

Resilient Electricity Networks for Great Britain (RESNET)

Project Aim

To develop and demonstrate a systems-level approach to analysing, at the GB scale, the resilience of existing and proposed electricity networks to a changing climate, including societal and technical adaptation.

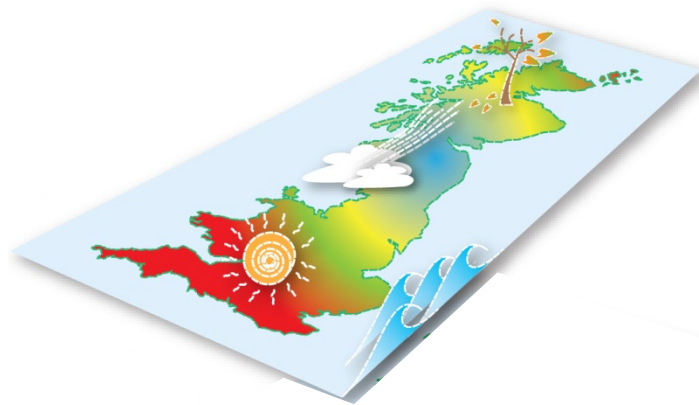
Project Team

Multi-disciplinary expertise from Manchester & Newcastle

- University of Manchester:
 - Kevin Anderson, Ruth Wood, Dana Abi Ghanem, Sarah Mander, Stephen Glynn, Clair Gough (Tyndall Centre for Climate Change)
 - Ian Cotton, Pierluigi Mancarella, Xiaolong Hu (Electrical Engineering)
 - John Moriarty, James Blair (Mathematics)
- University of Newcastle
 - Sean Wilkinson (Structural Engineering), Richard Dawson (Earth Systems Engineering), Gaihu Fu (Infrastructure Resilience), Lucy Manning (Climate Change), Chris Kilsby (Climate Change)

Project part funded by National Grid

RESNET Comprises 5 Work Packages



WP1: Spatial Climate Scenarios

- Future climate scenarios generated using UKCP09
- Emphasis on extremes & climate change disrupting large areas
- Model temperature, rainfall, flooding & wind speed
- Timescales of 2020, 2050, 2080

Objectives:

- *To develop a weather generator for producing scenarios of spatially coincident weather extremes in future climates at a national scale*
- *To apply a weather typing approach to the regional climate models used by UKCP09 to produce a wind storm component for the weather generator*

WP2: Future Energy Scenarios

- Generate **energy** demand & supply scenarios for 2C, CCC & BAU emissions
- Detail the **electricity** dimension of the energy scenarios
- Focus on 2020, 2030, 2050 and 2080s timeframes
- Consistent with UKCP09 climate scenarios (*plus, 4C by 2050*)

Objective:

To generate spatially and temporally resolved scenarios of future electricity demand and supply, with different scales of decentralisation

WP3: Network Performance Analysis

- Develop component models for use in probabilistic power system analysis
- Examine changed performance (impact of climate on rating)
- Represent component failures (from failure data, modelling & stakeholders)
- Characterise future / emerging technologies

Objective:

To develop models relating changes in the severity of weather related events to performance / failure rate of individual network components; and to identify measures that can improve the future performance of equipment

WP4: Quantified Analysis Of Resilience & Effectiveness Of Adaptation

- Estimates of climate change impacts on day-to-day performance of grid,
- Existing grid used as benchmark
- Climate change impact quantified wrt. cost, maintenance, demand, outages, etc
- Critical system aspects / components quantified

Objective:

To quantify the potential impacts of future climate on the operational and infrastructure resilience of the overall GB power system

WP5: Social Responses To Adaptation Measures

- Societal adaptation measures considered alongside technical
- In-depth interviews to scope knowledge on electricity shortages etc
- Perceptions of the adaptation measures (& impacts) identified

Objectives:

To explore the societal implications and identify potential barriers to measures intended to make the grid more resilient to climate change

Intended Outcomes

- A description of how climate may impact the transmission system
- Outline opportunities for addressing such impacts
- Understand risks posed by climate change to system components
- Recommend spec' of equipment for future-proofing
- Propose network configurations for reducing climate impacts
- Understanding how society may respond to grid adaptation measures

WP2 RESNET Scenarios

Framing and approach

Kevin Anderson

Steven Glynn, Ruth Wood – Quantitative

Clair Gough, Sarah Mander - Qualitative

Scenario Scope

- Energy system – electricity and non-electricity
- Energy use across all sectors (inc aviation/shipping)
- Timeframes: 2020, 2030, 2050, 2080
- Temp' by 2050; 2C and 4C
 - well above A1FI & Betts carbon cycle feedbacks;*
 - latest CO2 emissions, global ~6% rise, UK ~4% rise*

Boundaries of the scenarios:

- All UK energy system (*electricity, heat, transport – inc. international*)
- Demand & Supply
- Timeline (*now to 2080 – as a pathway not end point*)
- Low carbon (from 2°C to statutory carbon budgets)
- Affordable and secure/resilient energy ‘services’

