People and power: Heat

system dynamics and smart control

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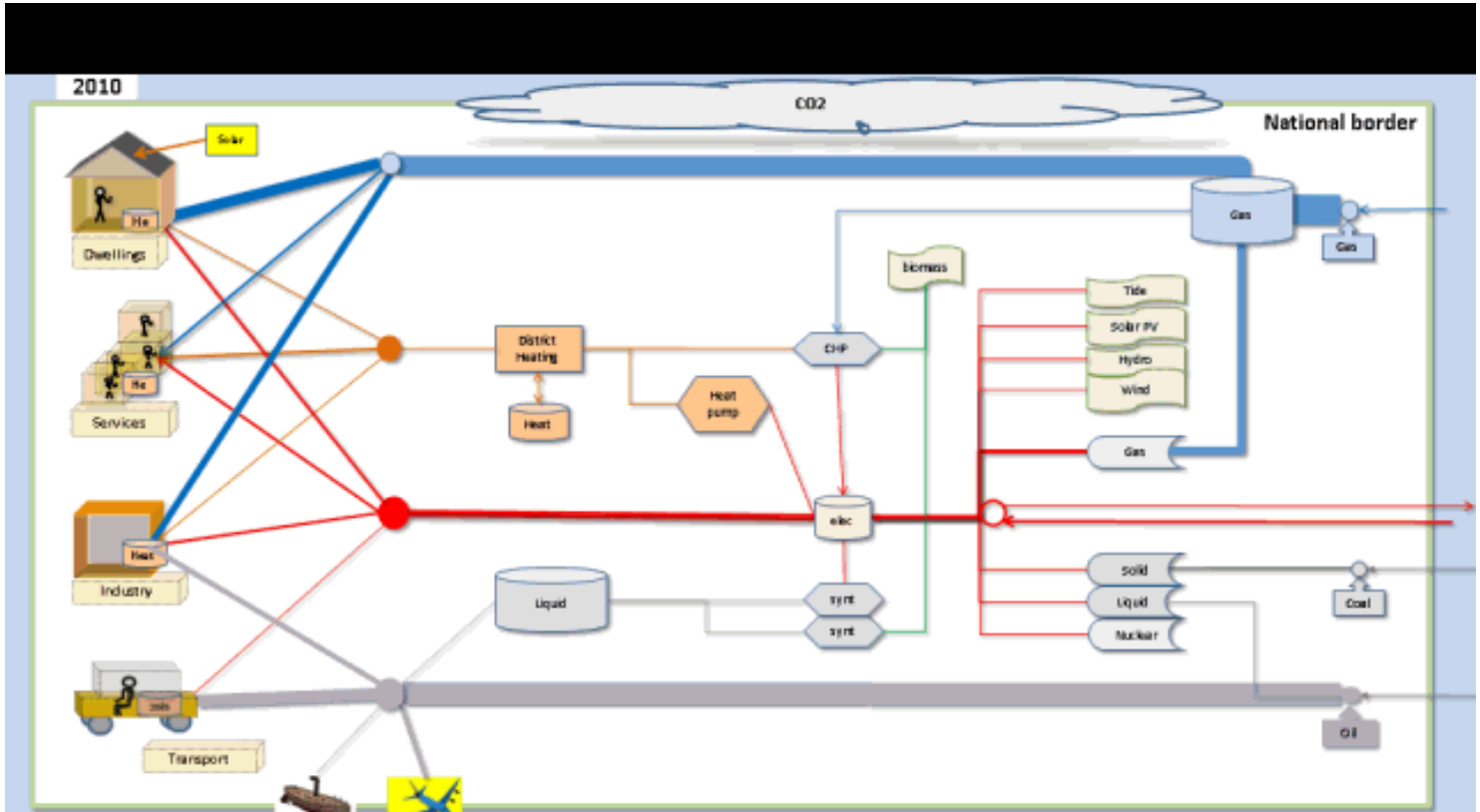
Energy Systems Workshop: Integrated energy systems of the future
IEA CERT-ETP20121 7, 8 November 2011, IEA Headquarters, Paris, France



Run presentation with F5 to see animations

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Contents

- Policy objectives
- Whole system
- Heat
  - Demand
  - Supply
- Heat, electricity and integration

OBJECTIVES OF STRATEGY

SOCIAL, ECONOMIC, POLITICAL

- Meet objectives at least cost with social equity
- Avoid irreversible, risky technologies

ENERGY SECURITY

- Reduce dependence on finite fossil and nuclear fuels
- UK 20% of energy from renewables by 2020 => ~35% renewable electricity?
- renewable transport fuels: 5% of by 2010, 10% by 2020

ENVIRONMENT

UK

- Government targets for GHG reduction from 1990: 12-20% by 2010, ~30% by 2020, 80% 1990-2050, including international transport.
- **Require >95% GHG reduction for climate control and global equity**

Europe 2020

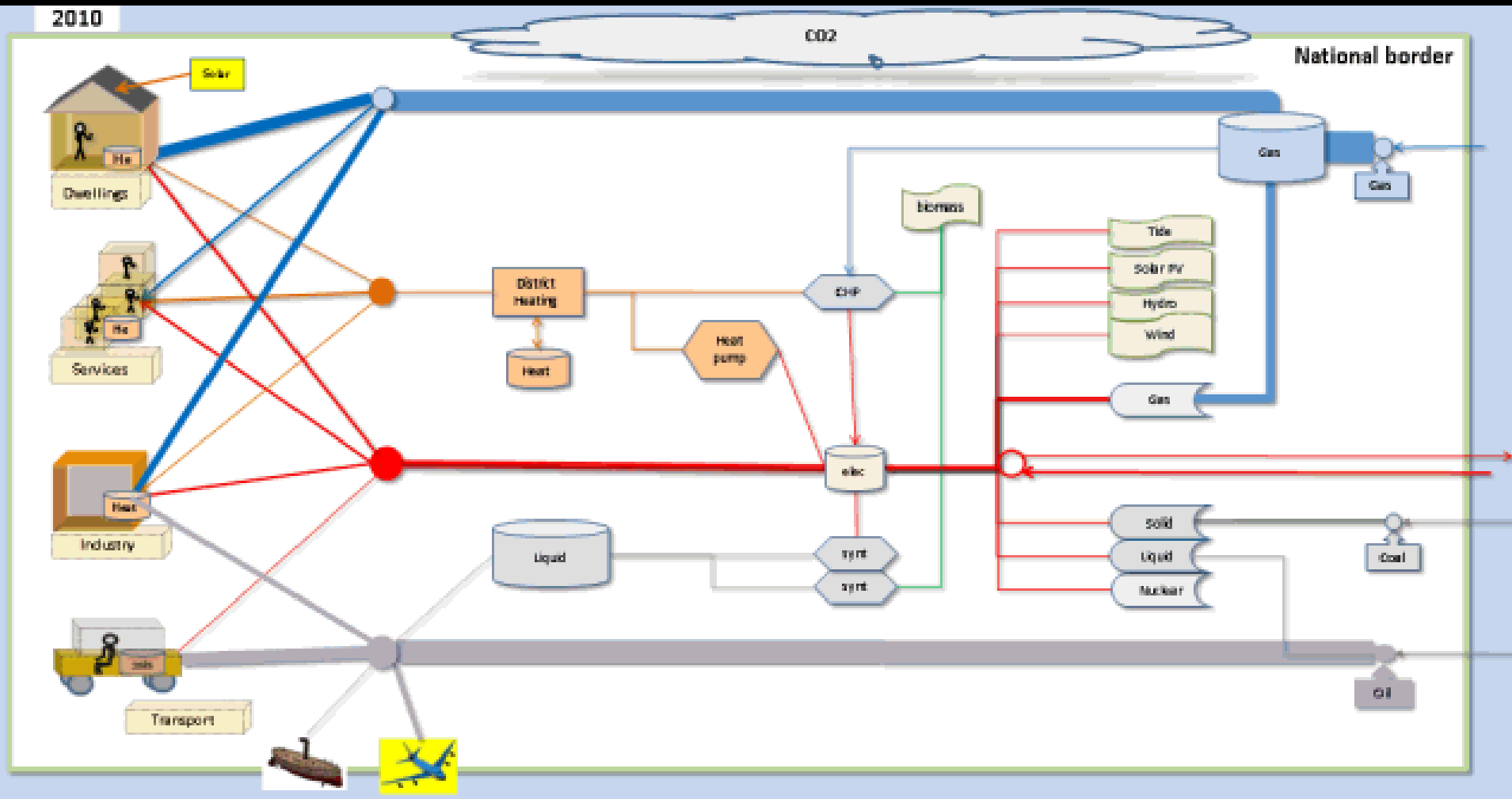
- 20/30% GHG reduction
- 20% renewable energy fraction

Policy options

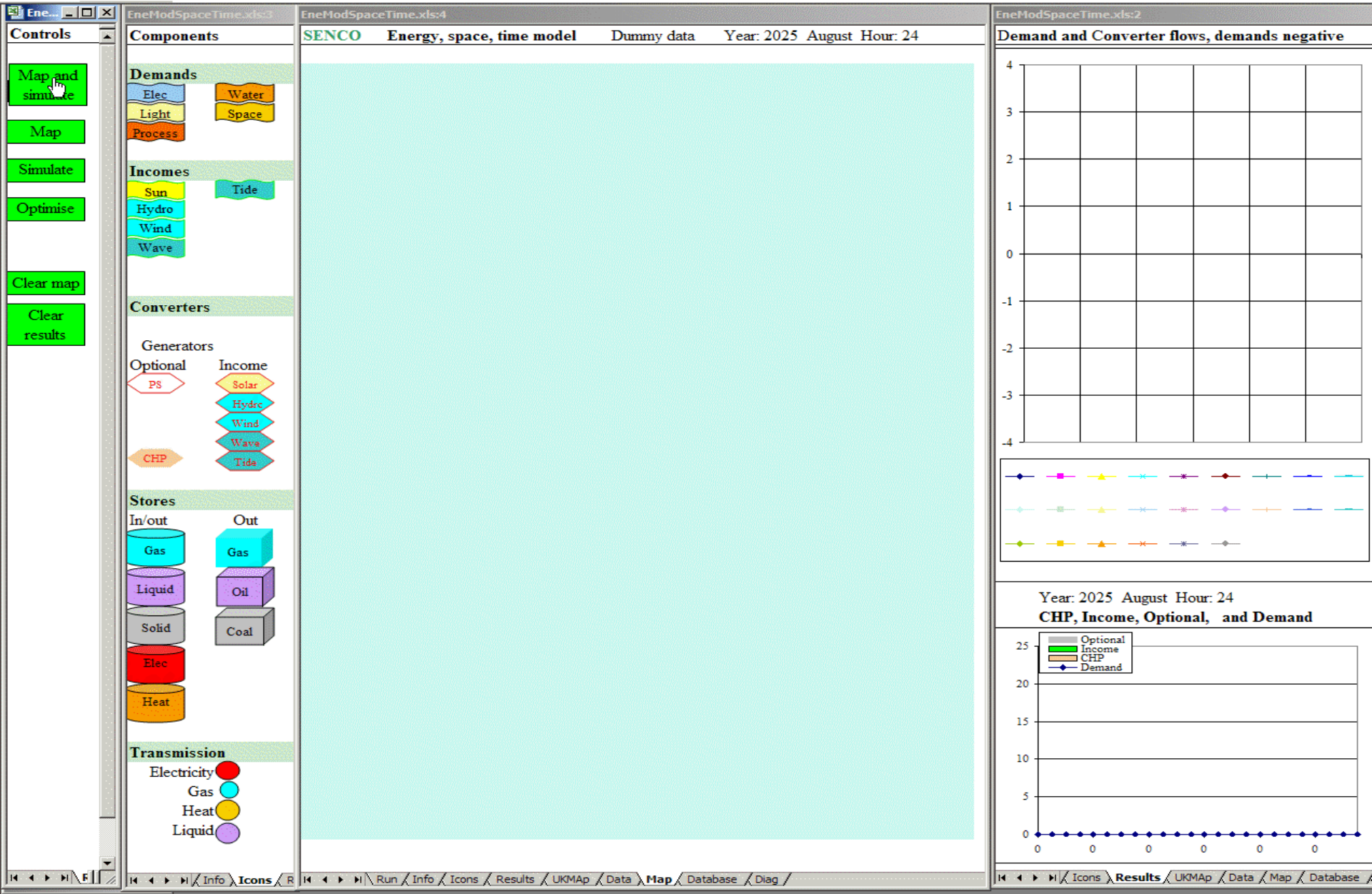
The policy aims are to be met using five classes of option:

- **Behavioural change**: demand, and choice and use of technologies
  - demand substitution, less air travel
  - modal shift from car and truck to bus and rail, lower motorway speeds, building temperatures
  - smaller cars
- **Demand management**
  - insulation, ventilation control, recycling, efficient appliances...
- **Energy efficient conversion**
  - cogeneration...
- **Fuel switching**
  - to low/zero emission renewable and other sources
- **Emission control technologies**
  - flue gas desulphurisation, catalytic converters, particulate traps...

