EF936: Sustainable Engineering Group Project

University of Strathclyde Engineering

Low Carbon Future Grid Study for the UK

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Source: www.bbc.co.uk

Presentation Contents

Project Background

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Modelling Work

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Source: www.robedwards.com

Project Aim and Objectives

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AIM:

To investigate how the UK can integrate the most low-carbon energy systems into the electricity grid by 2050

Objectives

Source: uk.reuters.com

Objectives

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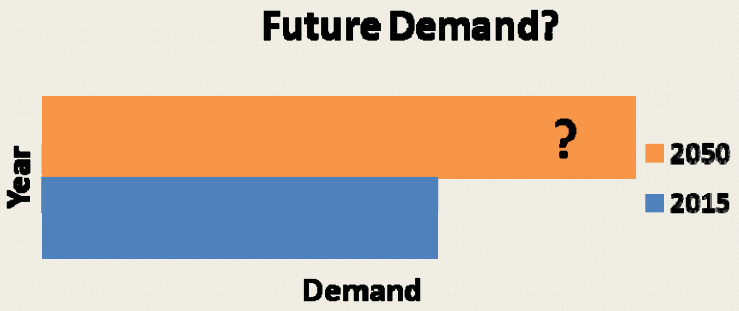
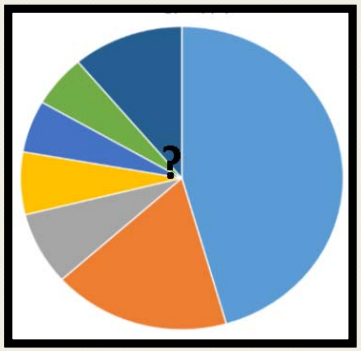
1. Estimate Future Demand

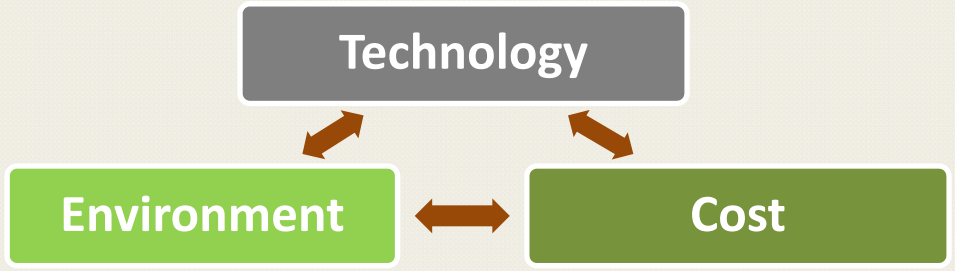


2. Modelling



Modelling Methodology
Next slide

3. Feasibility assessment



Modelling Methodology

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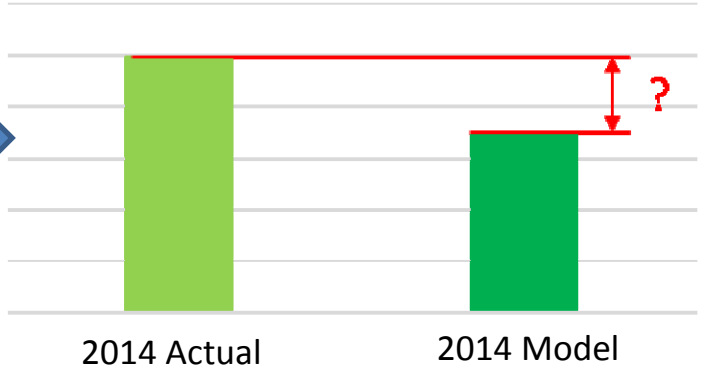
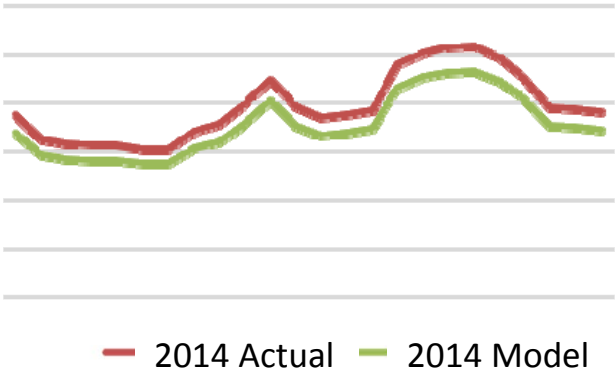
1. Select Modelling Software

Software	Cost	Large Scale	Demand matching	Storage Inclusion	Input own data trends	Economic analyses	User friendly
Merit	🟢	🔴	🟢	🟢	🟡	🔴	🟡
Homer	🔴						
Excel	🟢	🟢	🟡	🟡	🟢	🟡	🟡
EnergyPLAN	🟢	🟢	🟢	🟢	🟢	🟢	🟢

2. Verify Software using Reference Model





3. Model Future Scenarios (2050)

Project Motivation

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Why 2050?

- The EU 2050 CO_2 emission target (European Commission, 2011);
- 2050 is a target year in many academic publications;
- Enough time for planning and implementation.

Source: www.sunzu.com

Project Scope

UK grid as single system

Electricity generation only

Established technologies

2050 Demand Estimations

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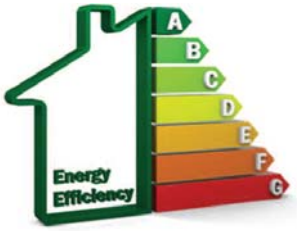
No. of households

% households with electric heating

Improved efficiency

Demand reduction incentive policies



Domestic Electrical Demand

150TWh (from 110TWh)

No. of cars

% electric cars

Increase in electric train lines

Transport Electrical Demand

60TWh (from 3.6TWh)

2050 Demand Estimations

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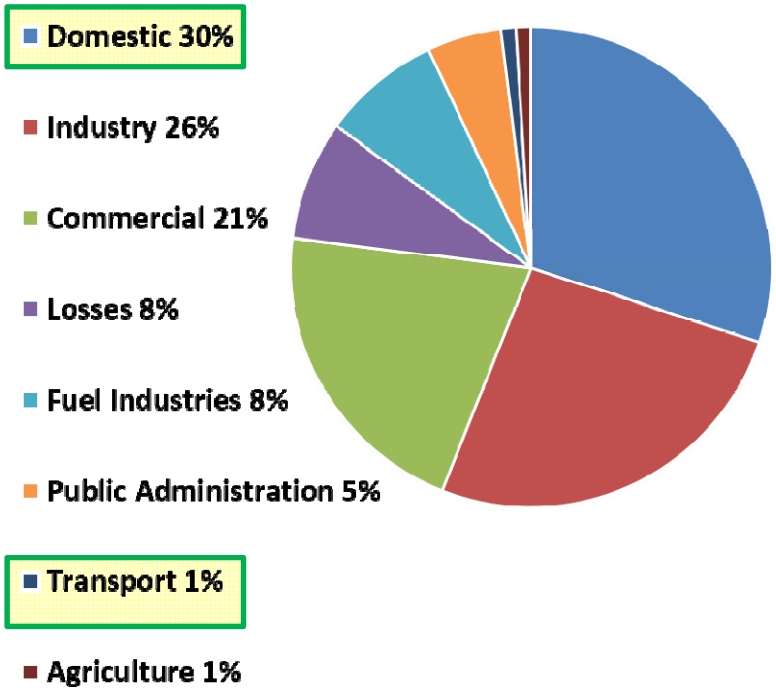
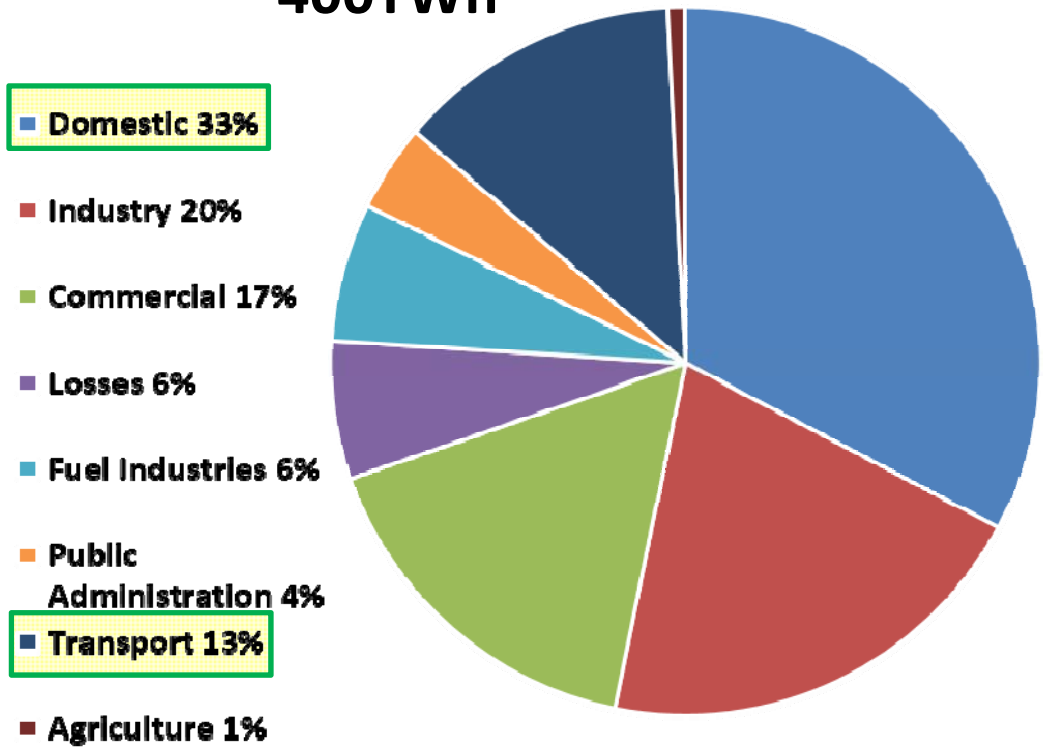
Total demand 2014
302TWh