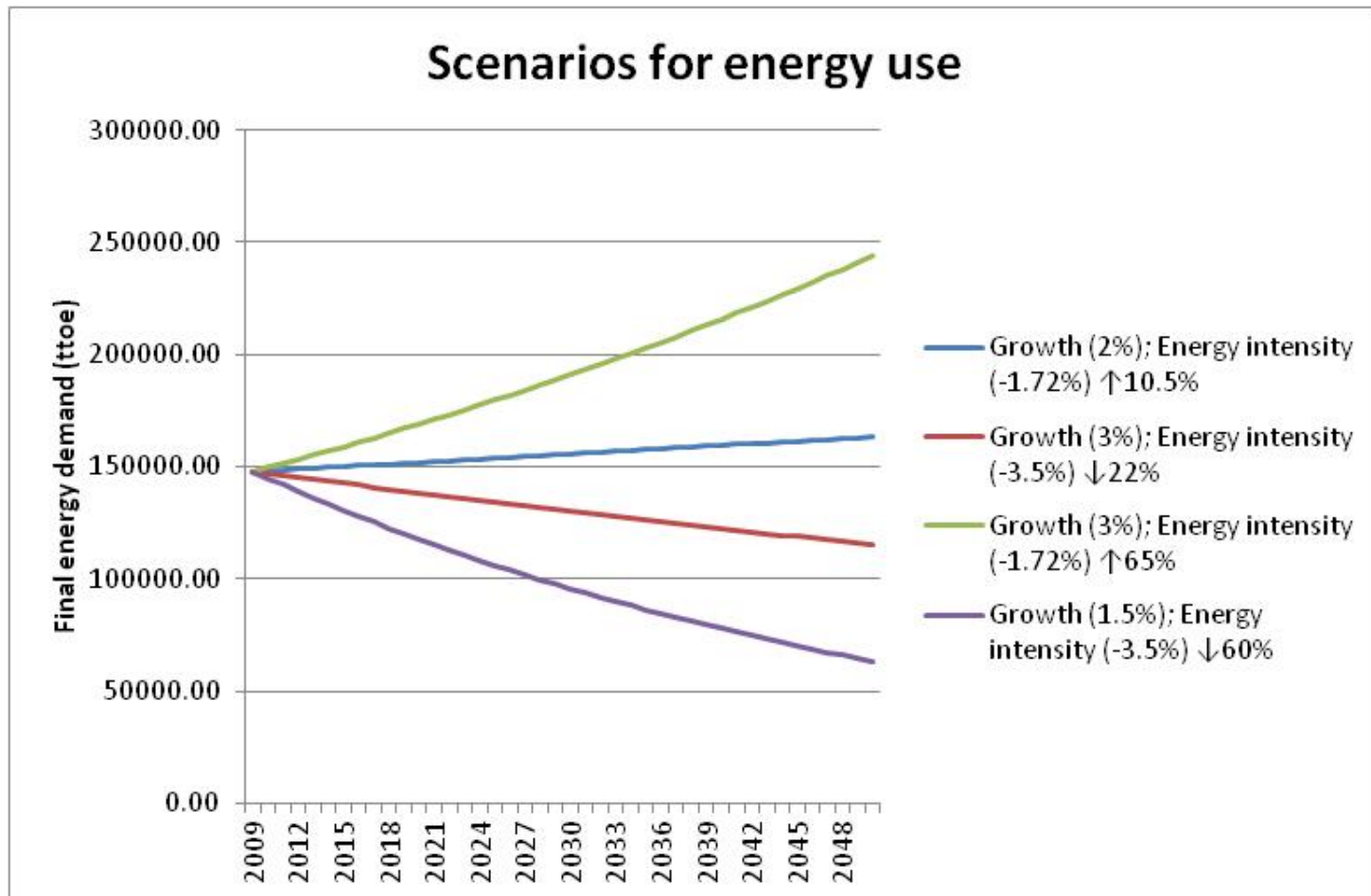
Outline of method:

- Use **ASK** to develop suite of alternative energy scenarios for UK
- Different to **UKERC**, **CCC**, etc, as:
 - bottom-up technology & user driven (c.f. top down economic modeling)*
 - pathways and phased transitions rather than endpoints*
 - carbon budgets and not 2050 reduction targets*
 - much higher electricity penetration*
 - greater range of **final energy use***
- Balance supply & demand (with consideration of storage)
- Analyse energy system as dynamic (active & passive management)
- Stakeholder engagement throughout (industry, regulators, policy)