The whole system animated

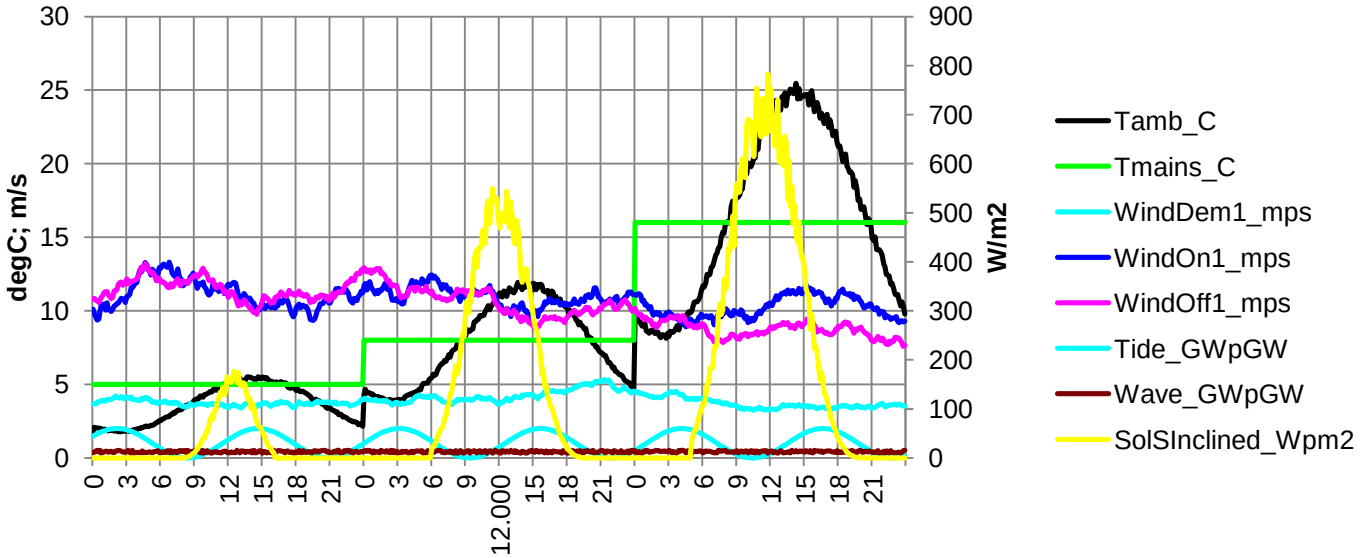


UK energy, space and time : animated

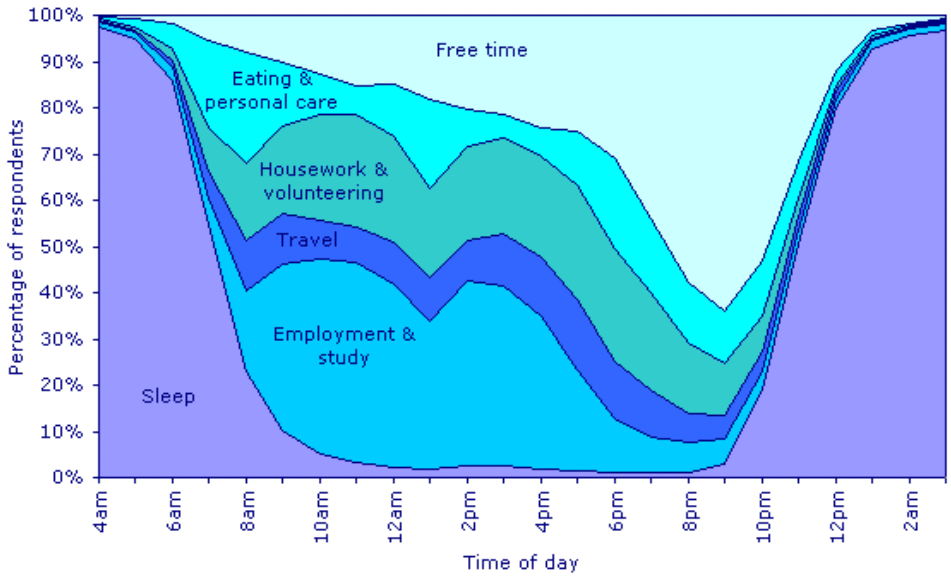


Temporal drivers

Weather



Use of time - UK average



Heat development – strategic issues

Long development time so need to consider several decades.

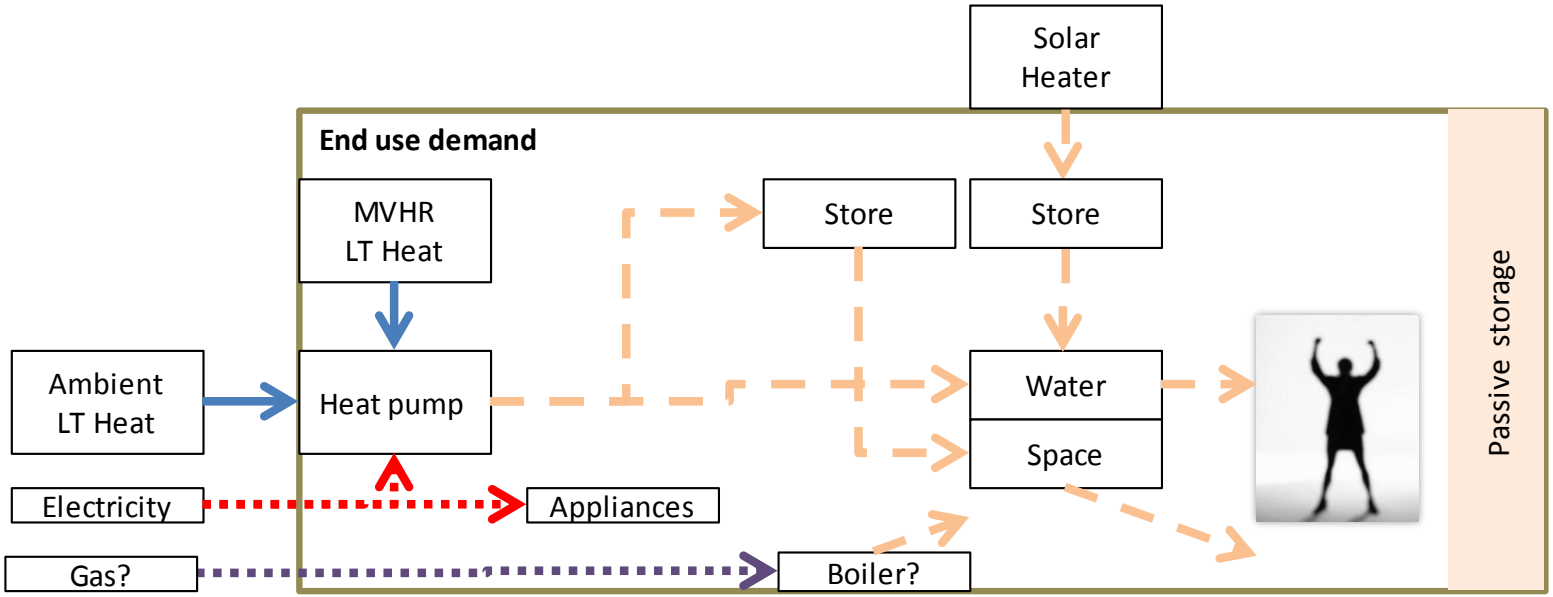
Given socioeconomic development and efficiency improvements, what is the 'end state' for:
Heat demands in terms of:
- quantity
- temperature
- space
- time

Heat loads:
- Buildings – HW, space
- Industry – process heat
- Fuel synthesis – HT heat

Heat supply:
- Electric heat pumps
- Biomass – availability and spatial distribution
    - fuel synthesis (ammonia, hydrocarbons, hydrogen and processing
- Solar, geothermal
- Waste heat
    - industry

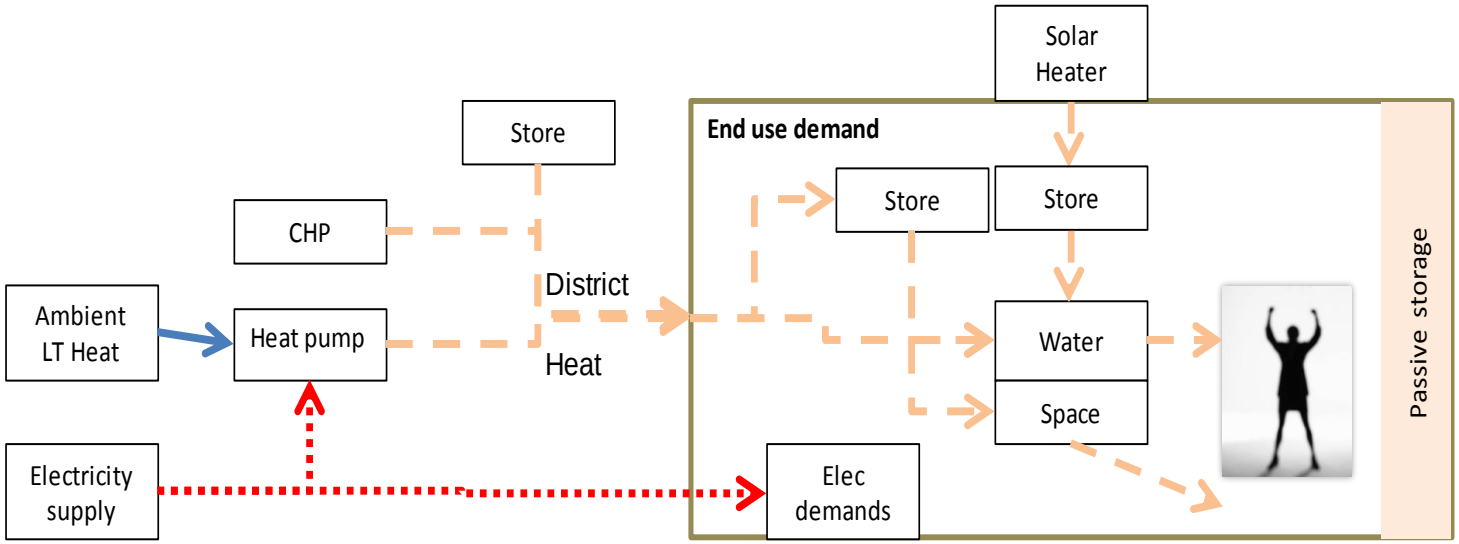
Dwellings; two archetypes

Heat pump
single source
peaks
little storage



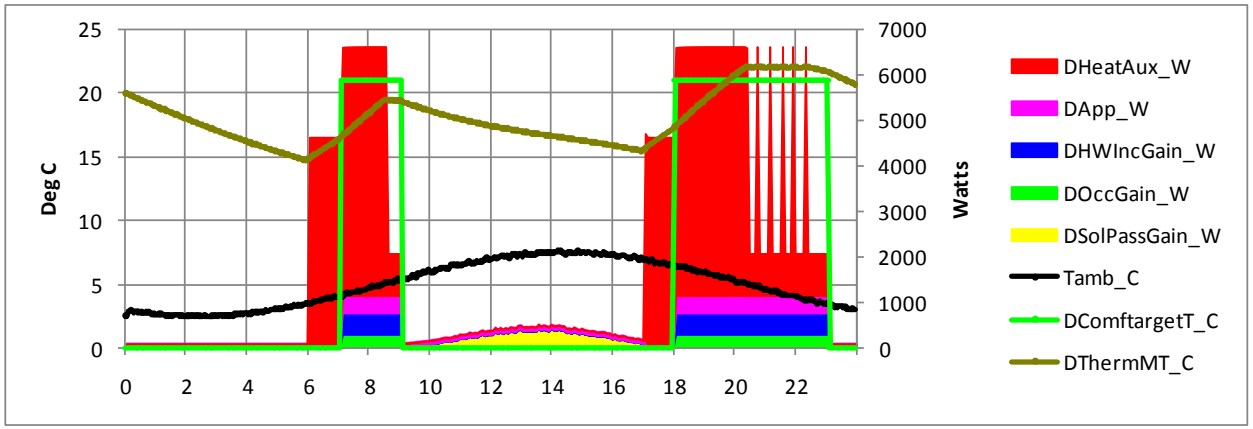
District heat
diversity
multiple inputs
cheap storage