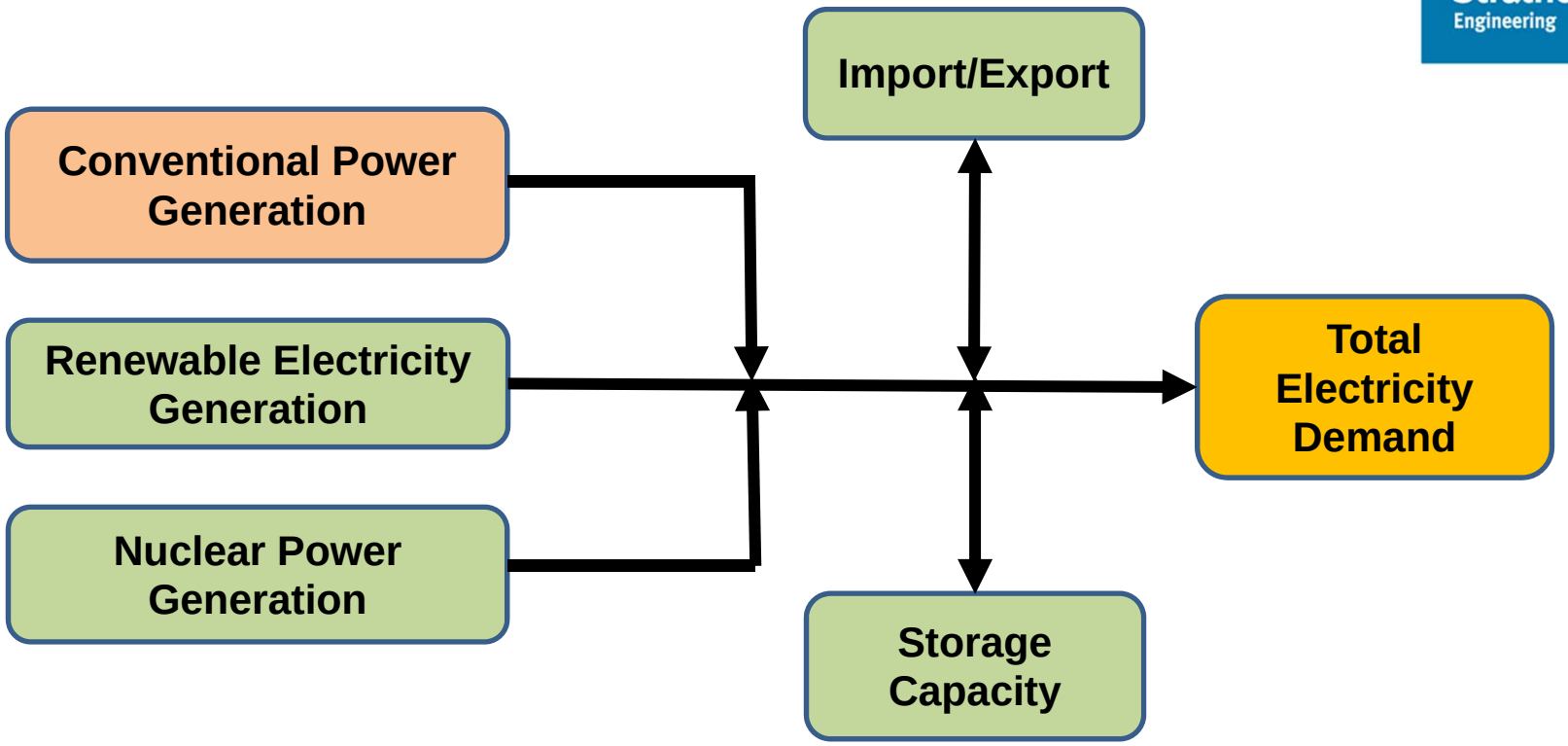
Estimated demand 2050
400TWh



32% increase

Higher value than National Grid
'Future Energy Scenarios' estimate

EnergyPLAN Verification
UK 2014 Grid

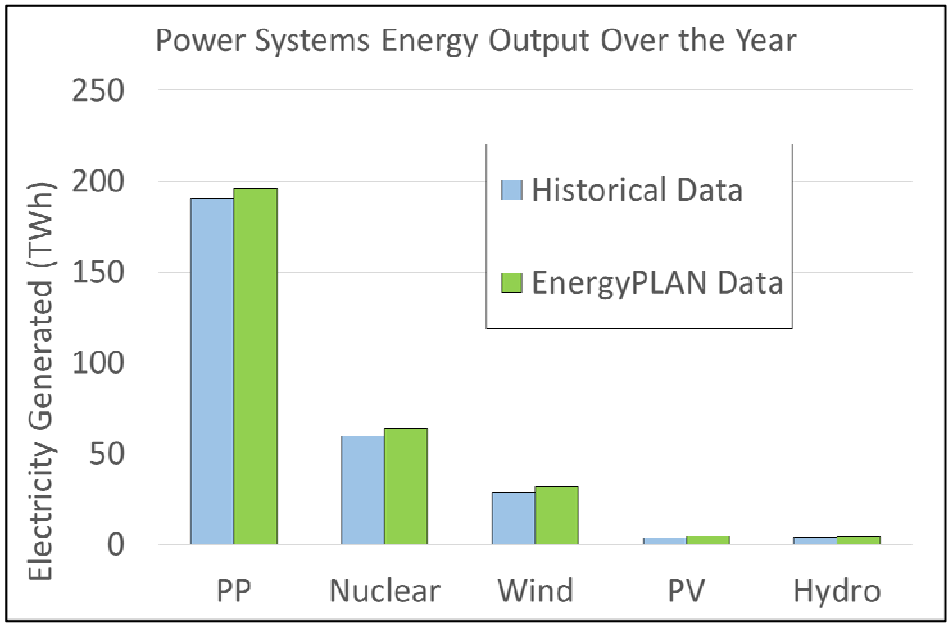


Input UK 2014 capacities and distribution profiles

Verify Model by analysis of EnergyPLAN Power Generation and CO_2 Emissions

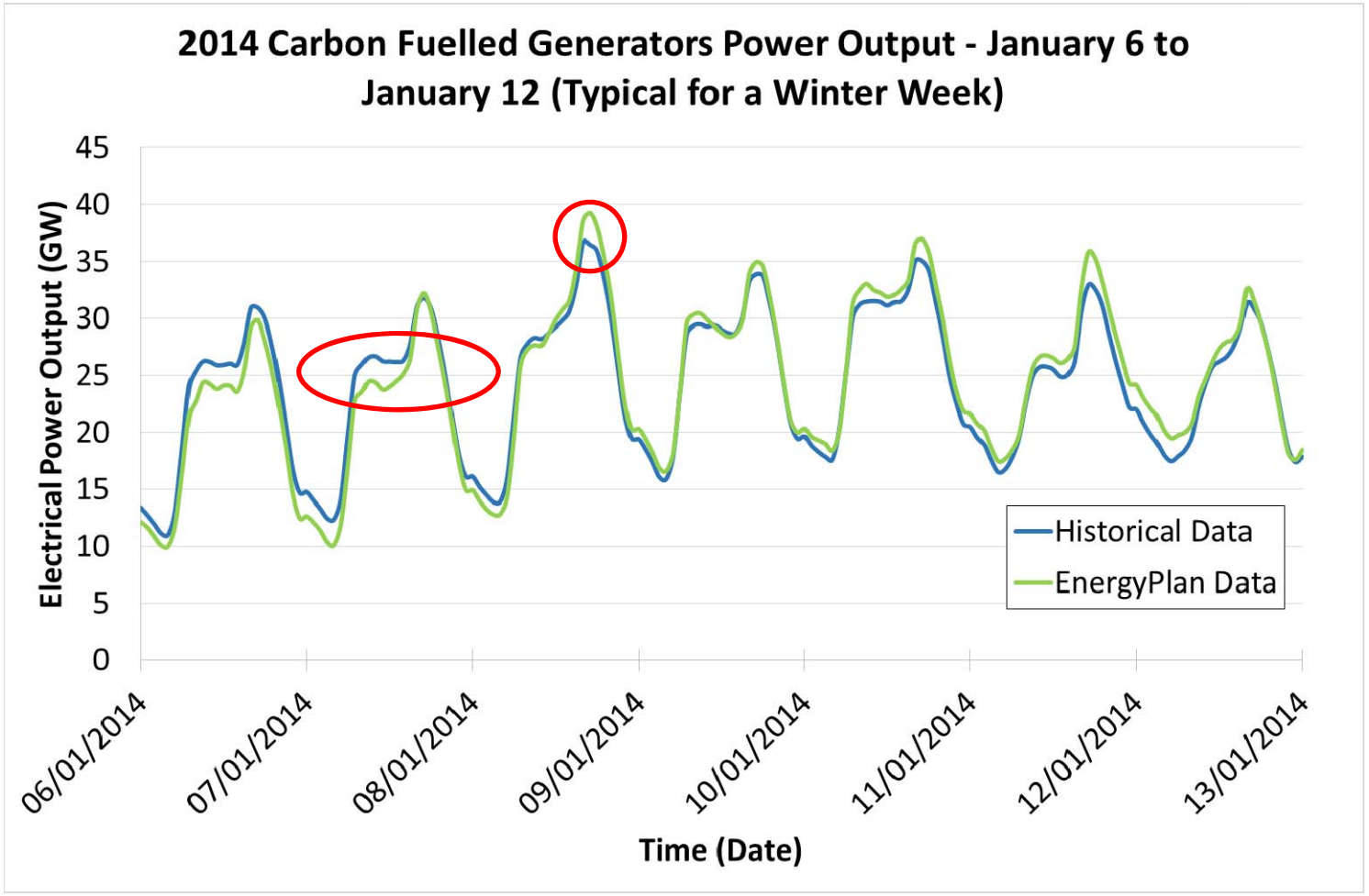
EnergyPLAN Verification
UK 2014 Grid

	Gridwatch/DUKES Historical Data	EnergyPLAN Verification
Energy Generated from Conventional Power Plants	**191 TWh**	**196 TWh (within 2.6%)**
Total CO2 Emissions	**133 Mt**	**128 Mt (within 3.8%)**
Conventional Power Plant Power Output Profile	**See next slide**	