Carbon Basis

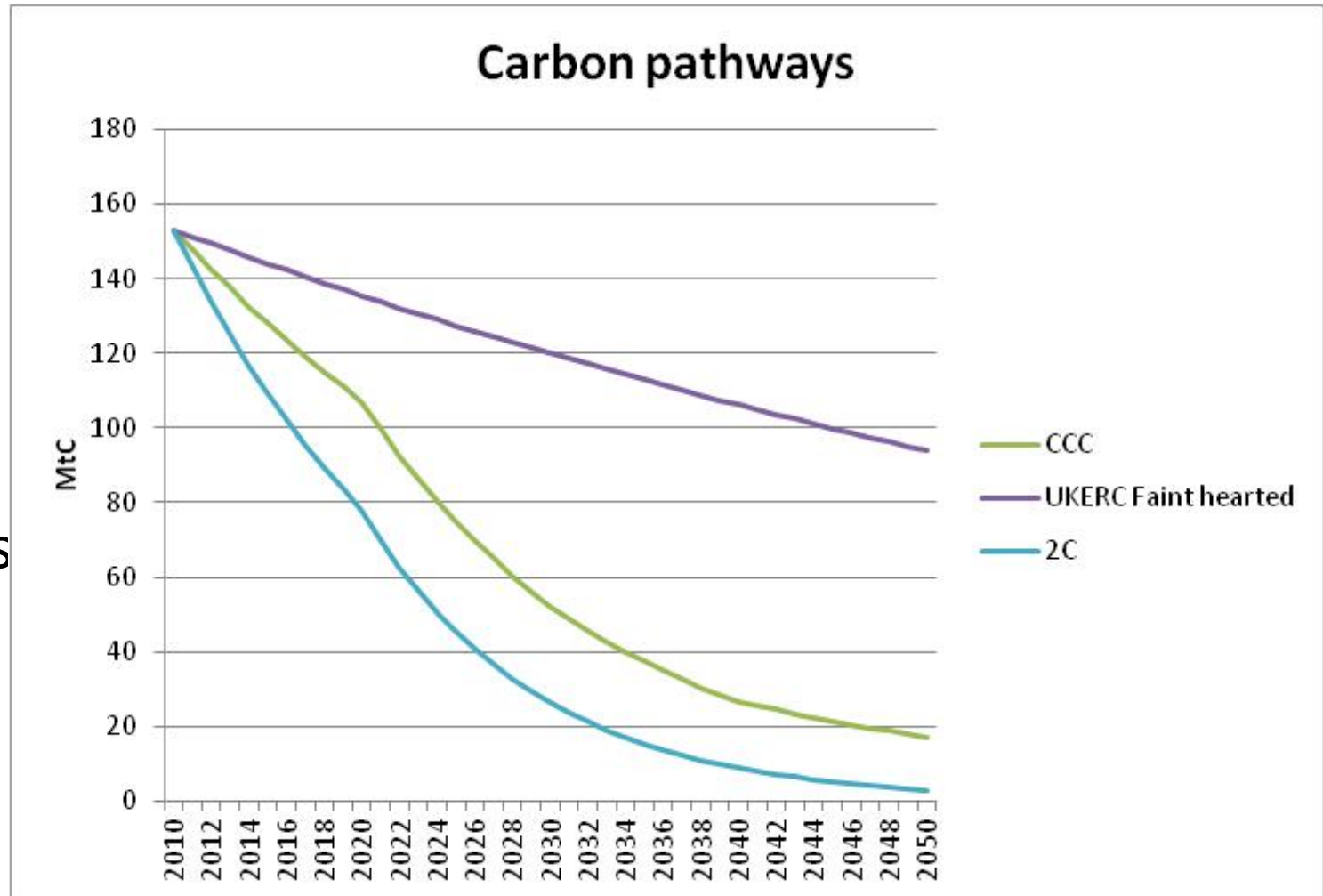
Framing the scenarios

Different
levels of
energy
demand

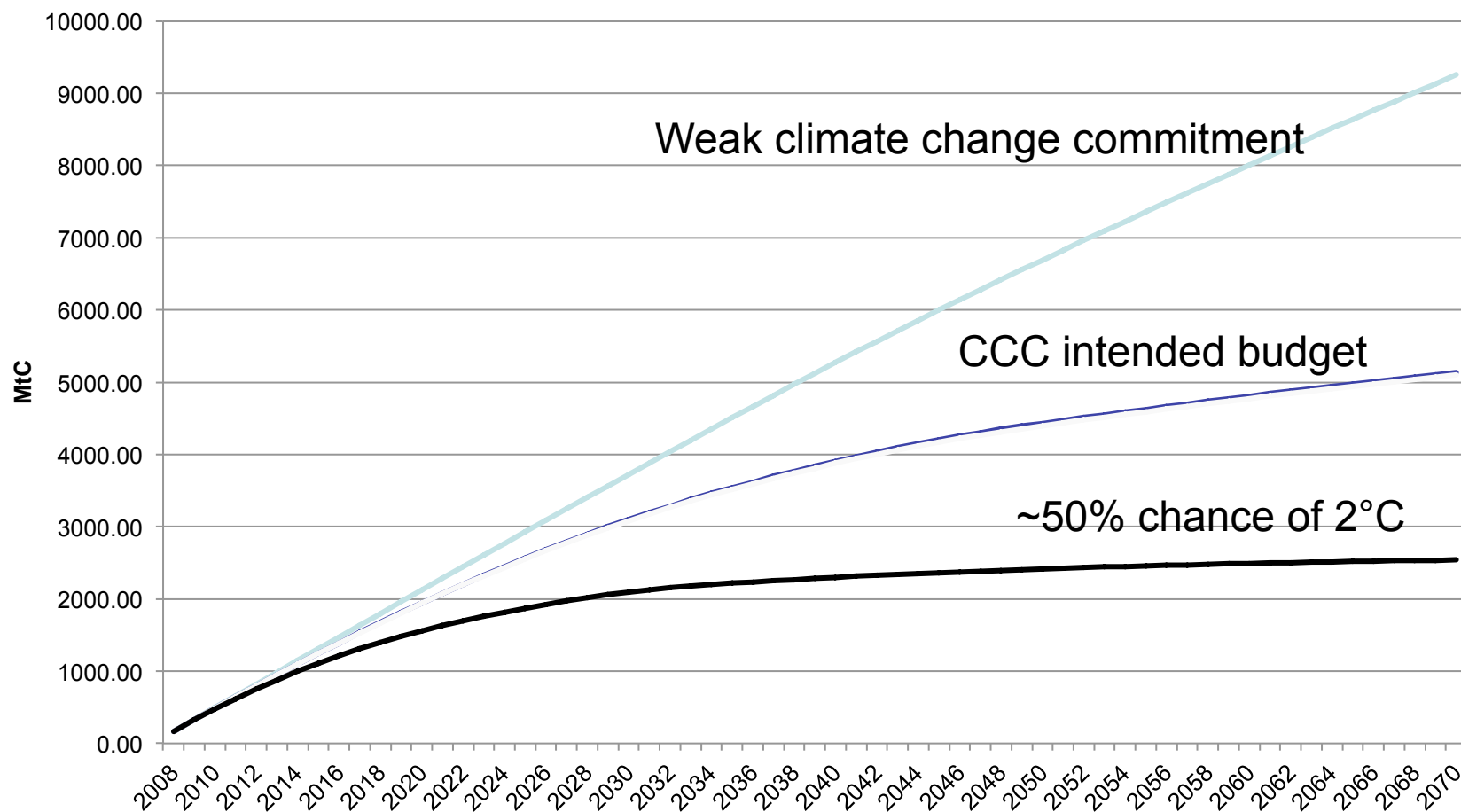


Framing the scenarios

Different
levels of
carbon
reductions



Cumulative Carbon emissions for each scenario



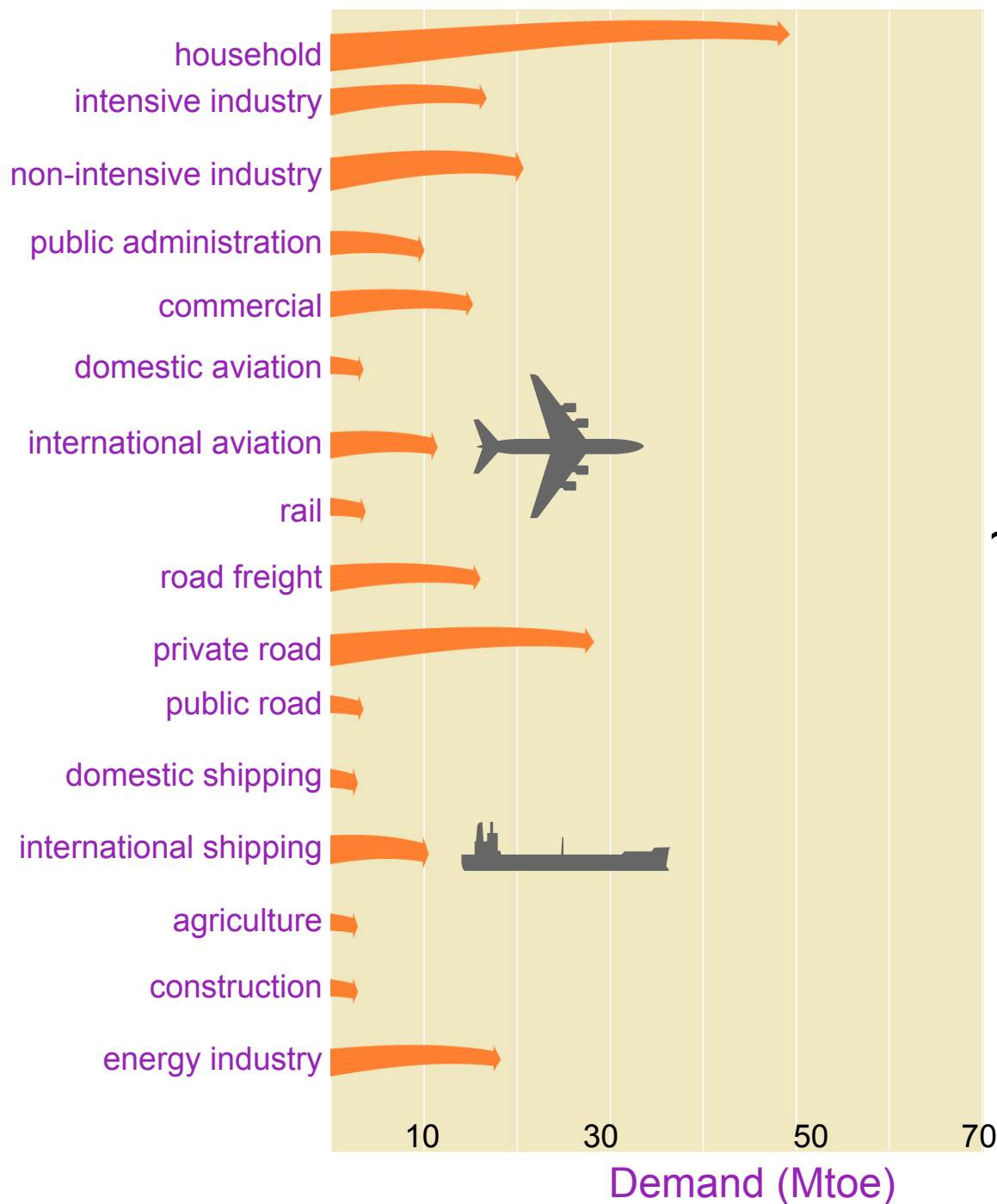
Differentiating electricity from energy

Energy scenarios translated into *electricity* scenarios; build on previous & CCC's analysis; headline electricity figures for the scenarios:

- ***Low electricity consumption*** ***300TWh by 2030 and static thereafter***
- ***Medium elec' consumptions*** ***600TWh by 2030 to 800TWh by 2050***
- ***High elec' consumptions*** ***1000TWh by 2030 to 1500TWh by 2050***

Proportion of energy met by electricity, level of intermittency, active demand, EVs, heating, storage, spatial distribution etc vary between/within scenarios,

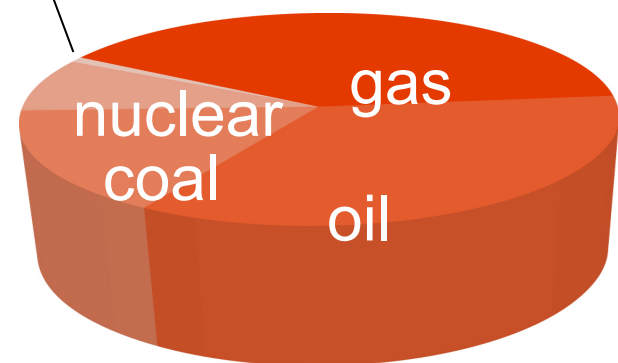
ASK energy system 'model'



‘Today’