implementation

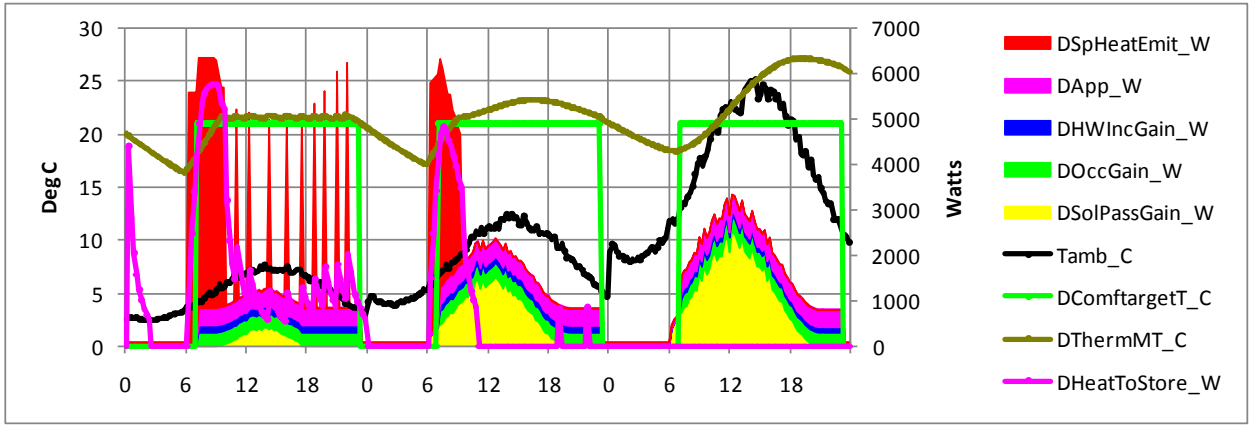


Building dynamics : heating

Winter's day



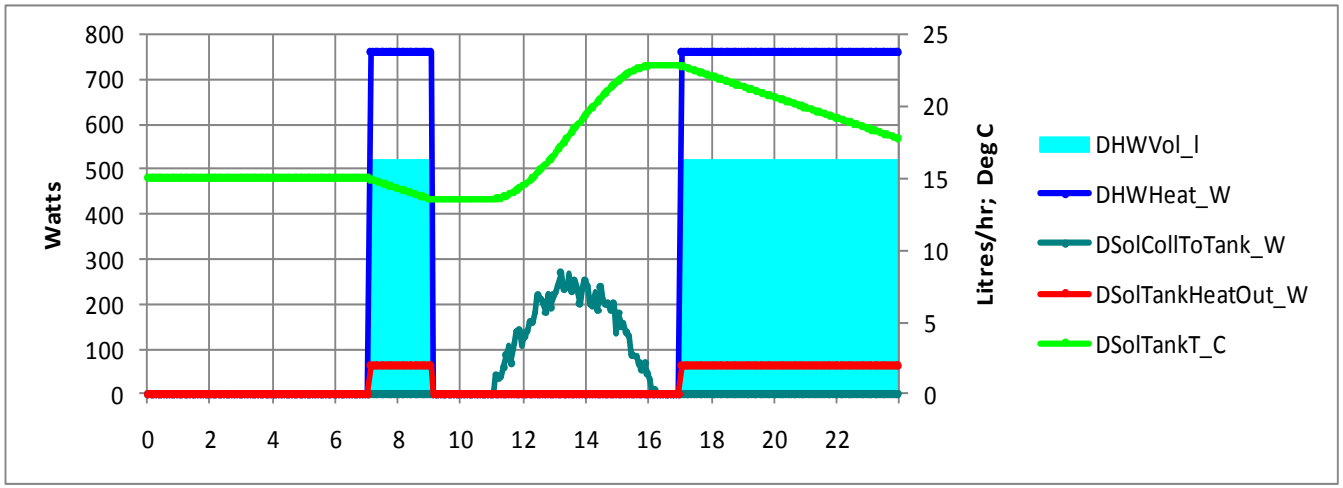
Months 1,4,7

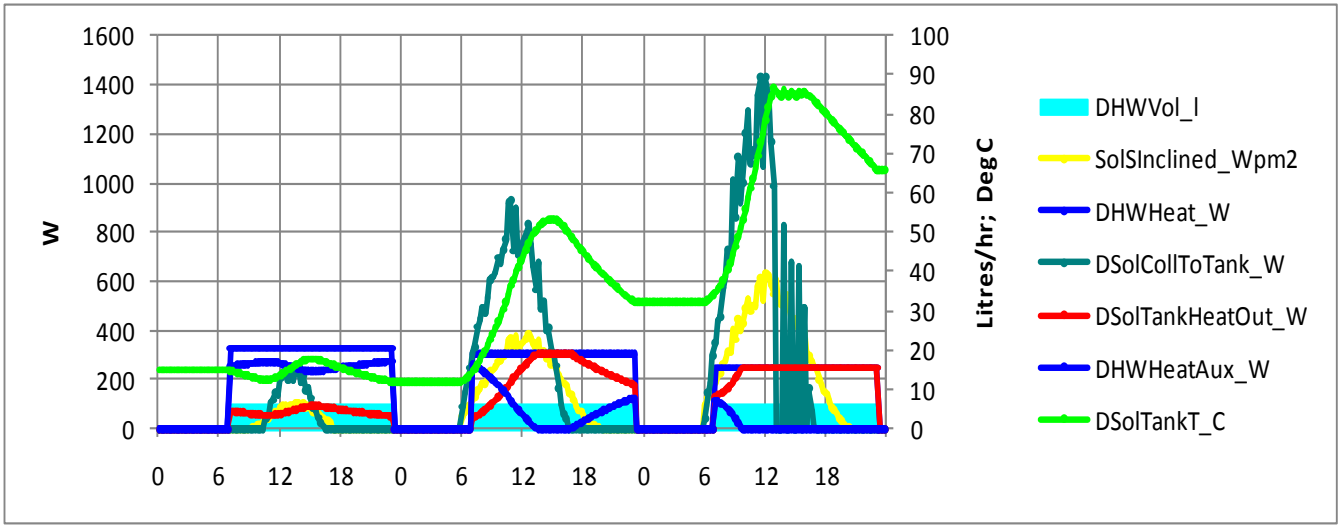


Building dynamics: solar heater

Winter's day

Months 1,4,7

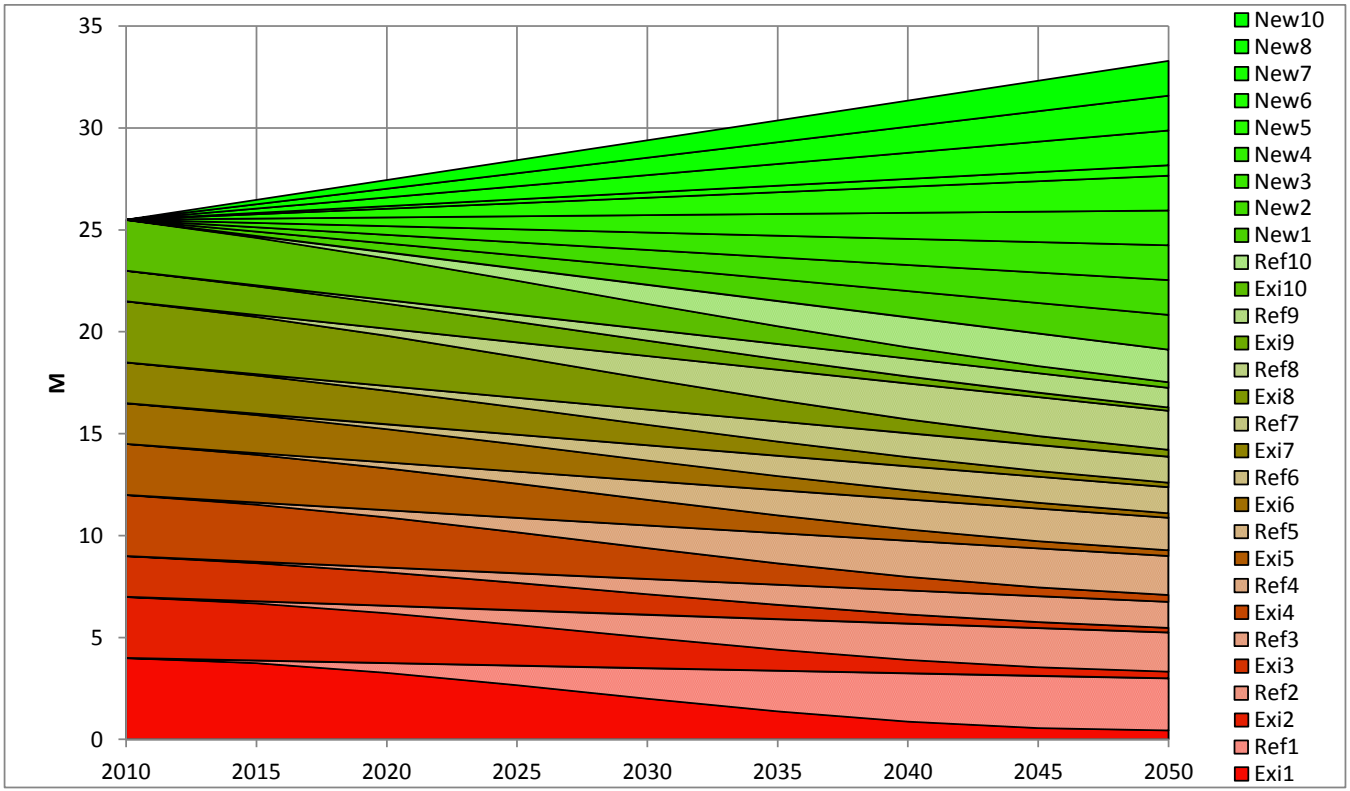




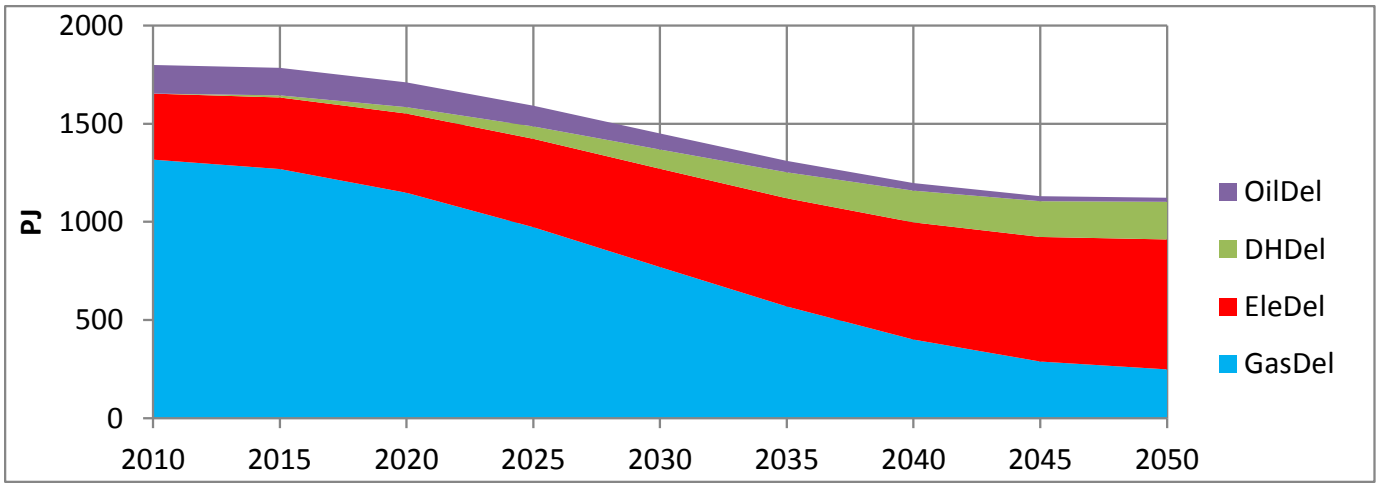
Person-Dwelling Combinations

Numbers of PDCs changing with:

- Demolition
- Refurbishment
- New build



Gradual change in fuel mix from mainly gas to electricity



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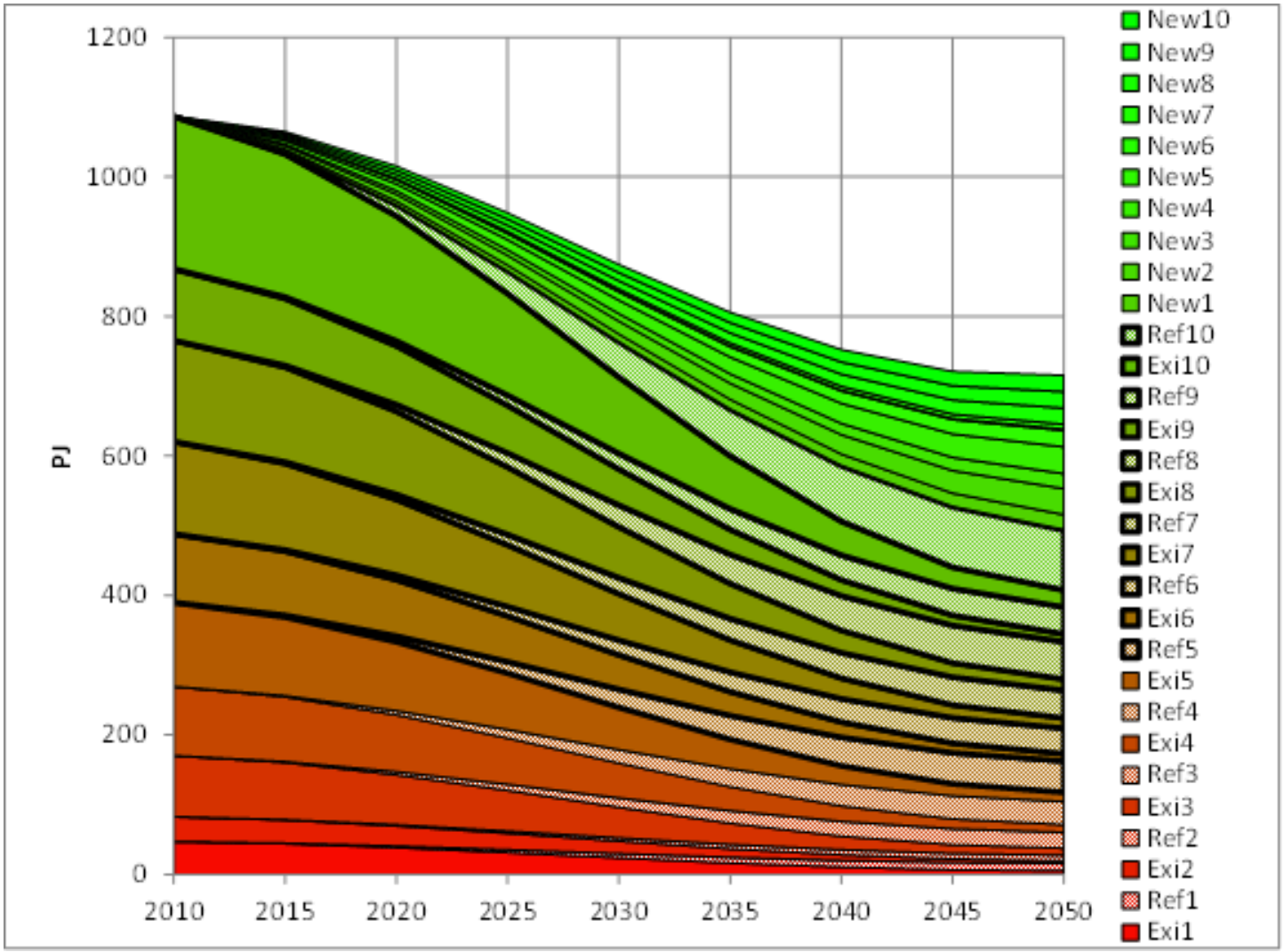
Person-Dwelling Combinations

Heat (space+water) demand of PDCs changing with:

- Demolition
- Refurbishment
- New build



Person-Dwelling Combinations

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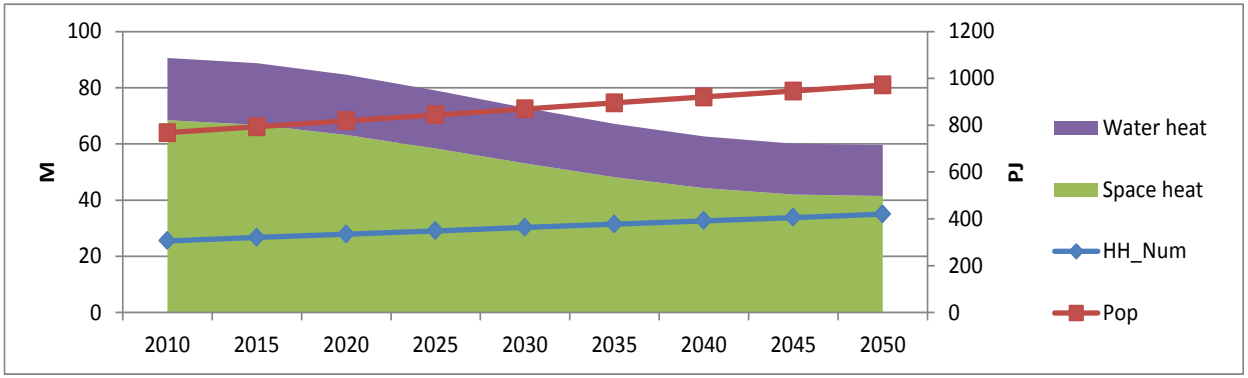

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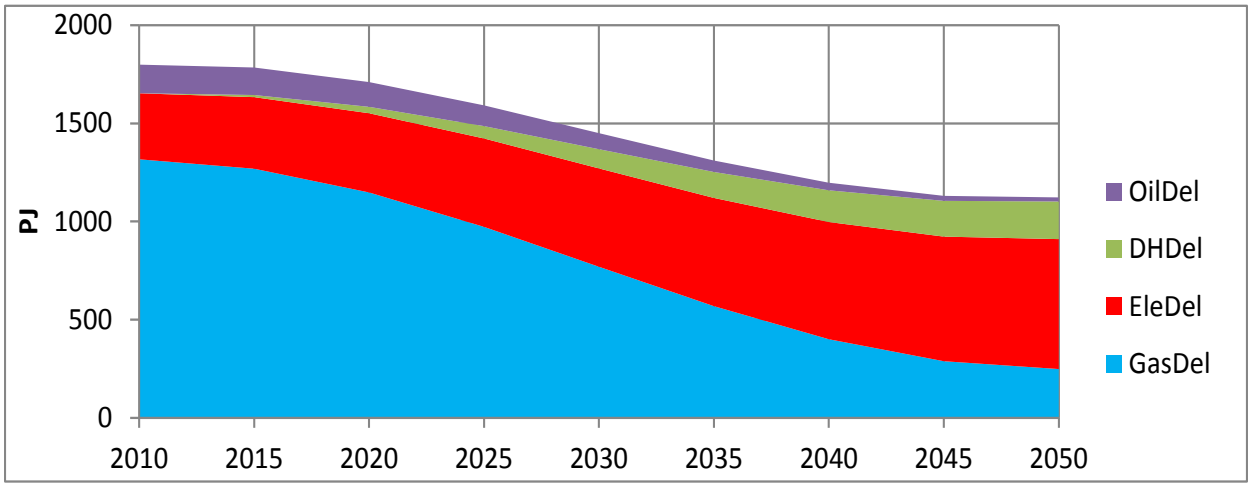
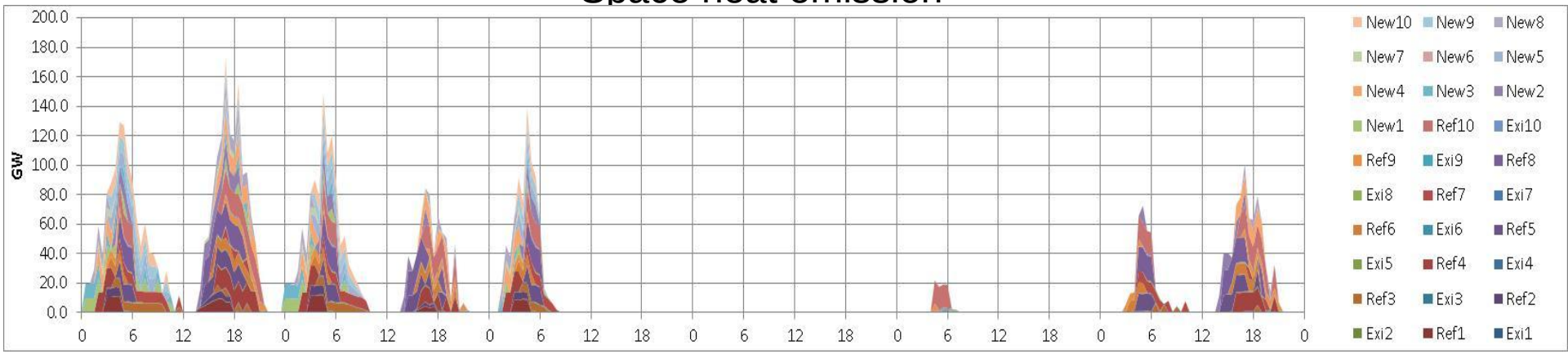


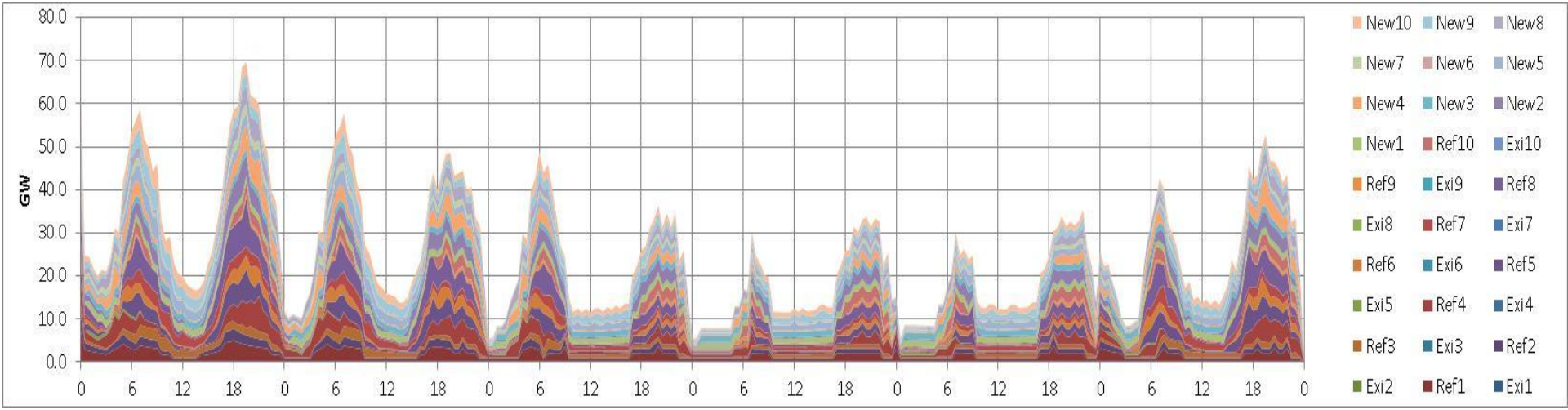
Load curves for Person-Dwelling Combinations

– one day for months 1,3,5,7,9,11

Space heat emission



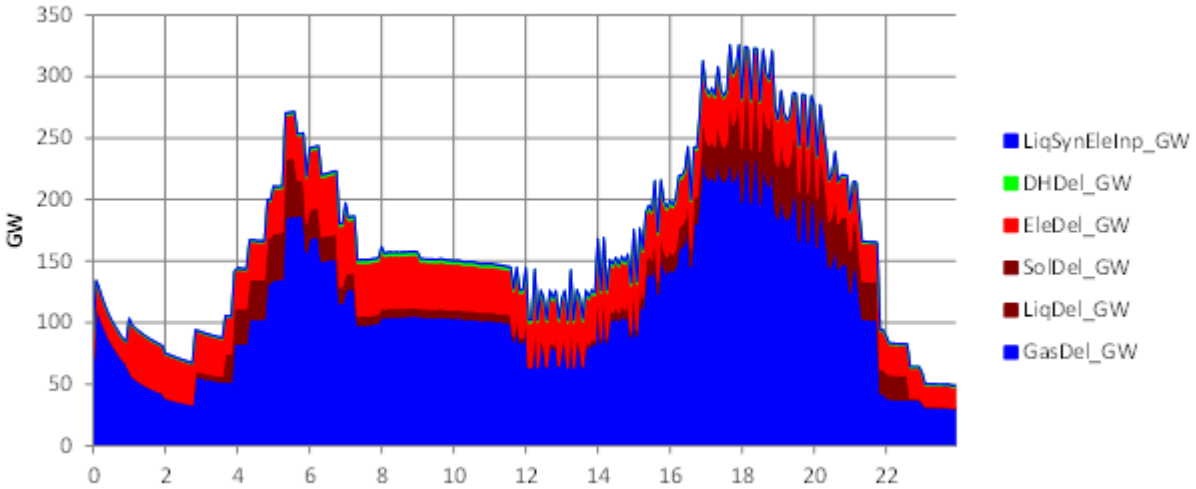
Delivered electricity



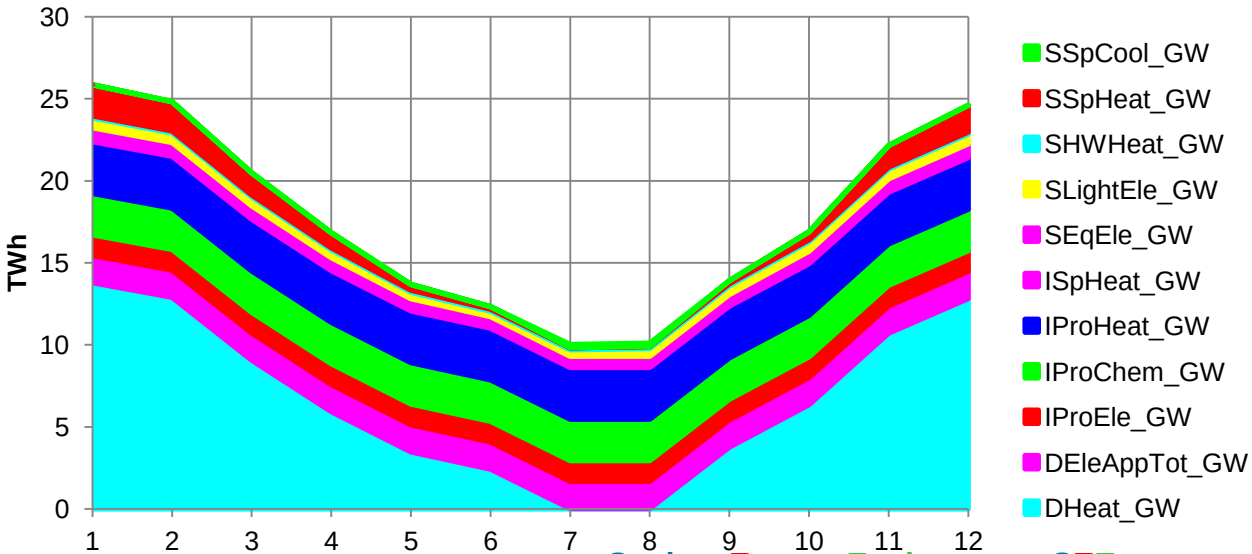
Energy demand and time

Currently most heat load met with gas, with a peak of about 250 GW.