Gridwatch/DUKES 2014 Historical Data → Compare → **EnergyPLAN 2014 Data**

EnergyPLAN Verification
UK 2014 Grid



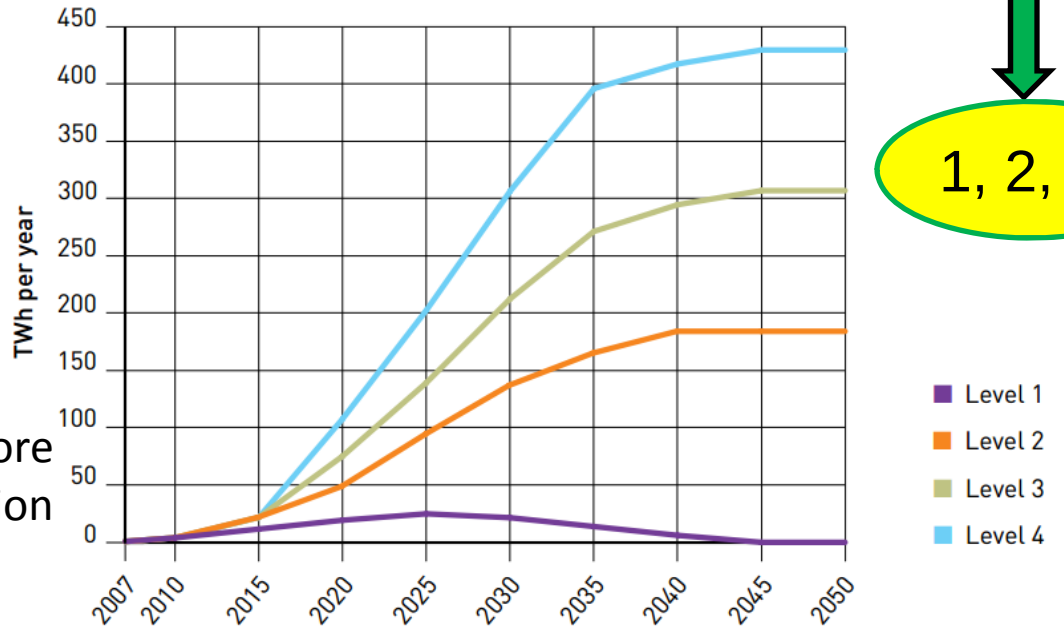
Monday → Sunday

EnergyPLAN 2050 Scenarios

Government 'Pathways Analysis' study

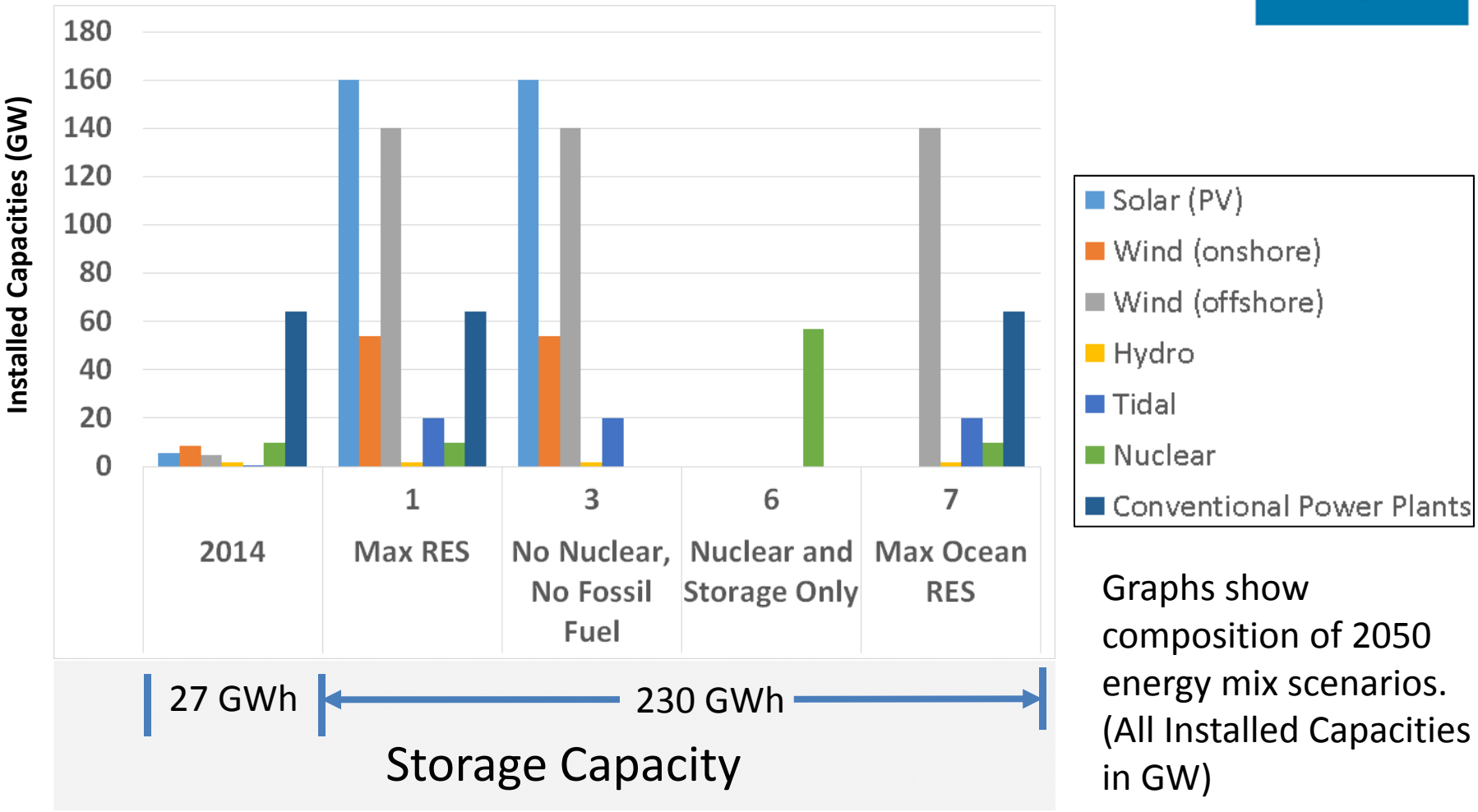
Supply Capacities → **Low Carbon Technologies** → **Scenarios**

1, 2, 3…



'Pathway Analysis' Offshore Wind Electricity Generation Trajectories (DECC)

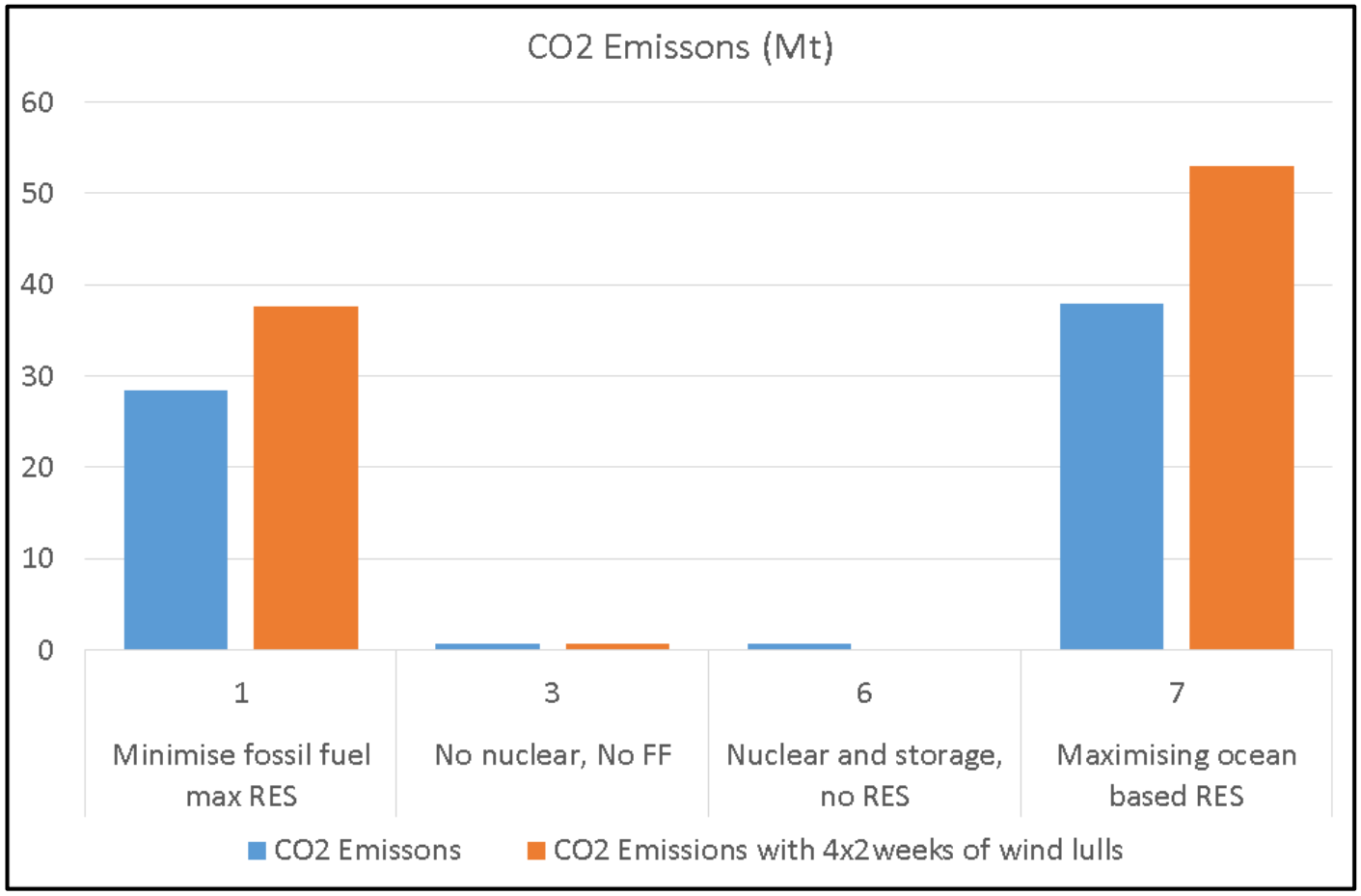
EnergyPLAN 2050 Scenarios



Graphs show composition of 2050 energy mix scenarios. (All Installed Capacities in GW)