Primary energy demand:
baseline

~1% renewables



~ 20% electricity

SCENARIO VARIATION, SUPPLY AND CARBON DIOXIDE EMISSIONS															2050 EMISSIONS										SUPPLY (Mtoe)									
BASELINE DATA (Mtoe)					ENERGY INDICATORS TO FORM 2050 ENERGY CONSUMPTION										2050 EMISSIONS					SUPPLY (Mtoe)														
SECTOR	ENERGY CONSUMPTION IN BASELINE YEAR	GVA AS % OF BASELINE YEAR GDP	CARBON DIOXIDE (MtC) BASELINE YEAR		CHANGE IN NUMBER OF HOUSEHOLDS (HH)	CHANGE IN HOUSEHOLD SIZE (POP/HH)	CHANGE IN CONSUMER EXPENDITURE (GEP/POP)	CHANGE IN ECONOMIC ACTIVITY (ACT)	CHANGE IN MOBILITY (MOB)	CHANGE IN MOBILITY PER COST (MOB/COST)	CHANGE IN ENERGY EFFICIENCY (ENY/ENY0)	CHANGE IN ENERGY INTENSITY (ENY/INT)	COMPOUND CHANGE IN ENERGY CONSUMPTION (ENY)	2050 FINAL ENERGY CONSUMPTION (Mtoe)	GVA PROPORTION	CARBON DIOXIDE (MtC)	CARBON INTENSITY (MtC/Mtoe)	SUPPLY MATCH DEMAND CHECK	2050 ENERGY CONSUMPTION (Mtoe)	TOTAL FROM GRID	CONVENTIONAL DEMAND FROM GRID	HYDROGEN FROM ELECTROLYSIS FROM GRID	COAL IGCC CONVENTIONAL	COAL IGCC PRODUCTION	CCGT	NUCLEAR CONVENTIONAL	NUCLEAR ALSO PRODUCTION	BIOFUEL PRODUCTION	BIOFUEL SWASTE PRODUCTION					
1. HOUSEHOLD	Other Energy	99%	24.27														0.60	0.60		1.00	100%			3%	4%	5%	1%	4%	3%	4%				
	Electricity	29%	16.73														1.73	0.09		19.50	5.05	1.00	1.05	0.15	1.00	0.25	0.05	1.00	0.15	1.00				
																	0.00	15.76		15.76		1.00		1.10				0.95		2.00				
	Total	41.73	43.00		0.2%	-0.2%	0.0%					-2.0%	0.7%	67.14			2.33	0.11	FALSE	20.50														
2. INDUSTRY - ENERGY INTENSIVE	Other Energy	67%	5.60														2.40	0.34		7.00														
	Electricity	33%	4.33														11.60	0.32		34.05	11.93	3.00	10.53	0.50	3.00	0.03	0.17	1.00	0.50	1.00				
																	0.00	SDIV01		24.76		10.00		2.30				0.95		2.00				
	Total	11.44	11.93					1.0%				-3.0%	-2.0%	4.52	3%		14.00	0.33	FALSE	43.05														
3. INDUSTRY - OTHER	Other Energy	72%	12.16														0.00	SDIV01		0.00														
	Electricity	28%	10.30														0.34	0.01		27.05	16.53	3.00	10.53	0.50	1.00	0.03	0.17	1.00	0.50	1.00				
																	0.00	24.76		24.76		10.00		1.10				0.95		2.00				
	Total	22.10	22.54					1.0%				0.0%	1.0%	34.93	13%		0.34	0.01	FALSE	27.05														
4. CONSTRUCTION	Other Energy	72%	0.29														0.00	SDIV01		0.00														
	Electricity	28%	0.24														0.34	0.01		27.05	16.53	3.00	10.53	0.50	1.00	0.03	0.17	1.00	0.50	1.00				
																	0.00	24.76		24.76		10.00		1.10				0.95		2.00				
	Total	0.55	0.55					1.0%				0.0%	1.0%	0.86	4%		0.34	0.01	FALSE	27.05														
5. PUBLIC ADMINISTRATION	Other Energy	75%	3.02														0.00	SDIV01		0.00														
	Electricity	25%	3.02														0.36	0.01		27.05	16.53	3.00	10.53	0.50	1.00	0.03	0.17	1.00	0.50	1.00				
																	0.00	24.76		24.76		10.00		1.10				0.95		2.00				
	Total	7.26	6.85					1.0%				0.0%	1.0%	11.47	23%		0.34	0.01	FALSE	27.05														
6. COMMERCIAL	Other Energy	38%	2.67														0.00	SDIV01		0.00														
	Electricity	62%	10.78														0.34	0.01		27.05	16.53	3.00	10.53	0.50	1.00	0.03	0.17	1.00	0.50	1.00				
																	0.00	24.76		24.76		10.00		1.10				0.95		2.00				
	Total	10.33	13.42					1.0%				-3.0%	-2.0%	4.00	51%		0.34	0.01	FALSE	27.05														
7. AGRICULTURE	Other Energy	61%	0.30														0.00	SDIV01		0.00														
	Electricity	39%	0.61														0.34	0.01		27.05	16.53	3.00	10.53	0.50	1.00	0.03	0.17	1.00	0.50	1.00				
																	0.00	24.76		24.76		10.00		1.10				0.95		2.00				
8. DOMESTIC																																		
9. INTERNATIONAL																																		
10. RAIL	Electricity	79%	1.16														0.34	0.01	FALSE	27.05	16.53	3.00	10.53	0.50	1.00	0.03	0.17	1.00	0.50	1.00				
																	0.00	24.76		24.76		10.00		1.10				0.95		2.00				
	Total	0.88	1.33					0.0%	1.4%	1.4%	-1.4%	-0.2%	-0.2%	0.79			0.34	0.01	FALSE	27.05														
11. ROAD FREIGHT	Other Energy	100%	13.50														0.00	SDIV01		0.00														
	Electricity	0%	0.00														0.00	-		24.05	13.53	3.00	10.53	0.41	0.00	0.60	0.14	0.00	0.41	0.00				
																	0.00	20.00		20.00		10.00		0.00				0.00		0.00				
	Total	15.27	13.50					0.0%	1.4%	1.4%	-1.4%	-0.2%	-0.2%	13.78			0.00	0.00	FALSE	24.05														
12. ROAD PASSENGER	Other Energy	100%	22.09														0.00	SDIV01		0.00														
	Electricity	0%	0.00														0.00	-		40.11	27.05	6.00	21.05	0.31	0.00	1.35	0.27	0.00	0.31	0.00				
																	0.00	20.00		20.00		10.00		0.00				0.00		0.00				
	Total	24.95	22.99					0.0%	1.4%	1.4%	2.0%	3.4%	3.4%	124.74			0.00	0.00	FALSE	40.11														
Private road	Energy	100%	23.69														0.00	SDIV01		0.00														
	Electricity	0%	0.00														0.00	-		24.05	13.53	3.00	10.53	0.41	0.00	0.60	0.14	0.00	0.41	0.00				
																	0.00	20.00		20.00		10.00		0.00				0.00		0.00				
	Total	25.61	23.69					0.0%	1.4%	1.4%	2.0%	3.4%	3.4%	120.70			0.00	0.00	FALSE	24.05														
Public road	Energy	100%	1.20														0.00	SDIV01		0.00														
	Electricity	0%	0.00														0.00	-		24.05	13.53	3.00	10.53	0.41	0.00	0.60	0.14	0.00	0.41	0.00				
																	0.00	20.00		20.00		10.00		0.00				0.00		0.00				
	Total	1.20	1.20					0.0%	1.4%	1.4%	1.0%	2.4%	2.4%	4.04			0.00	0.00	FALSE	24.05														
13. SHIPPING INLAND FREIGHT	Other Energy	100%	1.06														0.00	SDIV01		0.00														
	Electricity	0%	0.00														0.00	-		24.05	13.53	3.00	10.53	0.41	0.00	0.60	0.14	0.00	0.41	0.00				
																	0.00	20.00		20.00		10.00		0.00				0.00		0.00				
	Total	1.20	1.06					0.0%	1.4%	1.4%	5.0%	6.5%	6.5%	21.37			0.00	0.00	FALSE	24.05														
14. SHIPPING INTERNATIONAL FREIGHT	Other Energy	100%	10.12														0.00	SDIV01		0.00														
	Electricity	0%	0.00														0.00	-		24.05	13.53	3.00	10.53	0.41	0.00	0.60	0.14	0.00	0.41	0.00				
																	0.00	20.00		20.00		10.00		0.00				0.00		0.00</				

Windows taskbar showing the Start button, open applications (CORSAIR (E:), Microsoft Excel - the ..., Microsoft PowerPoint - [...]), and system tray icons (EN, network, volume, battery, clock showing 15:40).