What if this were done with electricity?



And seasonal variation



Heat supply development - transition

What will happen to the gas grid?
Will it be used for:
- Quantity supply with renewable gas and/or CCS
- Backup to biomass, heat pumps etc?

Will the whole gas system be retained, or just part?

District heating and electric heat pumps

Develop DH networks from:
- Nuclei of large heat loads (office blocks, hospitals etc.) initially with gas CHP input
- Existing urban power stations? Initially fossil, then biomass?
- Suitable heat source for heat pumps - e.g. sea, river (e.g. Stockholm)
- Industrial waste heat

Fuel production – heat load and low temperature waste heat
- Refining: coastal with ports. Currently ~10 GW CHP equivalent
- Fuel synthesis plants: electricity to ammonia, hydrocarbons, hydrogen, biofuels
    - Sited near coasts/ports to absorb off-shore wind/biomass and for sea transport or use (ammonia)
    - Sited at filling stations?

Demand – supply matching

High renewable fractions will include a large wind component;

- **w**hat will happen when there is a deficit or surplus of renewable energy of perhaps 100 GW?

Demands

- Vary with social activity and weather
- Electric heat supply with heat pumps that vary with weather

Supplies:

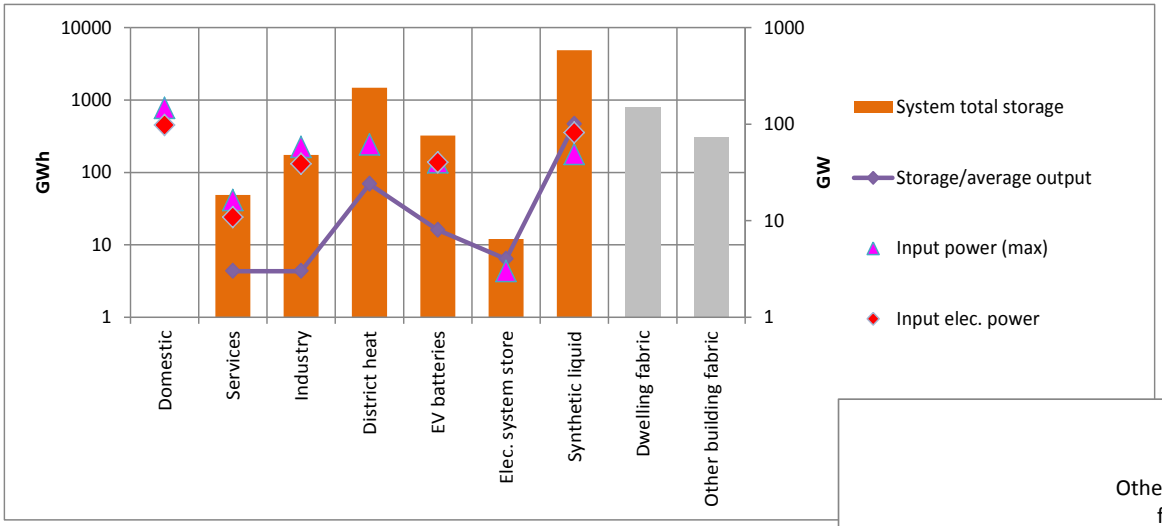
- Renewables that vary with weather
- Dispatchable renewables

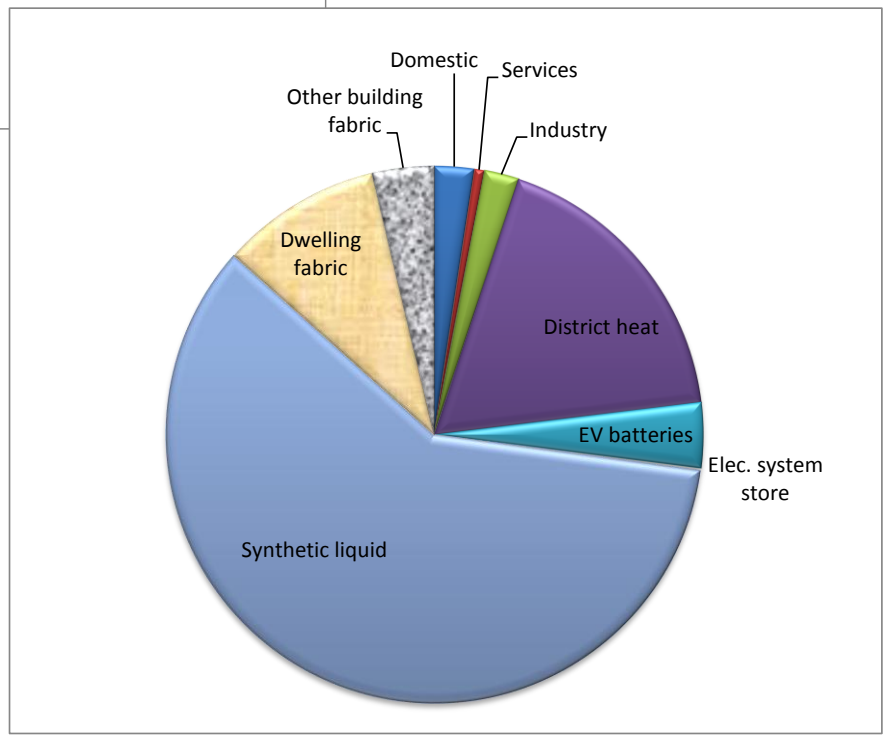
Matching

- Dispatchable supplies - chemical fossil/biomass
- Storage – heat, chemical, mechanical
- Transmisson

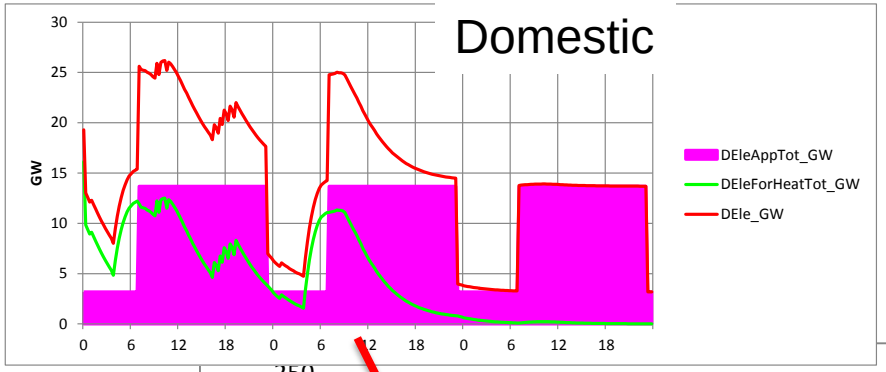
A large fraction of electricity will be used for heat.
Electricity is expensive to store, heat is cheap to store