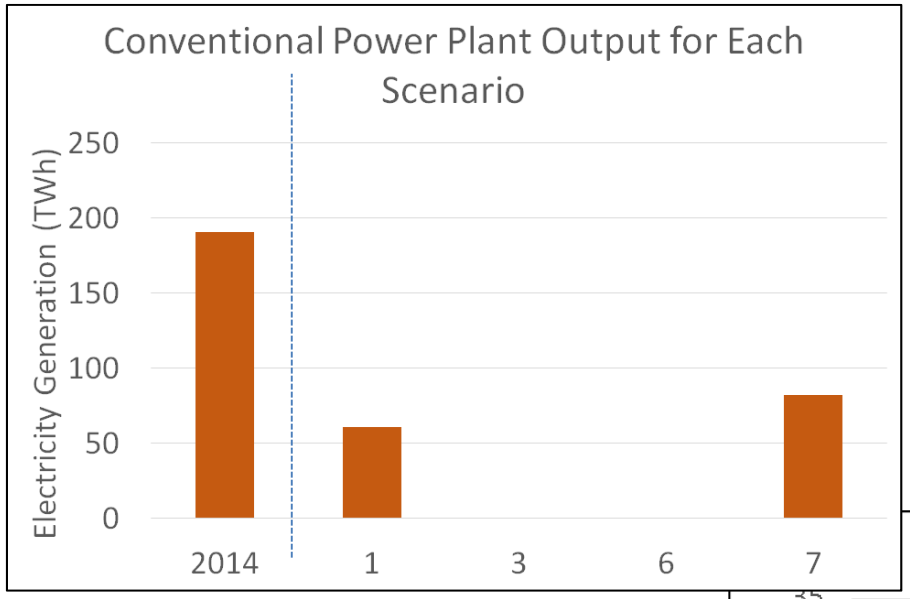
Scenario Assessment

CO_2 Emissions

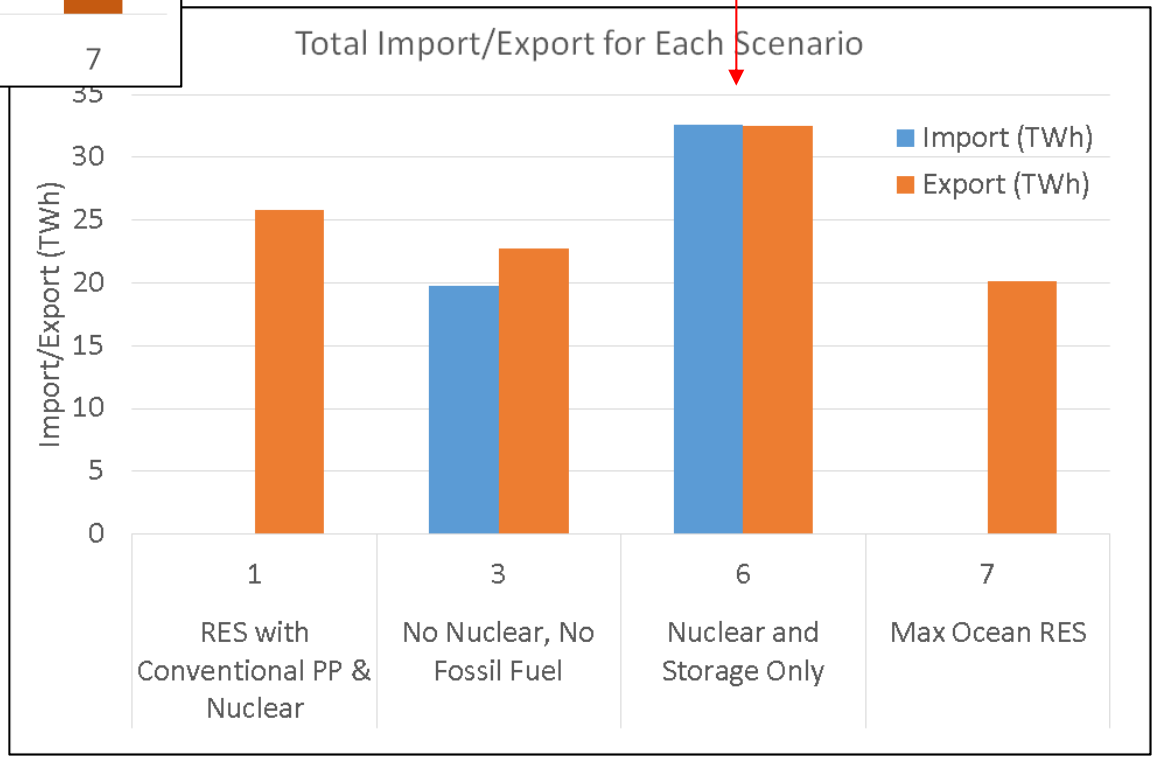


Note: 2014 CO_2 Emissions were 133 Mt

Scenario Assessment

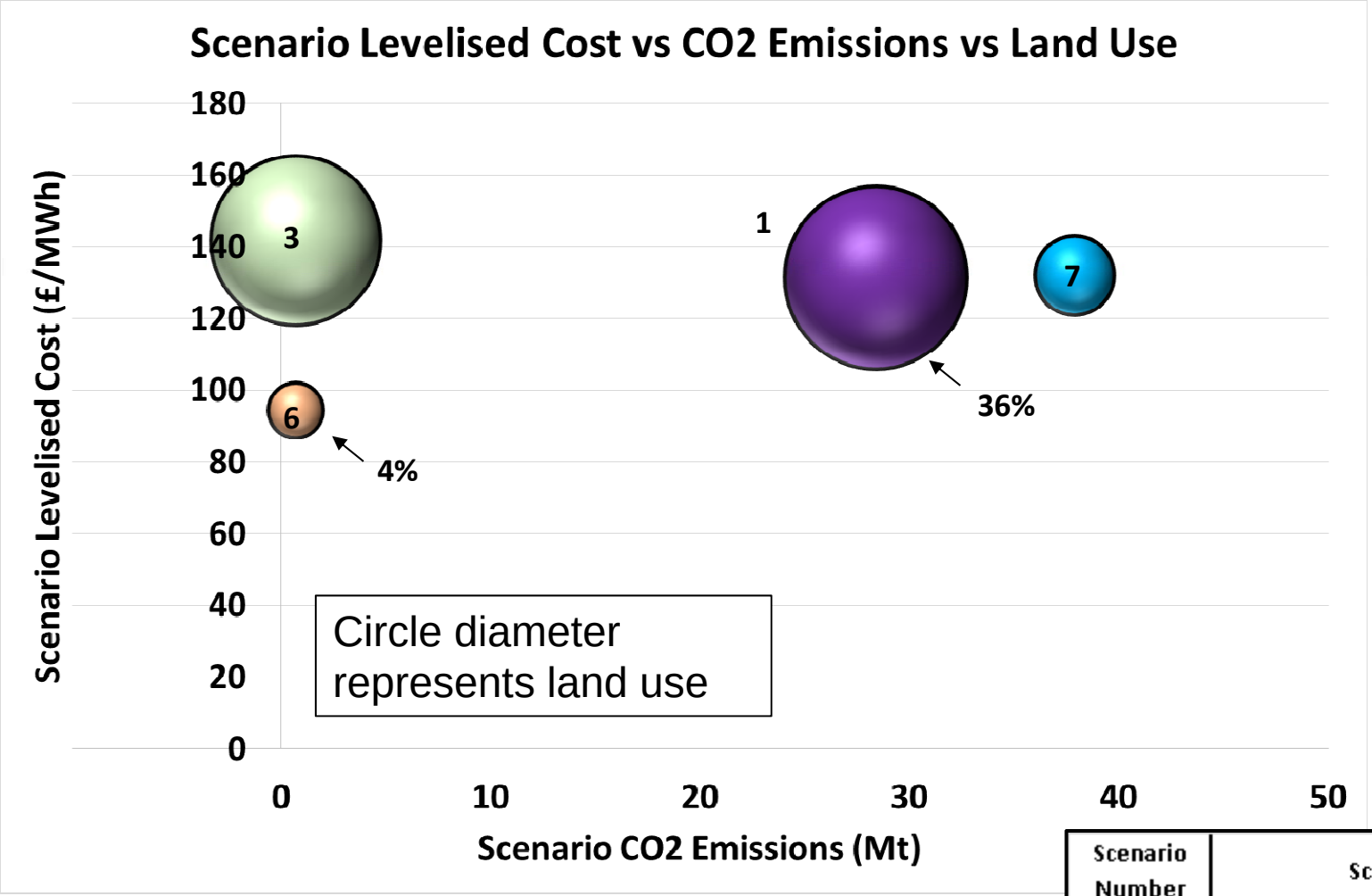


- **Scenario 1&7**: Reliance on Conventional Power Stations
- **Scenario 3&6**: No fossil fuel, then there is a need for import



- Increasing storage capacity could reduce the need for
  - Import/Export
  - Conventional power stations

Feasibility Assessments



Point to Note:

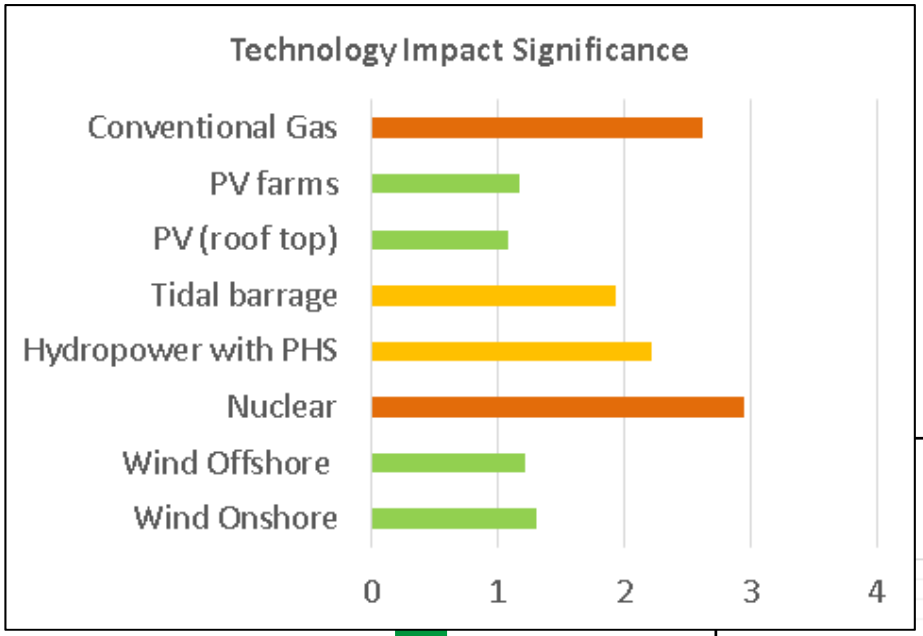
UK already uses 71% of land for agricultural purposes

(Source: UK Government)

Scenario Number	Scenario Title
1	Minimise fossil fuel max RES
3	No nuclear, No FF
6	Nuclear and storage, no RES
7	Maximising ocean based RES

Feasibility Assessments

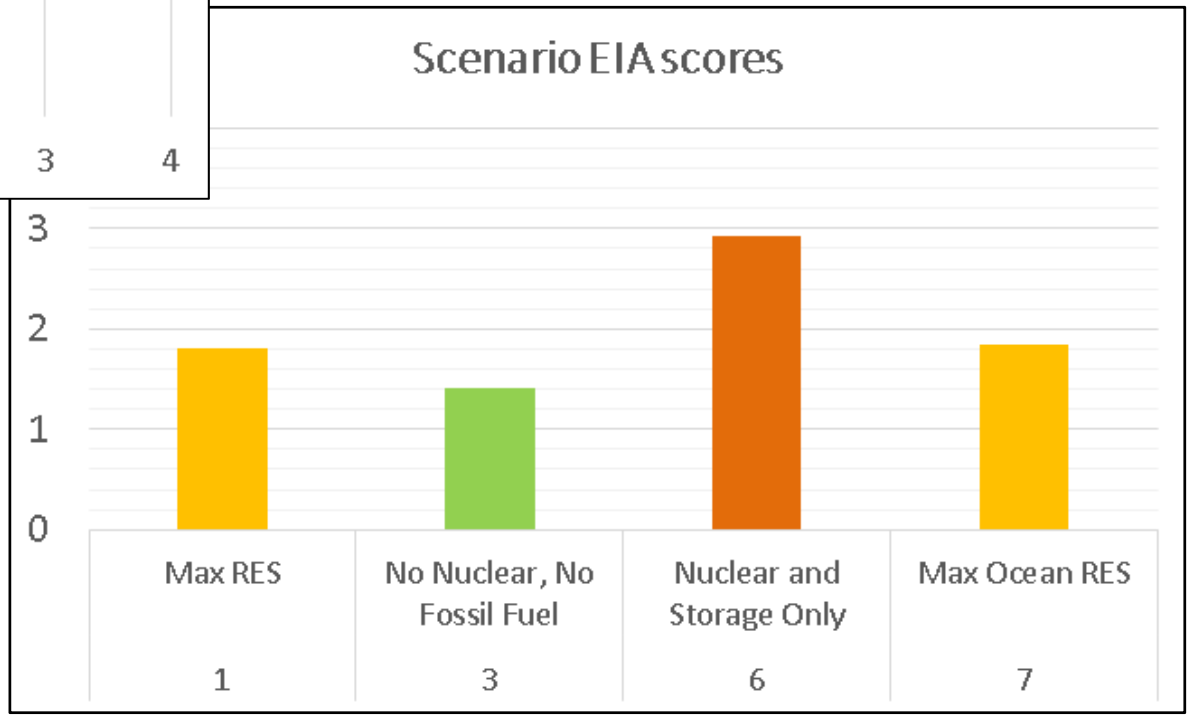
Environmental



Impact Significance Criteria defined by Wood (2008)
Grading:

1- No significance or negligible
2- Low significance
3- Moderate significance
4- High significance

by weighting the % of energy production coming from each technology…



Project Conclusions

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Energy PLAN

Was EnergyPLAN a good choice?
Yes

Can emission targets be achieved?
Probably, yes

Department of Energy & Climate Change

Is a huge effort required?
No

Project Conclusions

Did any technology show promising results?
Yes, but…

Can we get rid of nuclear or fossil fuels?
Technically yes, but...

Storage!!

Project Conclusions

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However…

- All future scenarios modelled require a **Coherent Policy** and decision making.

- Electricity generation only contributes a fraction of total CO2 emissions, **how** do we deal with the rest?

- Excess electricity production:
  - H_2?
  - cables?

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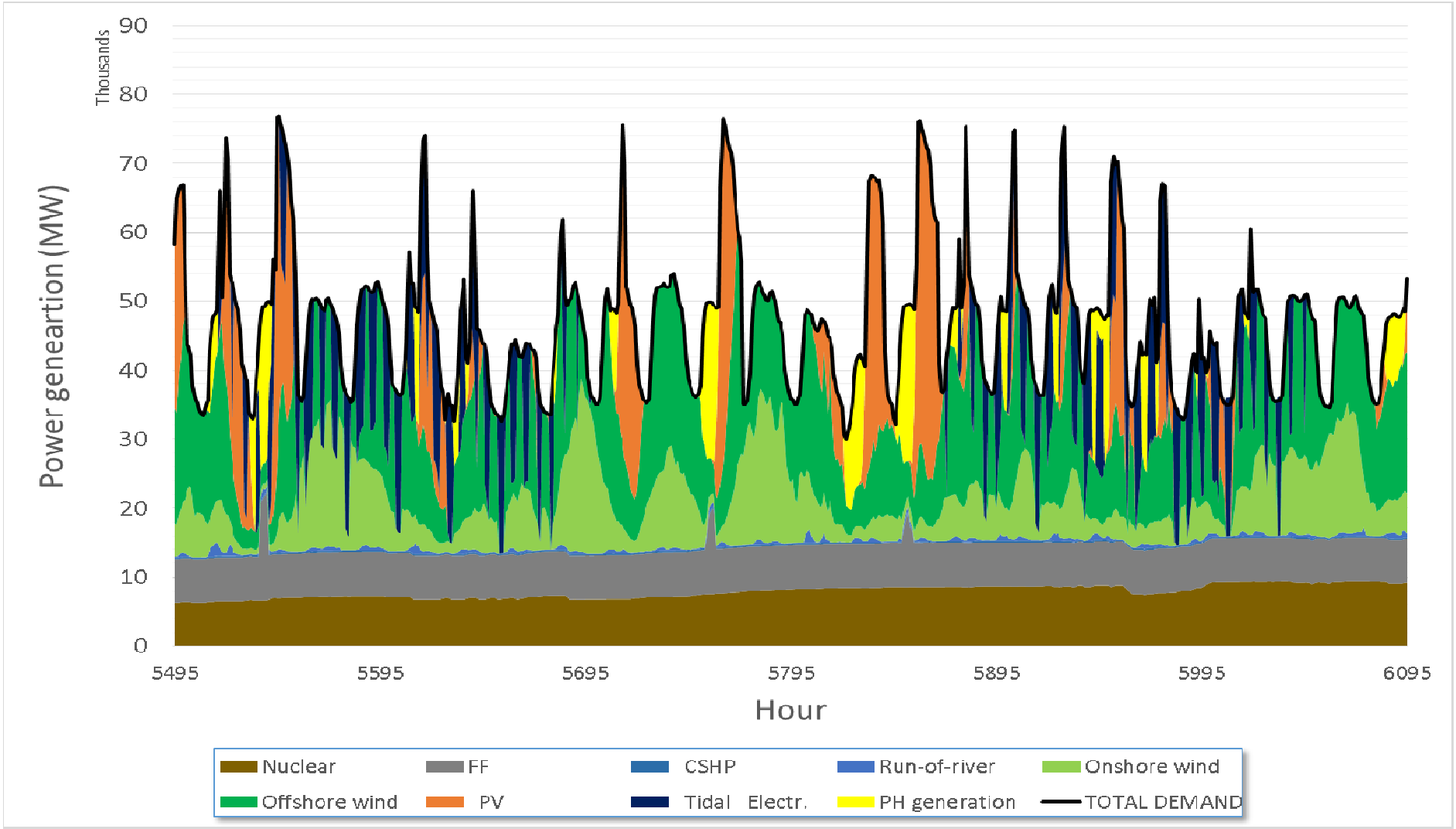
Glasgow

Scenario Assessment

Dynamic Graphs

(sample from 17th Aug to 11th Sep)