Scenario & Demand		Supply and Carbon Dioxide Emissions										2050 Emissions										Supply									
		Baseline Data (Mtoe)				Energy Indicators to Form 2050 Energy Consumption										2050 Emissions			Supply			2050 Emissions									
SECTOR		ENERGY CONSUMPTION IN BASELINE YEAR	GVA AS % OF BASELINE YEAR GDP	CARBON DIOXIDE (MtC) BASELINE YEAR	CHANGE IN NUMBER OF HOUSEHOLDS (HH)	CHANGE IN HOUSEHOLD SIZE (POP/HH)	CHANGE IN CONSUMER EXPENDITURE (GDP/POP)	CHANGE IN ECONOMIC ACTIVITY (ACT)	CHANGE IN MOBILITY COST (MOB/ACT)	CHANGE IN ENERGY EFFICIENCY (E/ACT)	CHANGE IN ENERGY INTENSITY (E/INT)	COMPOUND CHANGE IN ENERGY INTENSITY CONSUMPTION (E)	2050 FINAL ENERGY CONSUMPTION (Mtoe)	2050 GVA PROPORTION	CARBON DIOXIDE (MtC)	CARBON INTENSITY (MtC/Mtoe)	SUPPLY MATCH DEMAND CHECK	2050 ENERGY CONSUMPTION (Mtoe)	TOTAL FROM GRID	CONVENTIONAL DEMAND FROM GRID	HYDROGEN FROM ELECTROLYSIS FROM GRID	COAL IGCC CONVENTIONAL	COAL IGCC PRODUCTION	CCGT	NUCLEAR CONVENTIONAL	NUCLEAR ALSO PRODUCTION	BIOFUEL SWASTE CONVENTIONAL	BIOFUEL SWASTE PRODUCTION			
1. HOUSEHOLD		Other Energy	99%	24.27											0.60	0.60		Other Energy	1.00												
		Electricity	29%	16.73											1.73	0.09		Electricity	19.50	5.00	1.00	1.05	0.15	1.00	0.25	0.05	1.00	0.15	1.00		
		Hydrogen													0.00	0.00		Hydrogen	15.70			1.00		1.10							
		Total	45.73	43.00	0.2%	-0.2%	0.0%					-2.0%	0.7%	67.14	2.33	0.11	FALSE	Total	20.50												
2. INDUSTRY - ENERGY INTENSIVE		Other Energy		5.60											2.40	0.34		Other Energy	7.00												
		Electricity	33%	4.33											11.60	0.32		Electricity	34.05		3.00	10.53	0.50	3.00	0.93	0.10	1.00	0.10	1.00		
		Hydrogen													0.00	0.00		Hydrogen	24.90			10.00		2.30							
		Total	11.44	3%	11.93			1.0%				-3.0%	-2.0%	4.52	14.00	0.33	FALSE	Total	43.05												
3. INDUSTRY - OTHER		Other Energy		12.16											0.00	0.01	BDI/WT	Other Energy	0.00												
		Electricity	28%	10.34											0.34	0.01		Electricity	27.00			10.53	0.50	1.00	0.93	0.17	1.00				
		Hydrogen													0.00	0.00		Hydrogen	24.70			10.00		1.10							
		Total	22.10	13%	22.54			1.0%				0.0%	1.0%	34.93	0.36	0.01	FALSE	Total	27.05												
4. CONSTRUCTION		Other Energy	72%	0.29											0.00	0.00	BDI/WT	Other Energy	0.00												
		Electricity													0.00	0.00		Electricity	27.05		3.00	10.53	0.50	1.00	0.93	0.17	1.00	0.50	1.00		
		Hydrogen													0.00	0.00		Hydrogen	24.70			10.00		1.10							
		Total													0.00	0.00		Total	27.05												
5. PUBLIC		Other Energy													0.00	0.00		Other Energy	0.00												
		Electricity													0.00	0.00		Electricity	27.05												
		Hydrogen													0.00	0.00		Hydrogen	24.70												
		Total													0.00	0.00		Total	27.05												
6. COMM		Other Energy													0.00	0.00		Other Energy	0.00												
		Electricity													11.93	0.30		Electricity	27.05		3.00	10.53	0.50		0.93	0.17	1.00	0.50	1.00		
		Hydrogen													0.00	0.00		Hydrogen	24.70			10.00									
		Total													0.00	0.00		Total	27.05												
7. AGRIC		Other Energy													0.00	0.00		Other Energy	0.00												
		Electricity													16.53	0.30		Electricity	27.05		3.00	10.53	0.50		0.93	0.17	1.00	0.50	1.00		
		Hydrogen													0.00	0.00		Hydrogen	24.70			10.00									
		Total													0.00	0.00		Total	27.05												
8. DOMESTIC		Other Energy													0.00	0.00		Other Energy	0.00												
		Electricity													15.93	0.30		Electricity	24.05		3.00	10.53	0.47		0.70	0.16	1.00	0.47	1.00		
		Hydrogen													0.00	0.00		Hydrogen	23.60			10.00									
		Total													0.00	0.00		Total	24.05												
9. INTERNATIONAL		Other Energy													0.00	0.00		Other Energy	0.00												
		Electricity													15.93	0.30		Electricity	24.05		3.00	10.53	0.47		0.70	0.16	1.00	0.47	1.00		
		Hydrogen													0.00	0.00		Hydrogen	23.60			10.00									
		Total													0.00	0.00		Total	24.05												
10. RAIL		Other Energy													0.00	0.00		Other Energy	0.00												
		Electricity													11.93	0.30		Electricity	27.05		3.00	10.53	0.50		0.93	0.17	1.00	0.50	1.00		
		Hydrogen													0.00	0.00		Hydrogen	24.70			10.00									
		Total													0.00	0.00		Total	27.05												
11. ROAD		Other Energy													0.00	0.00		Other Energy	0.00												
		Electricity													11.93	0.30		Electricity	27.05		3.00	10.53	0.50		0.93	0.17	1.00	0.50	1.00		
		Hydrogen													0.00	0.00		Hydrogen	24.70			10.00									
		Total													0.00	0.00		Total	27.05												
12. ROAD		Other Energy													0.00	0.00		Other Energy	0.00												
		Electricity													11.93	0.30		Electricity	27.05		3.00	10.53	0.50		0.93	0.17	1.00	0.50	1.00		
		Hydrogen													0.00	0.00		Hydrogen	24.70			10.00									
		Total													0.00	0.00		Total	27.05												
13. SHIP INLAND		Other Energy													0.00	0.00		Other Energy	0.00												
		Electricity													11.93	0.30		Electricity	24.05		3.00	10.53	0.41		0.60	0.14	1.00	0.41	1.00		
		Hydrogen													0.00	0.00		Hydrogen	20.00			10.00									
		Total													0.00	0.00		Total	24.05												
14. SHIP INTERNATIONAL		Other Energy													0.00	0.00		Other Energy	0.00												
		Electricity													11.93	0.30		Electricity	24.05		3.00	10.53	0.41		0.60	0.14	1.00	0.41	1.00		
		Hydrogen													0.00	0.00		Hydrogen	20.00			10.00									
		Total													0.00	0.00		Total	24.05												
15. MISC		Other Energy													0.00	0.00		Other Energy	0.00												
		Electricity													11.93	0.30		Electricity	32.05		3.00	10.53	0.41		0.60	0.14	1.00	0.41	1.00		
		Hydrogen													0.00	0.00		Hydrogen	20.00			10.00									
		Total													0.00	0.00		Total	40.05												
16. EMERGENCY		Other Energy													0.00	0.00		Other Energy	0.00												
		Electricity	15%	4.1											0.45	0.26		Electricity	32.05		3.00	10.53	0.41		0.60	0.14	1.00	0.41	1.00		
		Hydrogen													0.00	0.00		Hydrogen	20.00			10.00									
		Total													0.45	0.26		Total	40.05												
TOTAL		Other Energy													11.45	0.29	FALSE	Other Energy													