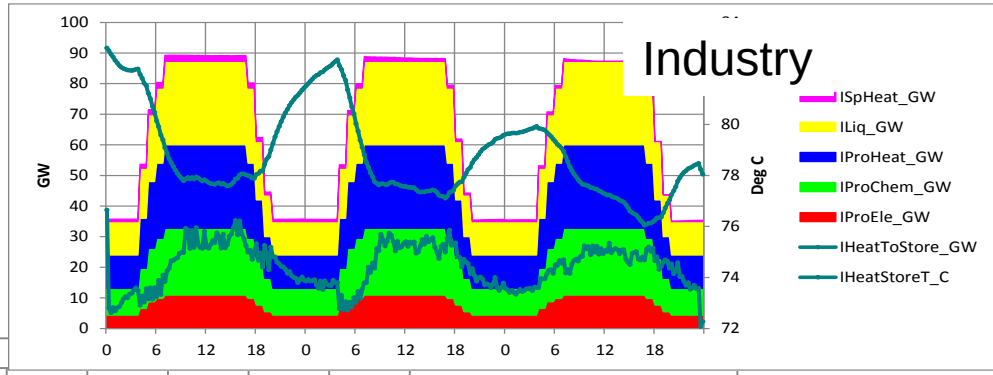
National system – storage

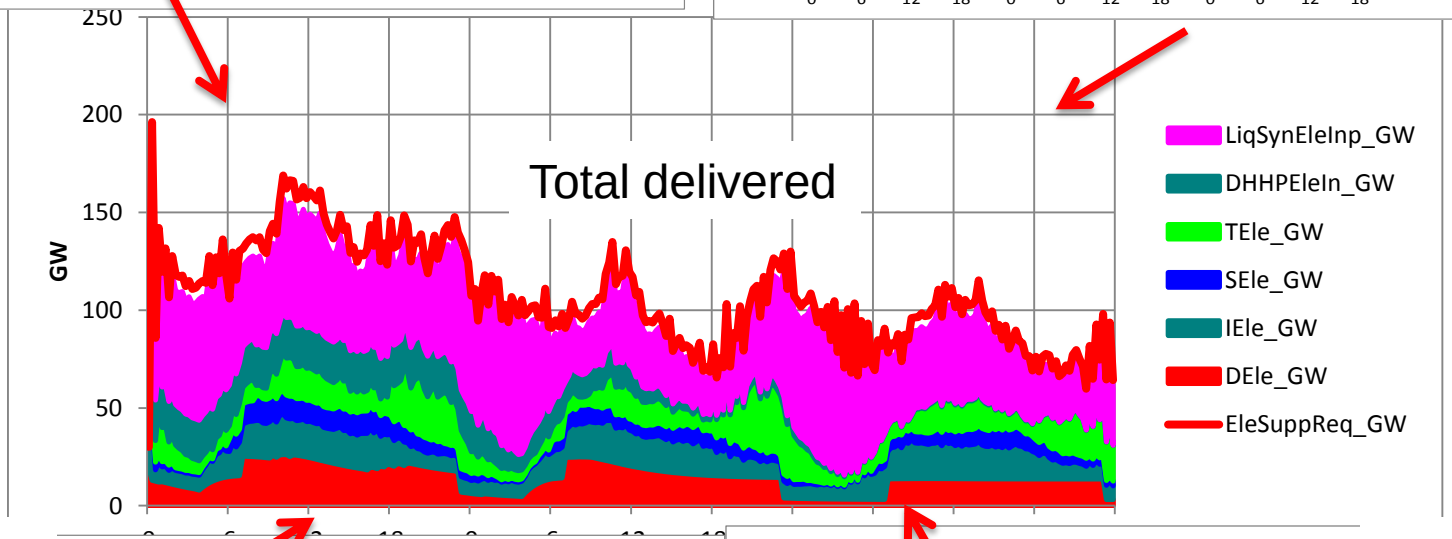


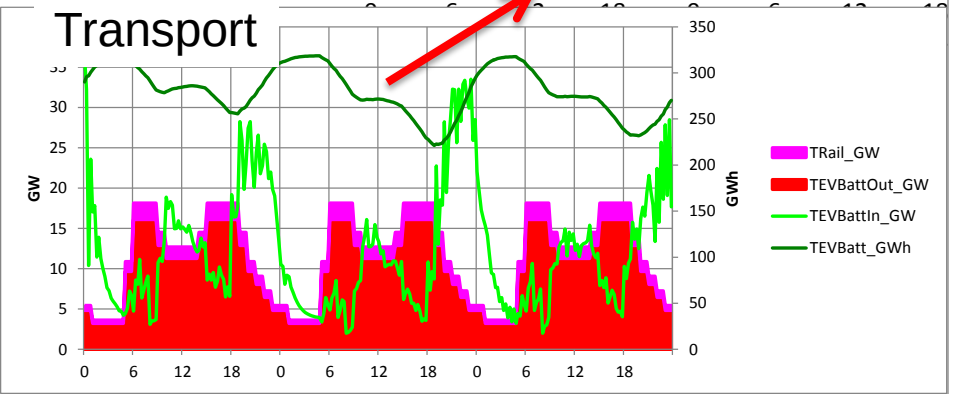


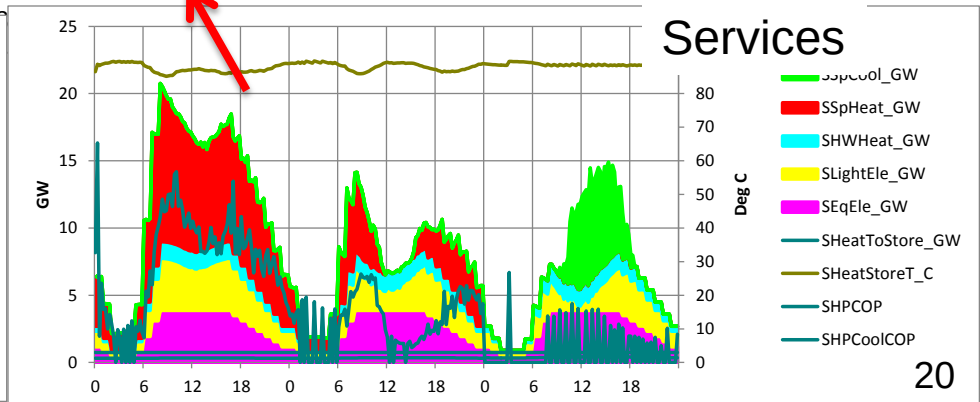
National energy deliveries – one day for months 1,4,7 ; modelled at 15 min intervals





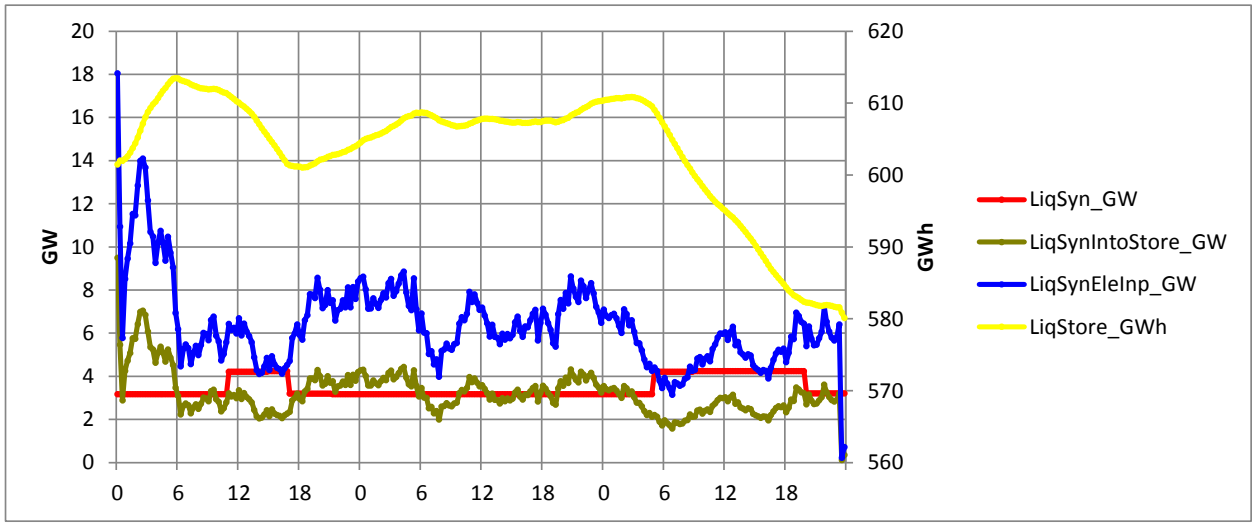




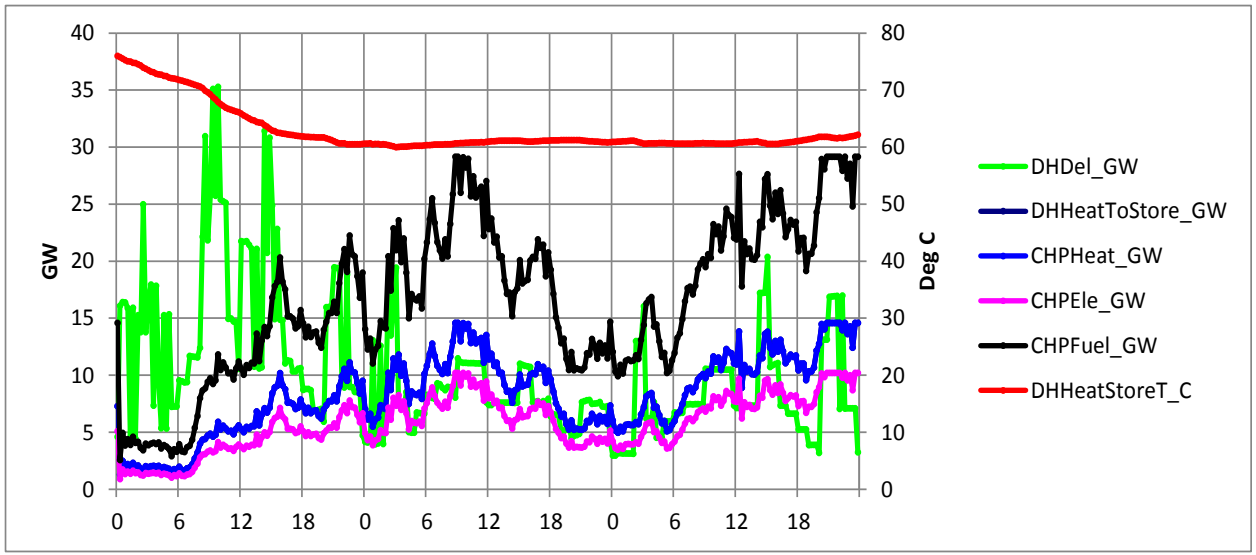


National system supply – 1 day for months 1,4,7 ; modelled at 15 min intervals

SYNTHETIC FUELS



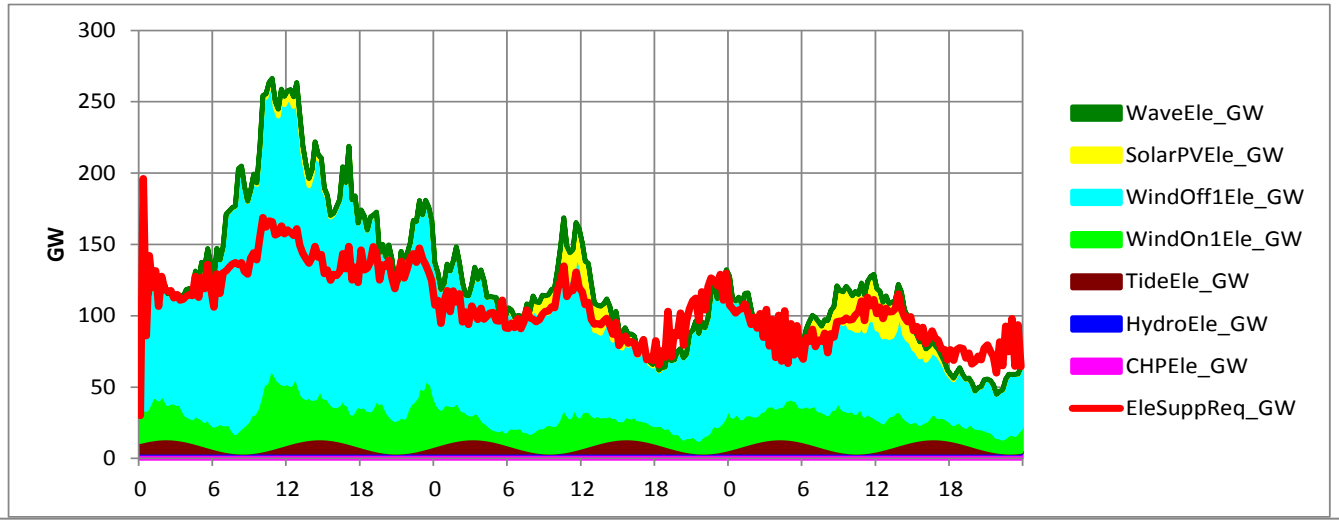
DISTRICT HEAT/CHP



National electricity supply – 1 day for months 1,4,7; modelled at 15 min intervals

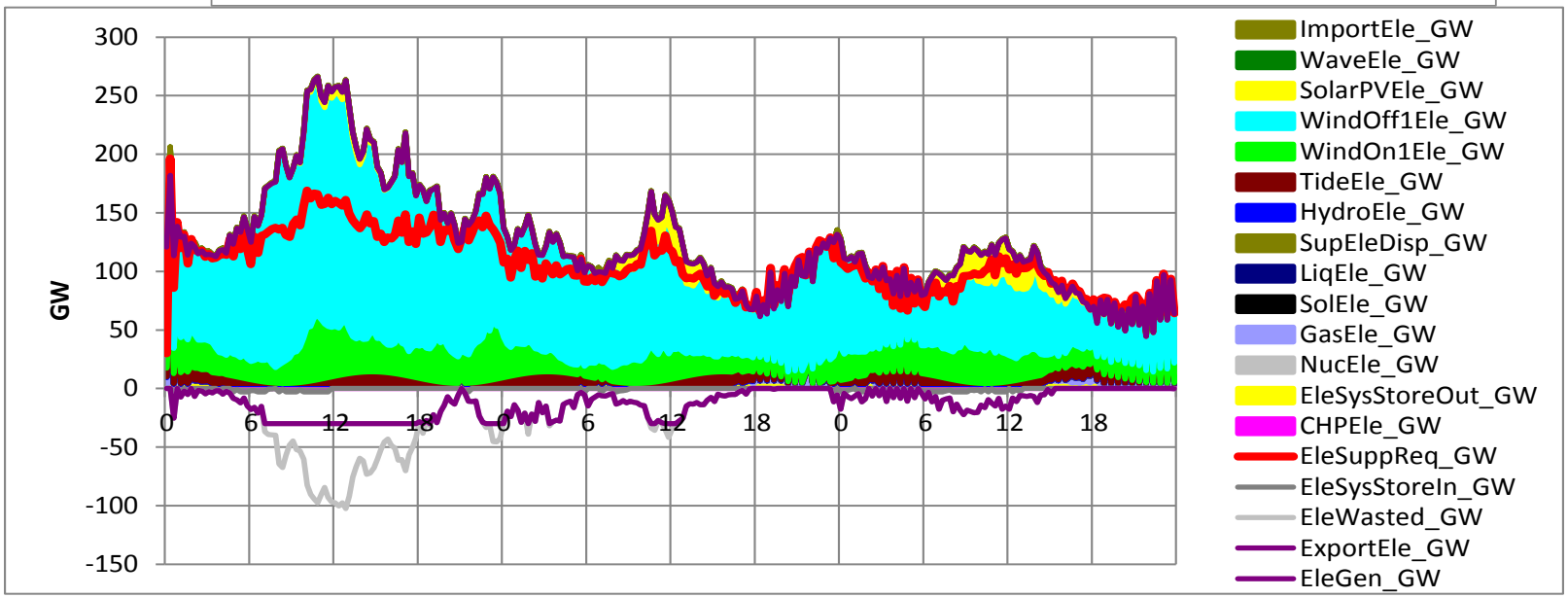
Smart grid algorithm applied to match demand and supply with storage

Renewable and CHP



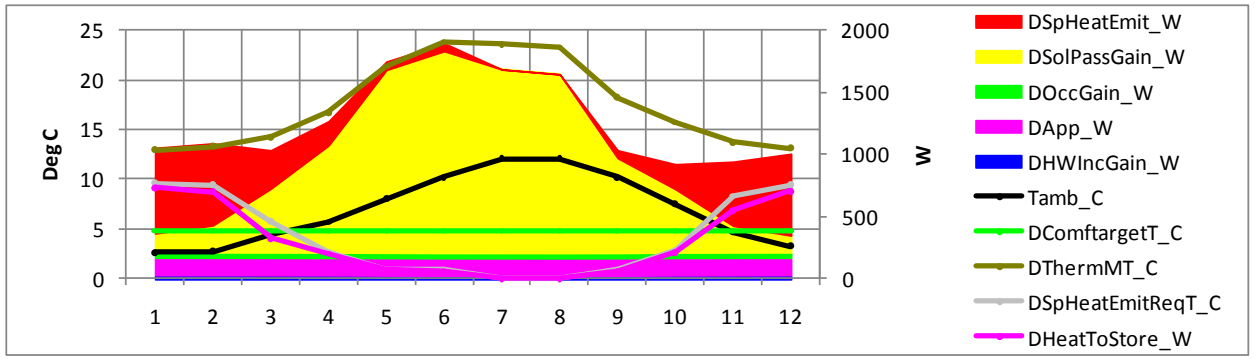
Electricity:

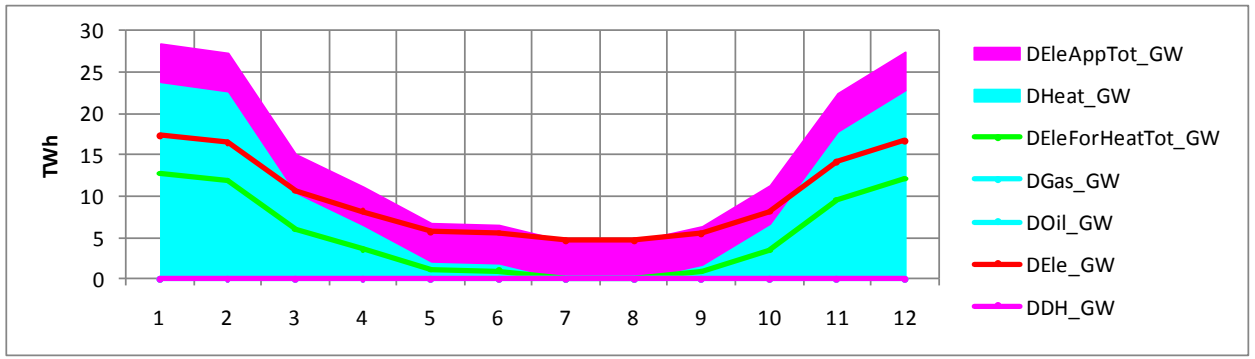
- Demand
- Renewables
- Trade



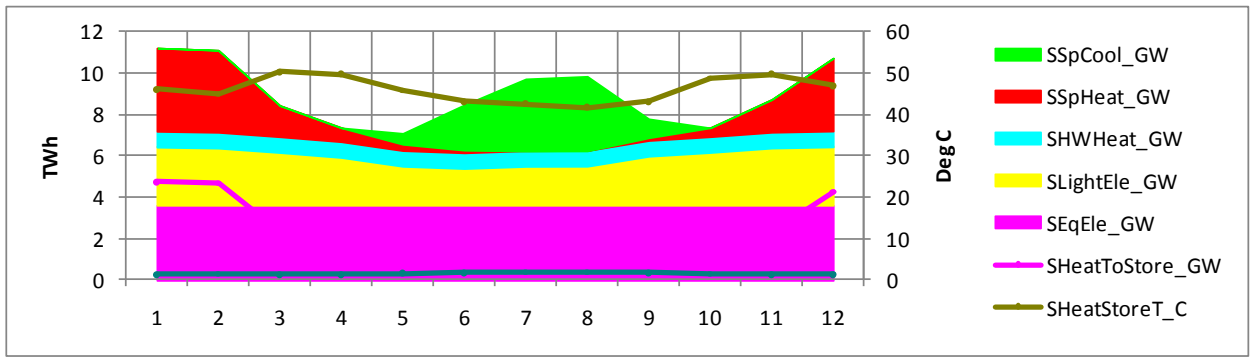
Monthly flows

Domestic





Services



Conclusions

Energy efficiency and renewable electricity are major options for meeting policy objectives

Electrification of heat produces major challenges in terms of peaks and demand-supply matching

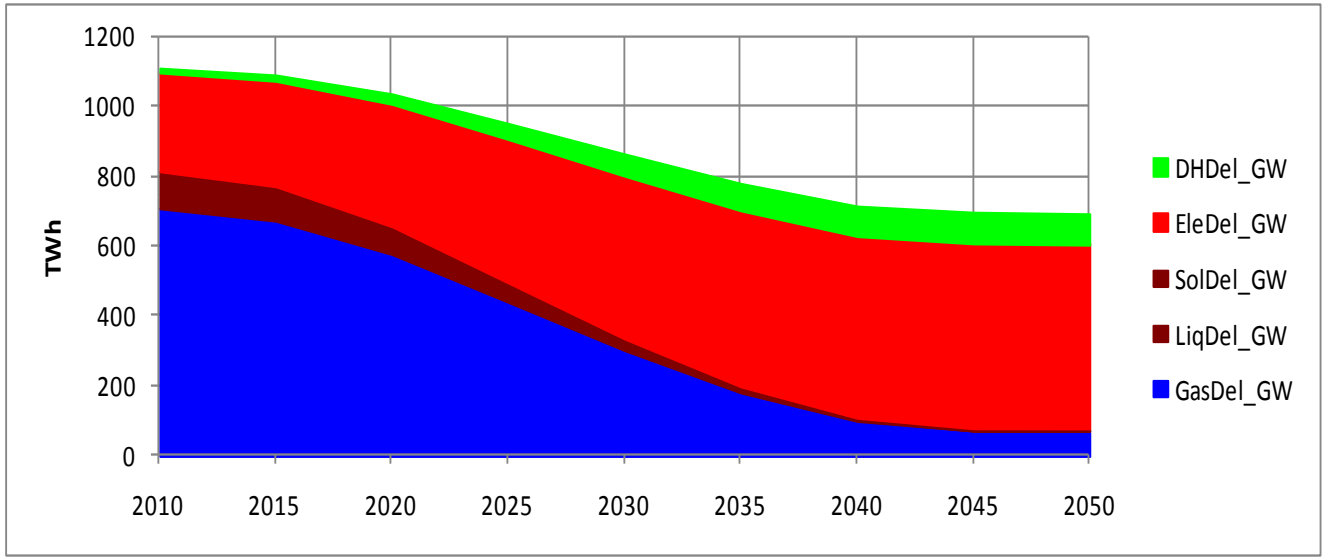
Robust, least cost system designs will integrate all demands and supplies

Electricity demand-supply matching will require the extensive use of a mix of:

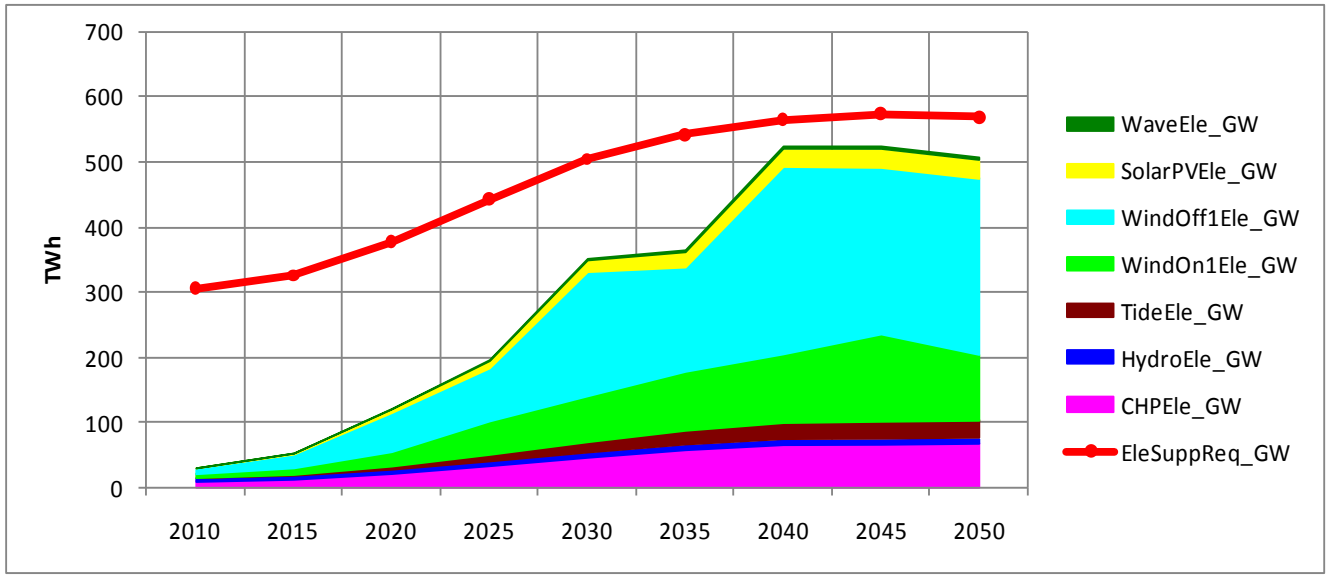
- heat storage
- chemical storage of synthetic fuels
- dispatchable biomass CHP plant
- heat pump inputs to district heating
- long distance transmission

National system scenario

Deliveries



Electricity supply: Renewable and CHP



Heat and DH

National context for DH

A.Heat demand

1.domestic, industry, services, refineries etc.:

- quantities, load density, temperatures, temporal pattern

B. Fundamental technical and economic analysis

1.What fraction of heat demand to be met by DH? What densities of heat loads and total size

2.What heat inputs to DH: technologies - boiler/CHP/heat pumps/solar; fuels - biomass, gas.?

- What configurations? How much heat storage?

3.How will DH fit in to the national energy system and meet constraints like carbon and biomass availability?

4.How will DH system operate dynamically in high renewable energy systems?

C. Policy specific to DH

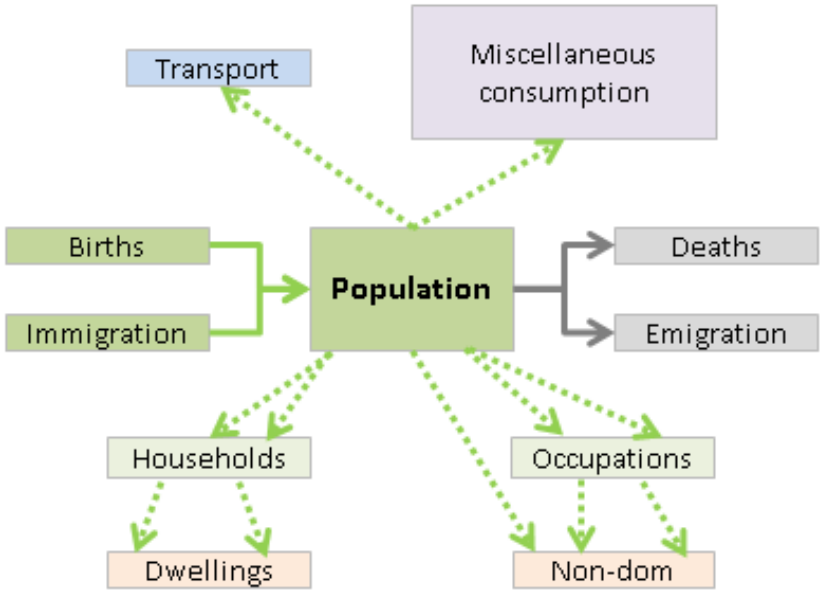
1.Implementation: Building regulations/ standards, local planning, utility requirements.

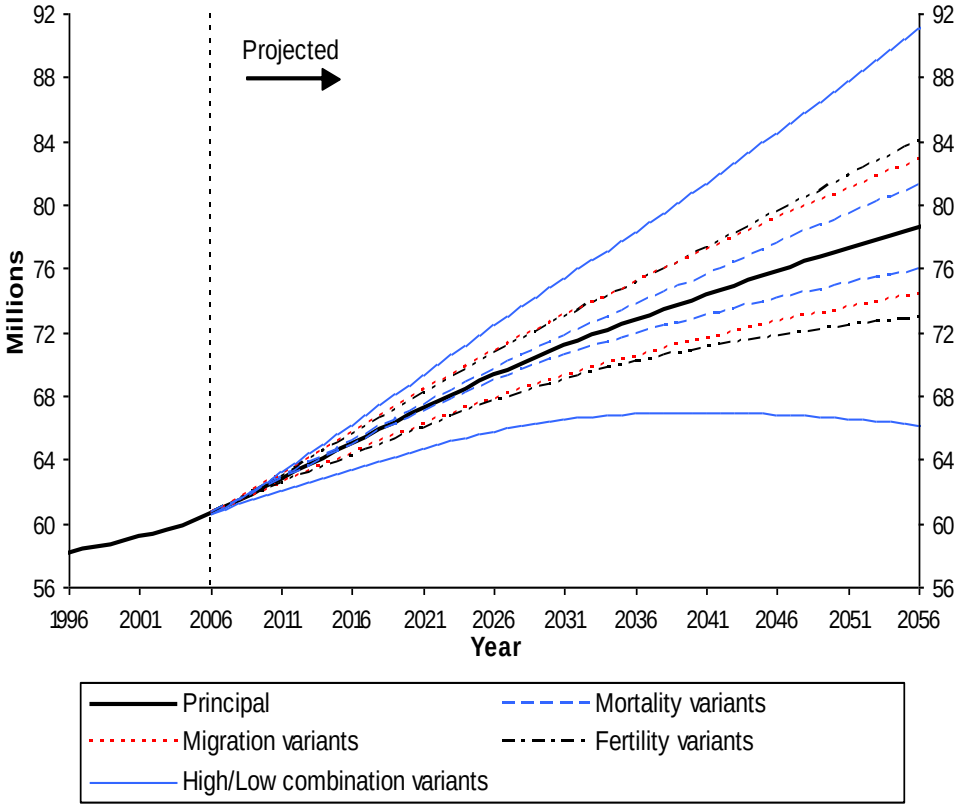
2.Public infrastructure investment

3.Heat, gas and electricity market structures: contracts, pricing etc.