Feasibility Assessments

Global Perspective – *pros & cons*

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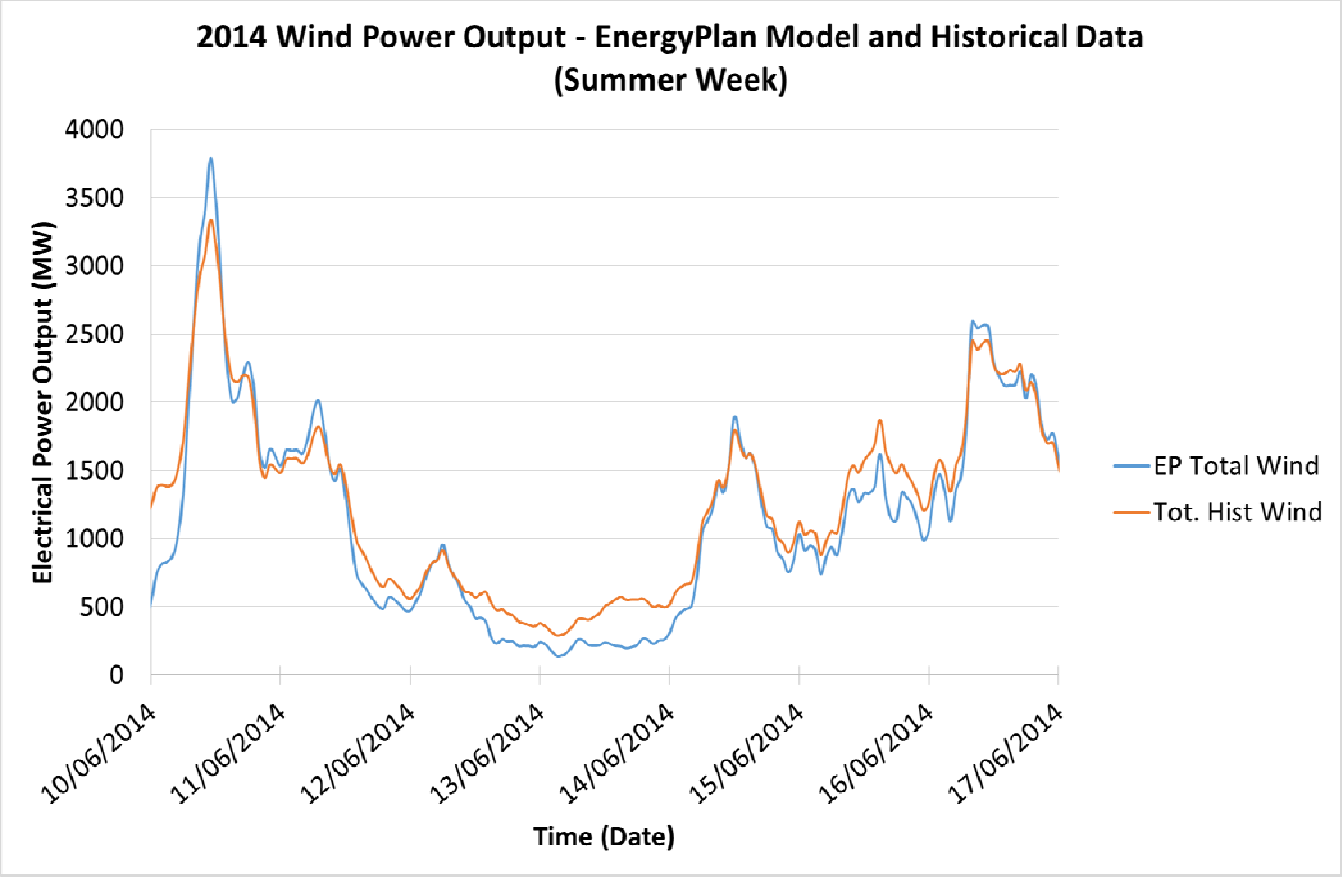
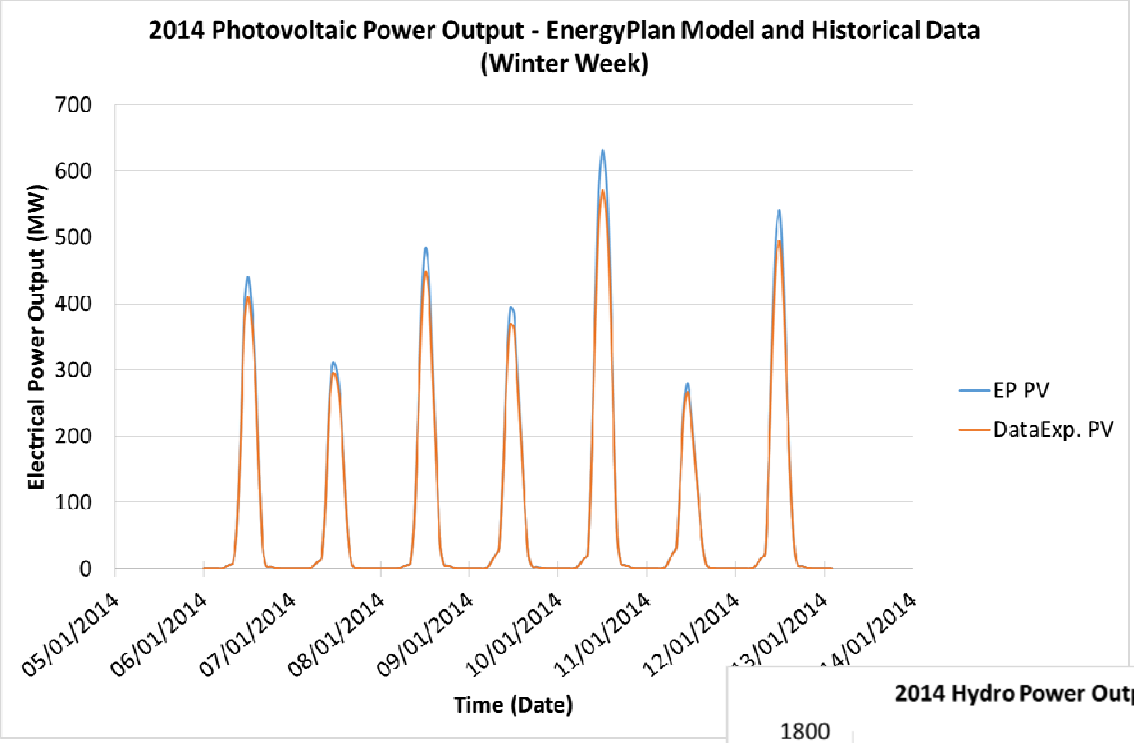
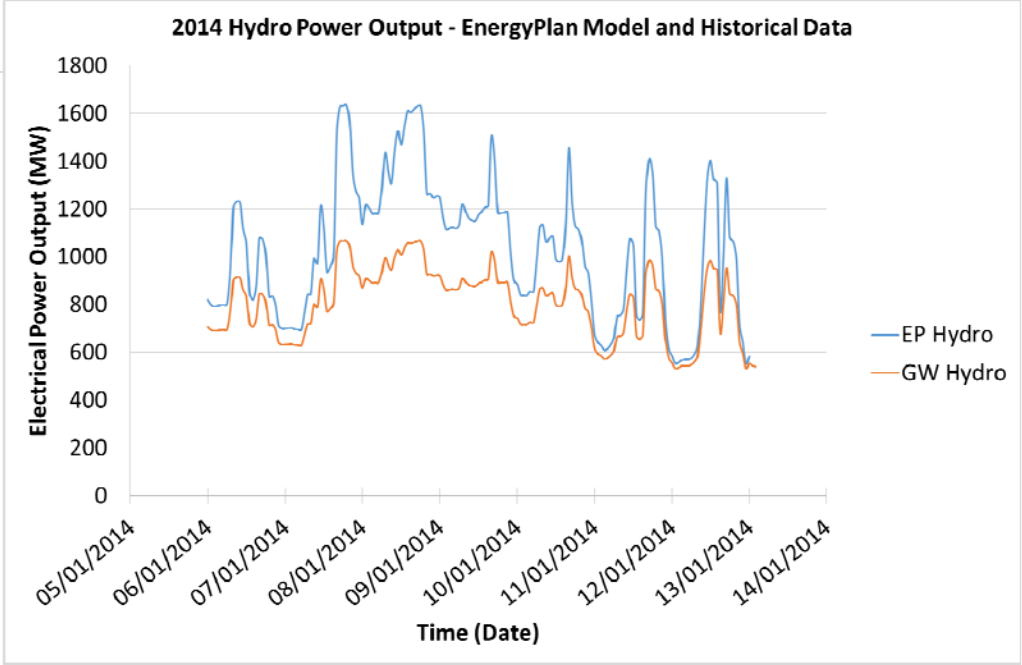
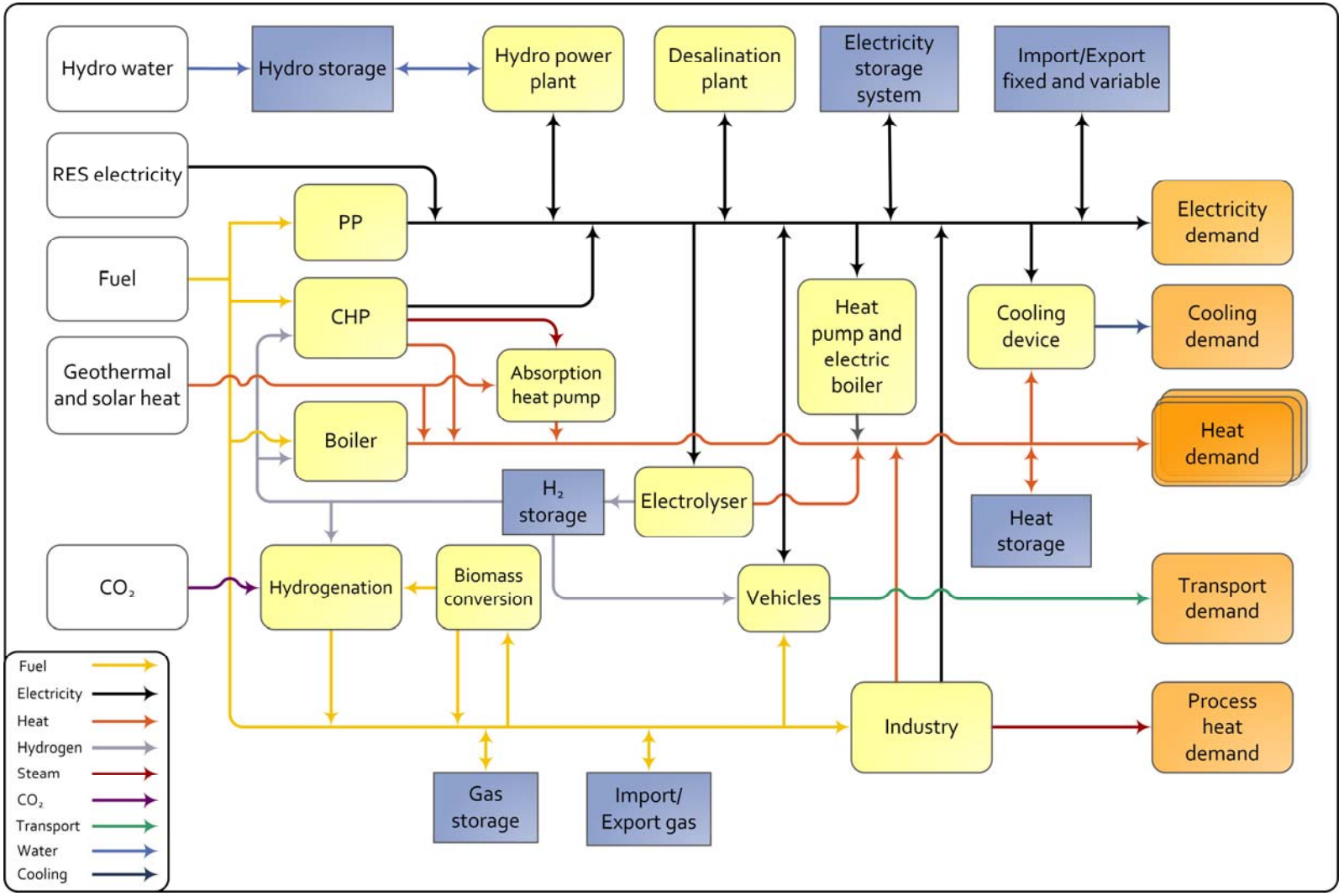
Scenario Number	Scenario description	CO_2 emissions (Mt)	LCOE (£/MWh)	Land use (% UK)	EIA score (1-4)
1	Max RES	28.4	£131.32	34.65	1.86
1b	Max RES	37.6	£133.04	36.48	1.92
2	No Nuclear	31.2	£139.53	36.03	1.69
2b	No Nuclear	43.8	£139.77	37.89	1.78
3	No Nuclear, No Fossil Fuel	0.7	£141.77	30.66	1.50
3b	No Nuclear, No Fossil Fuel	0.7	£132.80	31.56	1.52
4	More Nuclear	27.5	£127.47	32.54	1.95
4b	More Nuclear	35.2	£129.65	34.35	2.00
5	Max Nuclear	26.3	£117.15	22.83	2.38
5b	Max Nuclear	28.3	£119.00	28.39	2.39
6	Nuclear and Storage Only	0.7	£94.34	3.64	2.69
7	Max Ocean RES	37.9	£132.10	6.55	1.84
7b	Max Ocean RES	52.9	£127.27	7.17	1.95
8	Max Land RES	49.0	£134.92	36.54	2.00
8b	Max Land RES	57.0	£133.68	36.89	2.04