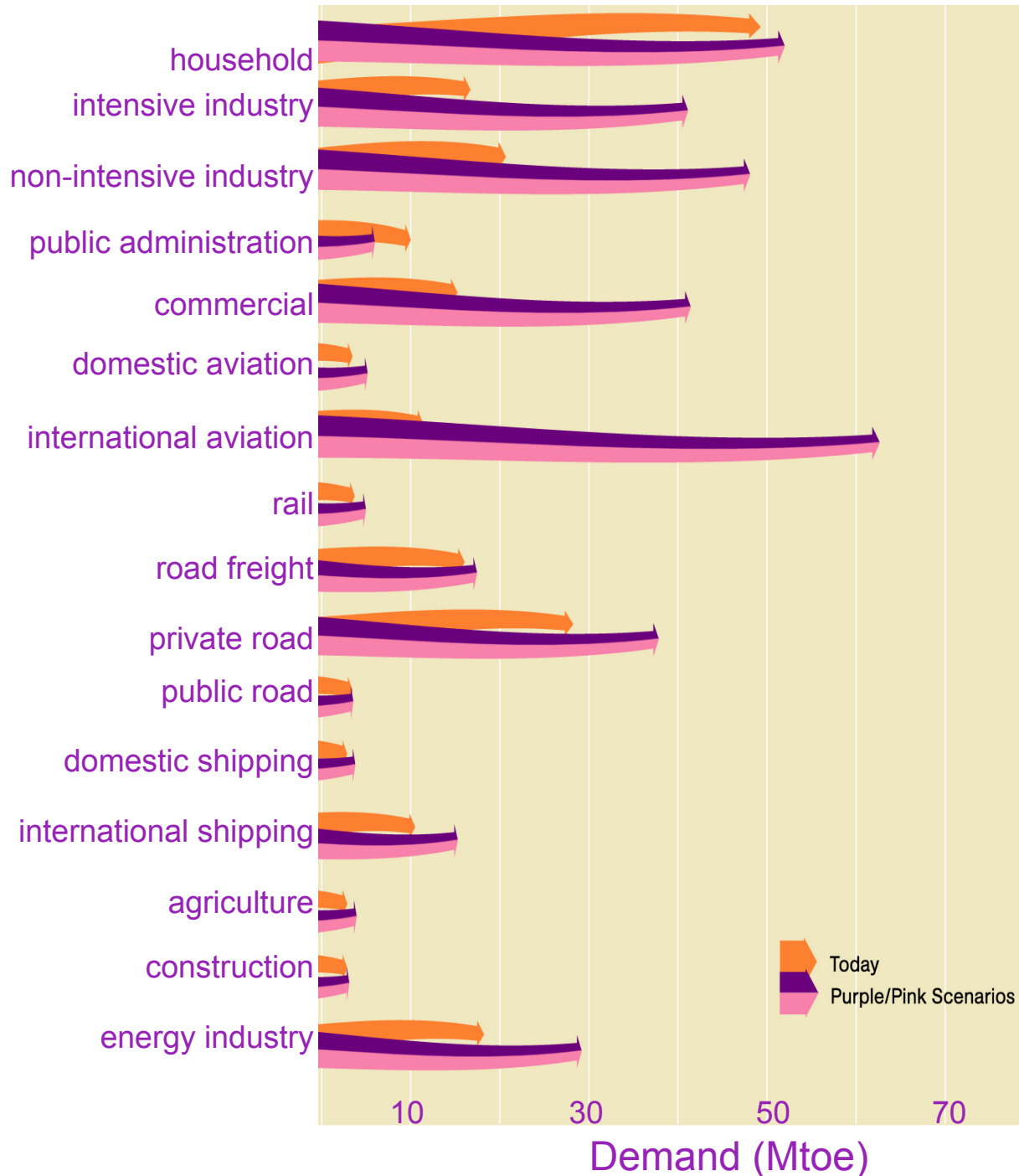
Start CORSAIR (E:) Microsoft Excel - the ... Microsoft PowerPoint - [... EN 15:40

