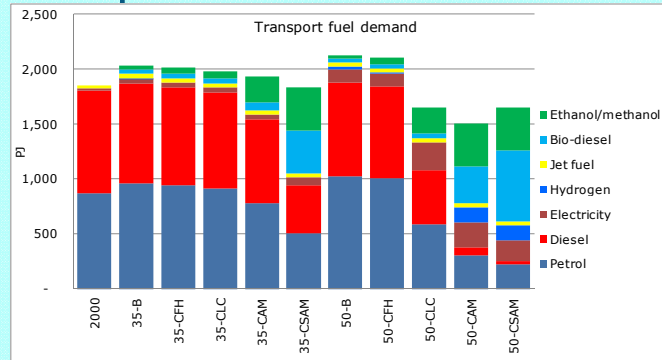


- Heat pump plays a major role in residential sector CO₂ emission reduction replacing gas boilers for heating.

Early decarbonisation

- Early decarbonising end-use sectors are transport and residential sectors in the CEA case as compared to the CAM case in 2035.
- Residential: Demand reduction in residential space heating, water heating and electricity (Less demand under CEA as compared to the CAM), plus technologies: Residential electric boiler night storage, more heat pumps for water heating in 2035.
- Transport: Demand reduction in Car, LGV and Shipping. Early shifting (from 2030) to Car (E85) and bus-battery and very low amount of shifting to Rail-Electric in the CEA.
- Early decarbonisation in transport sector in the CCSP case is by shifting to car hybrid and plug-in and hydrogen for heavy goods vehicles.

Transport Sector Fuel Demand

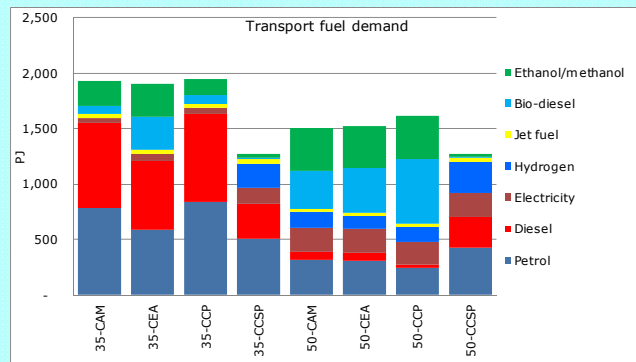


- Electricity demands comes from buses and car hybrid plug-in.
- Ethanol demand comes from car (E85)
- Biodiesel demand comes from car, HGV and LGV
- Hydrogen is for goods vehicles especially HGV (consumes over 80%)
- Car is the dominant mode consuming 2/3 of the transport energy

35

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Transport Sector Fuel Demand



- The CCSP has relatively low transport fuel demand. It is due to the shift to electricity and hydrogen instead of bio-diesel and ethanol from fossil fuel

36

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