2014 Wind Power Output - EnergyPlan Model and Historical Data (Summer Week)
Electrical Power Output (MW)
4000
3500
3000
2500
2000
1500
1000
500
0
10/06/2014
11/06/2014
12/06/2014
13/06/2014
14/06/2014
15/06/2014
16/06/2014
17/06/2014
Time (Date)
EP Total Wind
Tot. Hist Wind


2014 Photovoltaic Power Output - EnergyPlan Model and Historical Data (Winter Week)
Electrical Power Output (MW)
700
600
500
400
300
200
100
0
05/01/2014
06/01/2014
07/01/2014
08/01/2014
09/01/2014
10/01/2014
11/01/2014
12/01/2014
Time (Date)
EP PV
DataExp. PV


2014 Hydro Power Output - EnergyPlan Model and Historical Data
Electrical Power Output (MW)
1800
1600
1400
1200
1000
800
600
400
200
0
05/01/2014
06/01/2014
07/01/2014
08/01/2014
09/01/2014
10/01/2014
11/01/2014
12/01/2014
13/01/2014
14/01/2014
Time (Date)
EP Hydro
GW Hydro

EnergyPLAN



Source: EnergyPLAN.eu

Existing Future Grid Studies

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Gaps in other existing work:

- Tom Hoy dissertation: no future demand prediction, pumped hydro only storage considered, no tidal barrage considered
- DECC 2050: doesn’t consider storage, no demand/supply matching (only uses yearly averages)
- Mackay: out of date – technology has moved on, the overall assessment doesn’t consider demand and supply over time
- Jacobson – main focus is USA, the UK prediction doesn’t go into much detail and appears very optimistic, but will be useful as a comparison

Last 2 weeks

1. Gathering of current UK grid data to create reference model:
   - Gridwatch – supply and demand data over time in 5 min intervals;
   - DUKES – breakdown of more detailed data (industry/homes etc.);
   - National grid – info on grid infrastructure, however zonal assessment no longer part of scope. National grid ten year statement will be useful in helping predict future demand.
   - Data Processing.

2. Literature reviews and research of other projects (e.g. the NINES) for ideas.

3. Software selection process, software vs criteria relevant to project.

Software	Cost	Large Scale	Demand matching	Storage Inclusion	Input own data trends	Economic analyses	User friendly
Merit							
Homer							
Excel							
EnergyPlan							

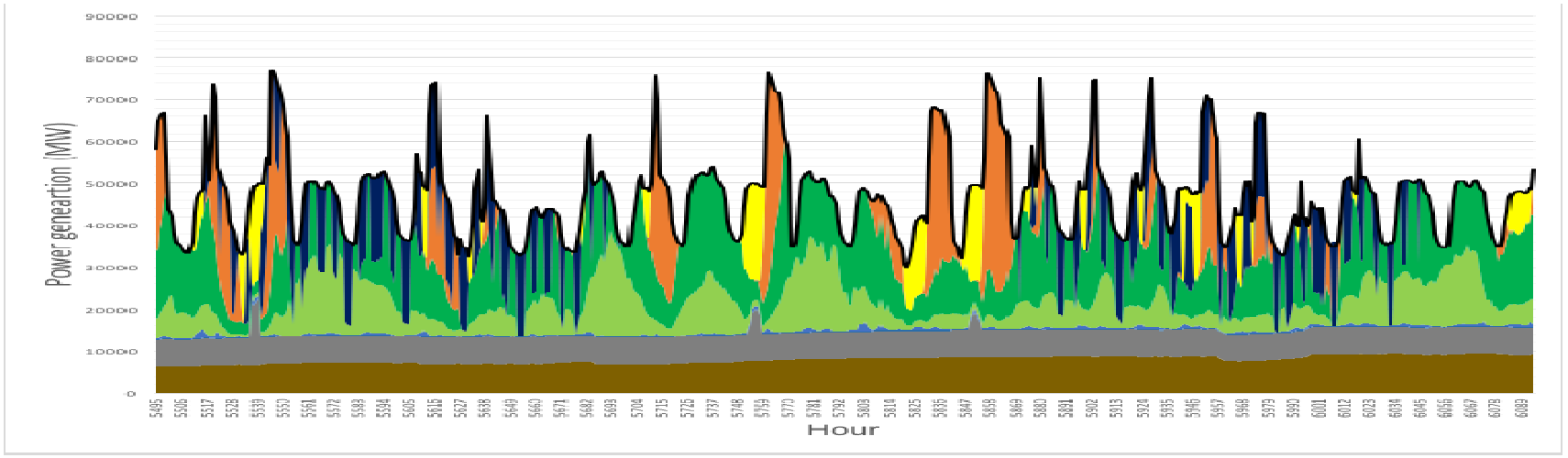
4. EnergyPlan training:
   - David Connolly's (Aalborg Uni.) input guide (2013);
   - EnergyPLAN Documentation;
   - Tutorial Exercises.

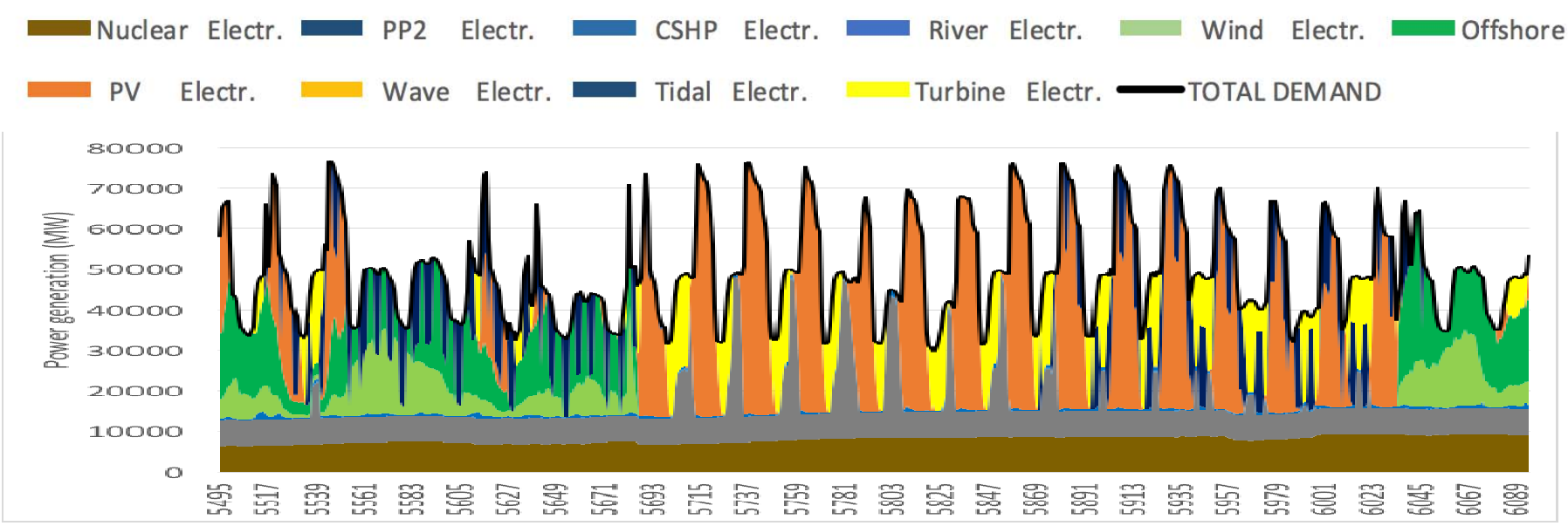
2050 Scenario Results

- CO2 emissions most important to this study.
- Import and export important in terms of grid stability.
- CEEP (Critical Excess Energy Production) indicates excess electricity above what is possible to export.