Purple/Pink scenario

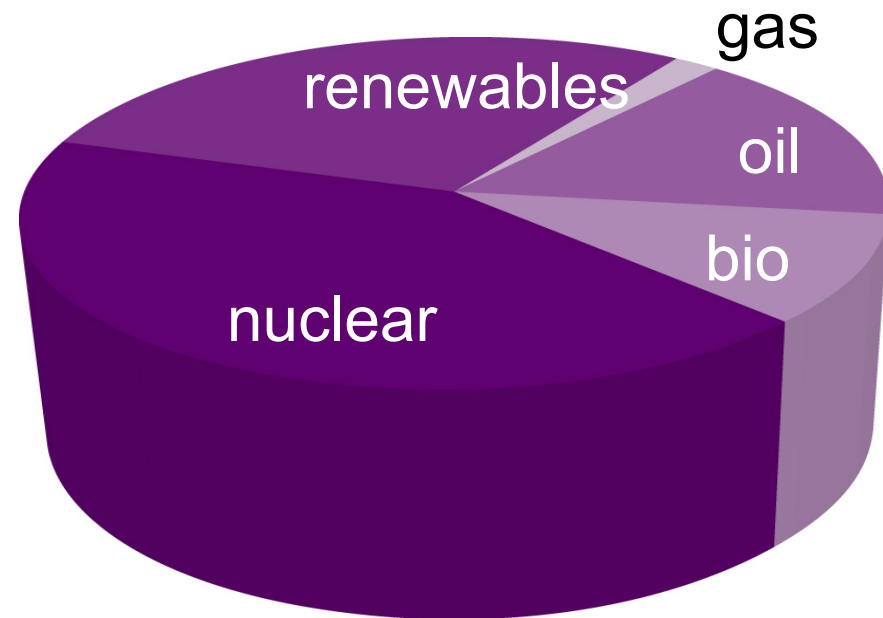
Energy demand ~ 330Mtoe
~ 2x today

Hi GDP growth
- some industrial renaissance

Very large mobility increases
- across all modes



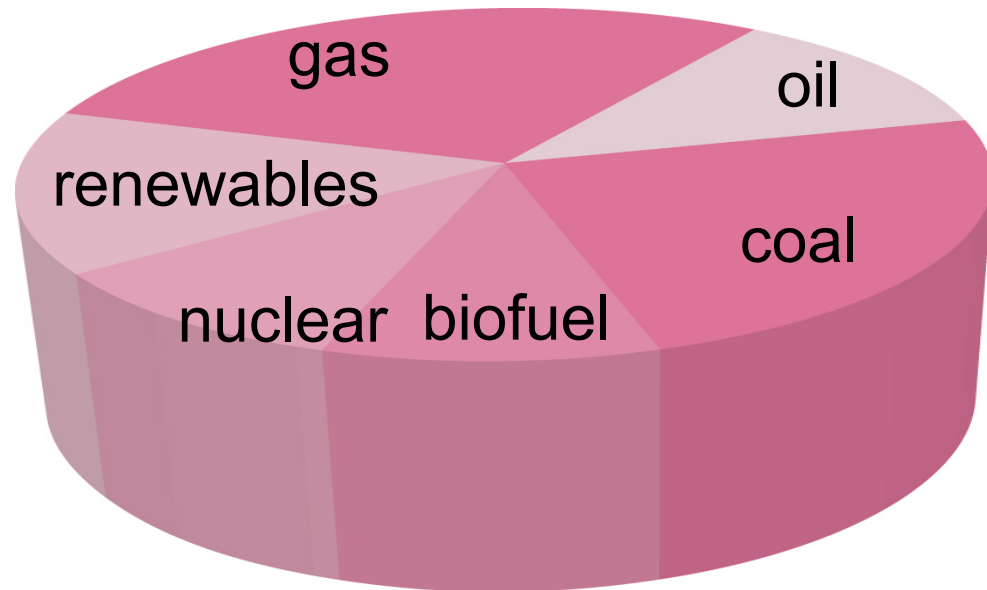
Purple 2050



461 Mtoe

~ 80% electricity

Pink 2050



495 Mtoe

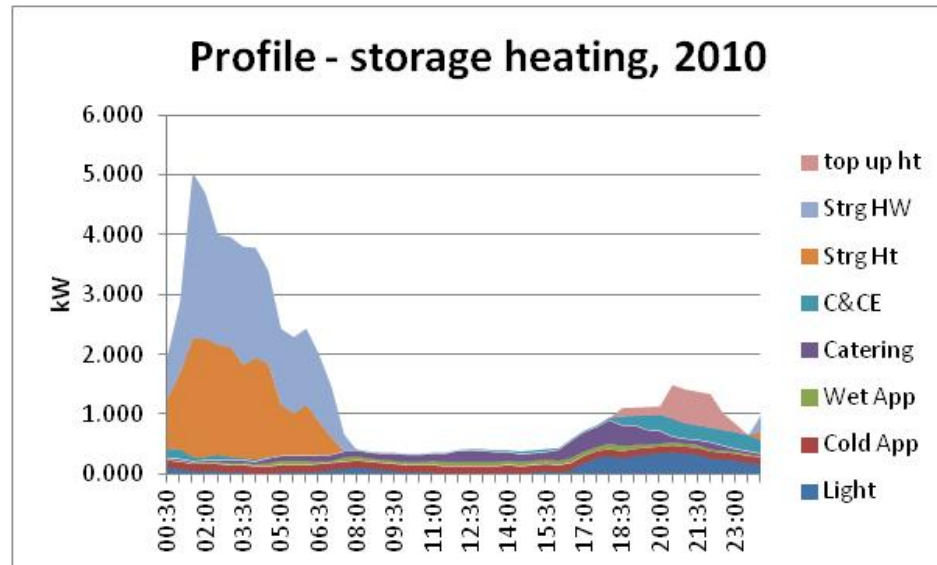
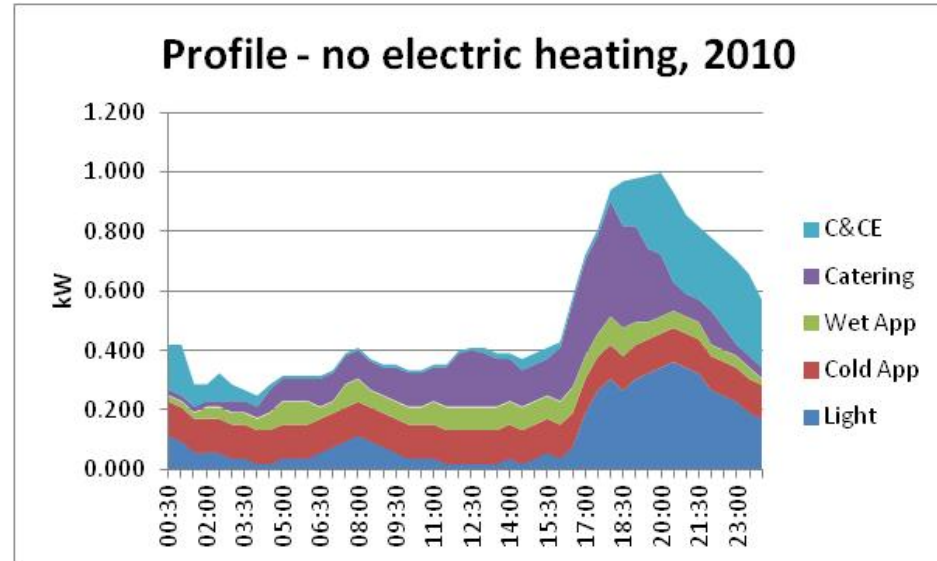
~ 40% electricity

Scenario development: 1 Household's diurnal electricity demand profile

Load profiles, an average house with:

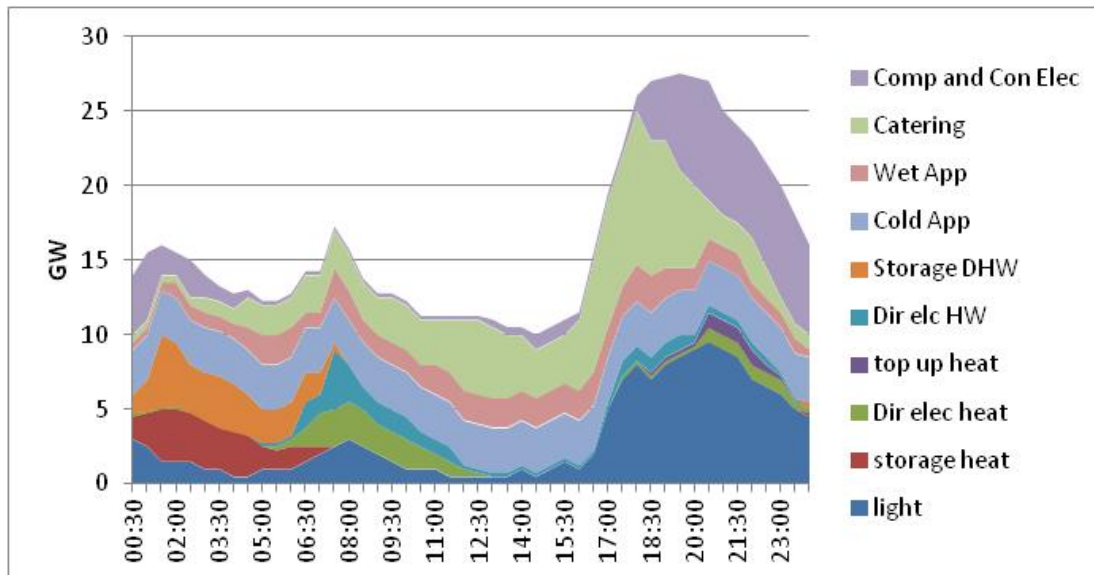
- No electric heating
- Storage heating
- Direct electric heating
- Heat pumps

Based on BRE / Exelon data (Not for heat pumps)



Scenario development

Load profiles



1. Develop current load profiles (domestic, non domestic, industry)
2. Sense check against NG data
3. New types of demand (heat pumps, electric cars)
4. Link to sector breakdown – changes in demand, efficiencies etc.
5. Produce new load profiles