	Scenario	CO2 Emissions (Mt)	CEEP (TWh)	Import (TWh)	Export (TWh)
Max RES	1	28.401	0.07	0	25.83
	1b	37.62	0.06	0	22.87
No Nuclear	2	31.186	0	0	24.19
	2b	43.774	0	0	21.29
No Nuclear, No Fossil Fuel	3	0.701	0	19.72	22.75
	3b	0.701	0	53.97	20.02
More Nuclear	4	27.528	0.7	0	27.26
	4b	35.188	0.65	0	24.3
Max Nuclear	5	26.307	18.84	0	48.28
	5b	28.338	17.94	0	45.26
Nuclear and Storage Only	6	0.701	17.99	32.55	32.52
Max Ocean RES	7	37.885	0.04	0	20.15
	7b	52.939	0.04	0	16.96
Max Land RES	8	49.014	0	0	14.12
	8b	57.044	0	0	13.24

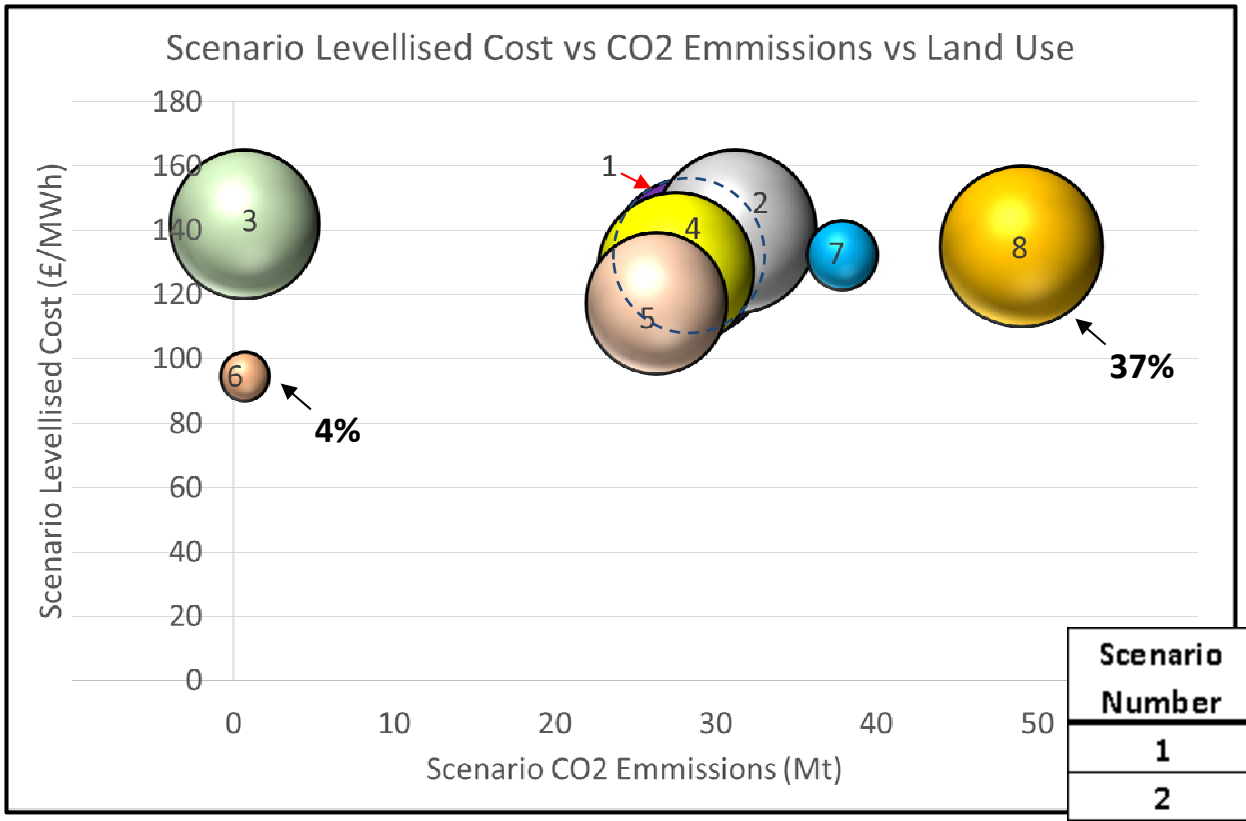
2050 Dynamic Assessment





Feasibility Assessments

Levelised Costs vs CO2 Emissions vs Land Use



Circle diameter represents land mass use per scenario

Scenario Number	Scenario Title
1	Minimise fossil fuel max RES
2	No Nuclear
3	No nuclear, No FF
4	More Nuclear
5	Max Nuclear (still inc. RES)
6	Nuclear and storage, no RES
7	Maximising ocean based RES
8	Maximising Land based RES

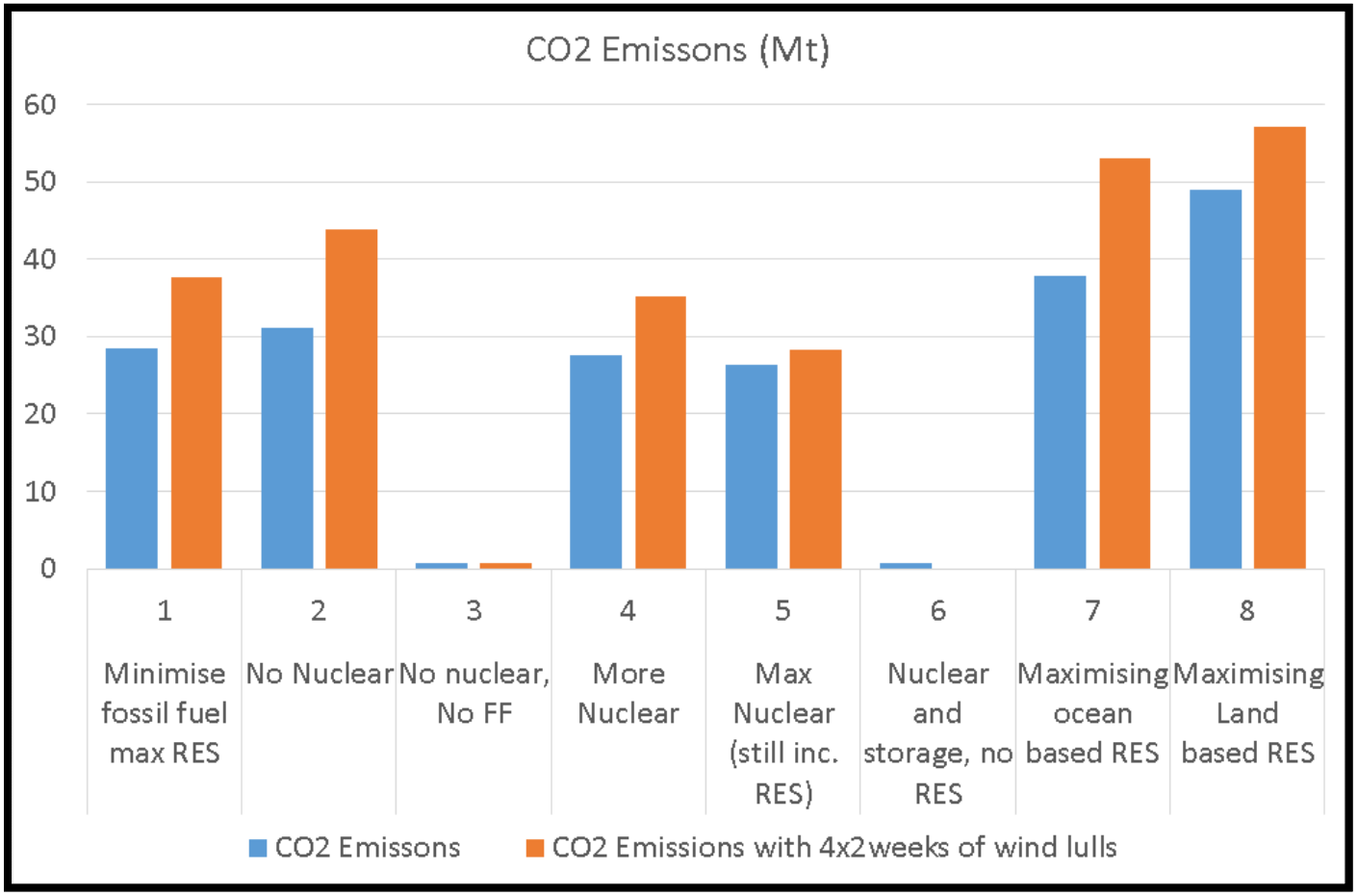
Point to Note:

UK already uses 71% of land for agricultural purposes

(Source: UK Government)

Scenario Assessment

CO2 Emissions



Note: 2014 CO2 Emissions was 133 Mt

Project Conclusions

EnergyPLAN proved to be a useful and comprehensive modelling tool for large scale grid system planning.

2050 'Pathway Analysis' Results showed more-conservative level-2 installed capacities may be sufficient.

CO_2 Emissions

Significant **CO_2** emissions reduction could be achieved despite the estimated **32%** increase in demand (worst case down to 57Mt from 133Mt in 2014).

Project Conclusions

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Land Use

- RES networks requires **large areas of land**;
  - up to 37%,
  - bearing in mind todays agriculture takes 71%,
  - how much more will be required with a higher population?

Nuclear Power Grid

- Significant cost, land use and emissions advantages but is **very contentious**
- **No Nuclear** and **No reliance on conventional power plants** is possible but at significant costs and land use.

Storage is Essential!

- We considered an increase by a factor of 9 in energy storage capacity

Project Conclusions

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However…

- All future scenarios modelled require a **Coherent Policy** and decision making.

- Electricity generation only contributes a fraction of total CO2 emissions, **how** do we deal with the rest?

- Dealing with excess electricity production:
  - opportunity to develop H_2 economy?
  - export to Europe: enough capacity in existing cables?