4.Foreign experience

Demography


Transport
Miscellaneous consumption
Births
Immigration
Population
Deaths
Emigration
Households
Occupations
Dwellings
Non-dom


Projected
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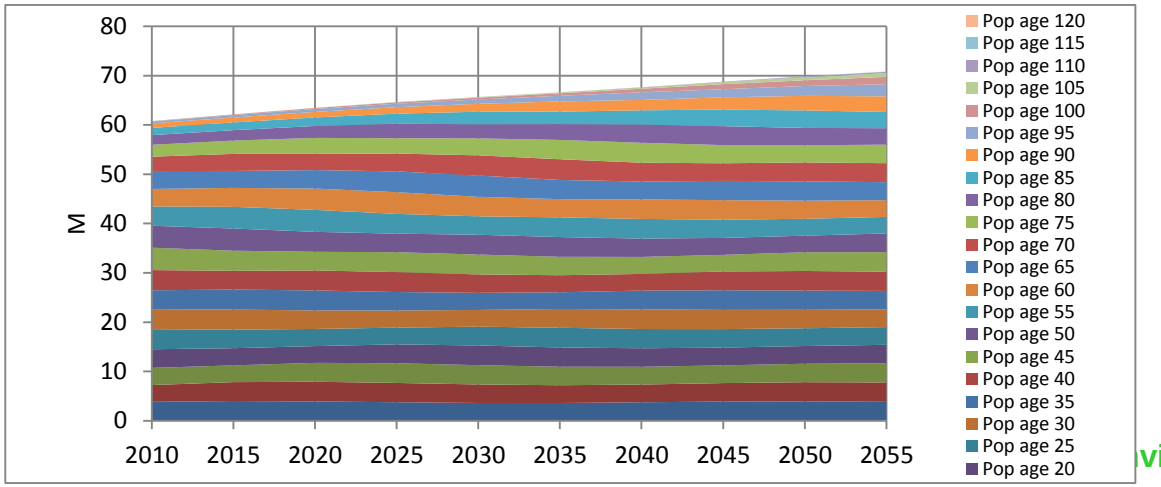
Principal
Mortality variants
Migration variants
Fertility variants
High/Low combination variants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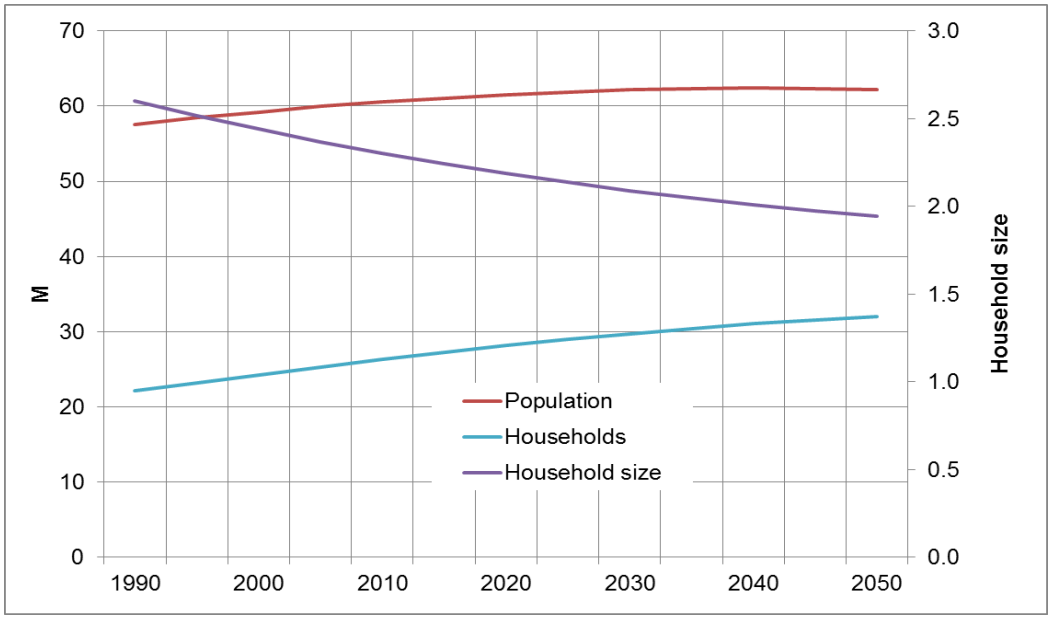
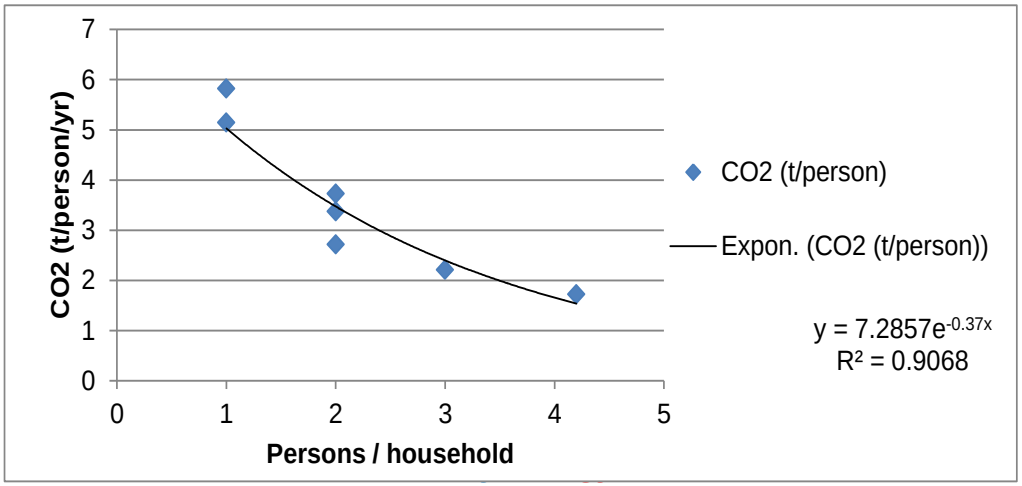
Pop age 20

Households and Dwellings - UK DEMOGRAPHY



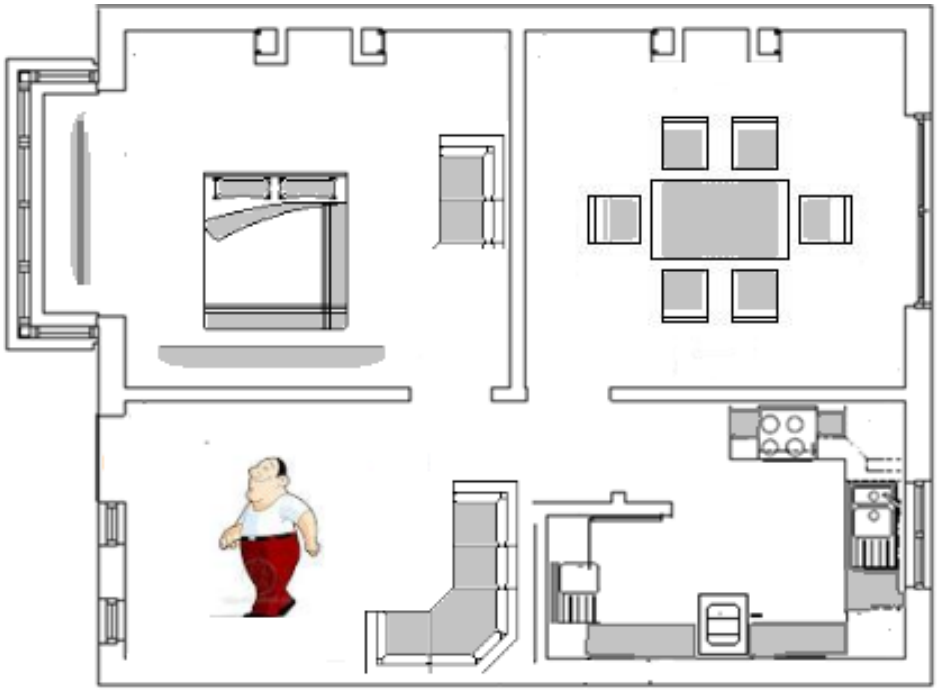
More people;
Smaller households;
More dwellings;
More energy per person

More carbon per person in small households



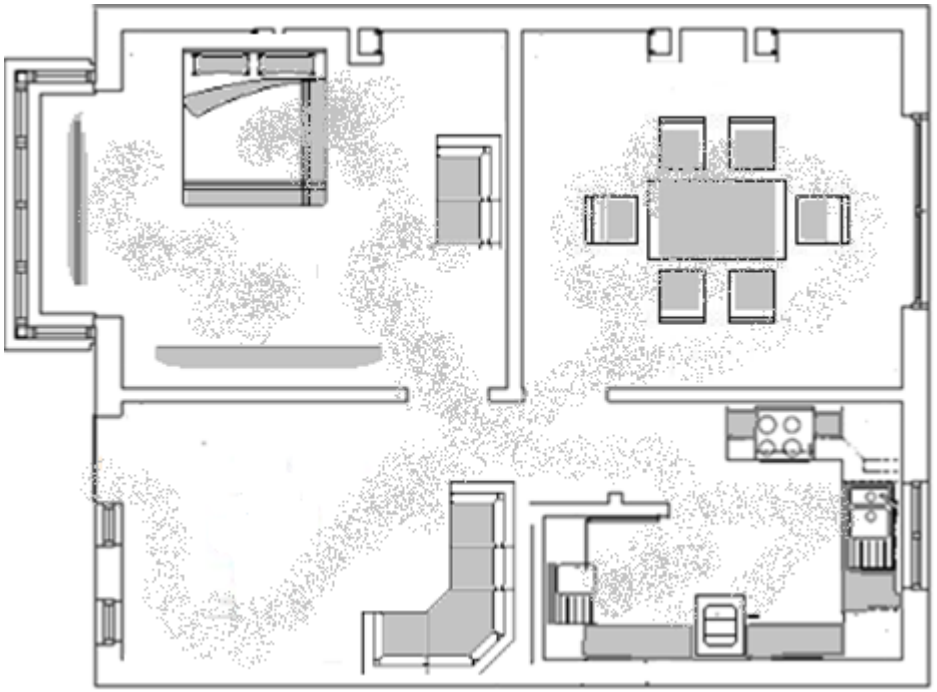
People: energy service demands, system use and control

Behaviour and energy services
Use of appliances
Control of systems
Monitoring – indoor environ imposes difficult challenges on location discovery due to the dense multipath effect and building material
Model occupancy patterns and energy consumption (OPEC)
Intention to extend to other sectors – especially transport

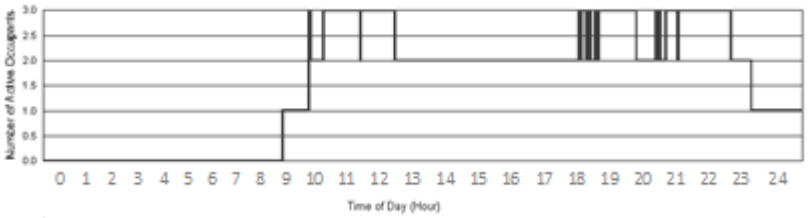


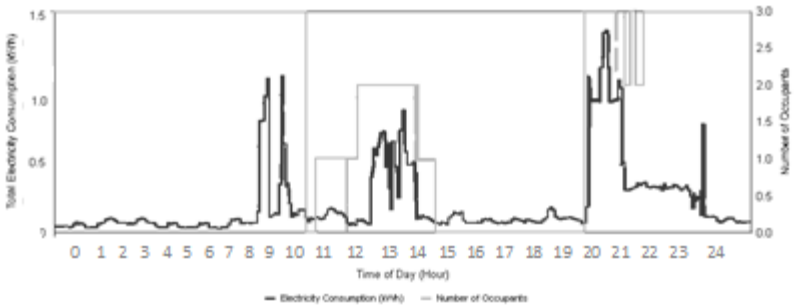
People: energy service demands, system use and control

Patterns of occupancy & Individual appliances energy usage = Individual energy load profiles



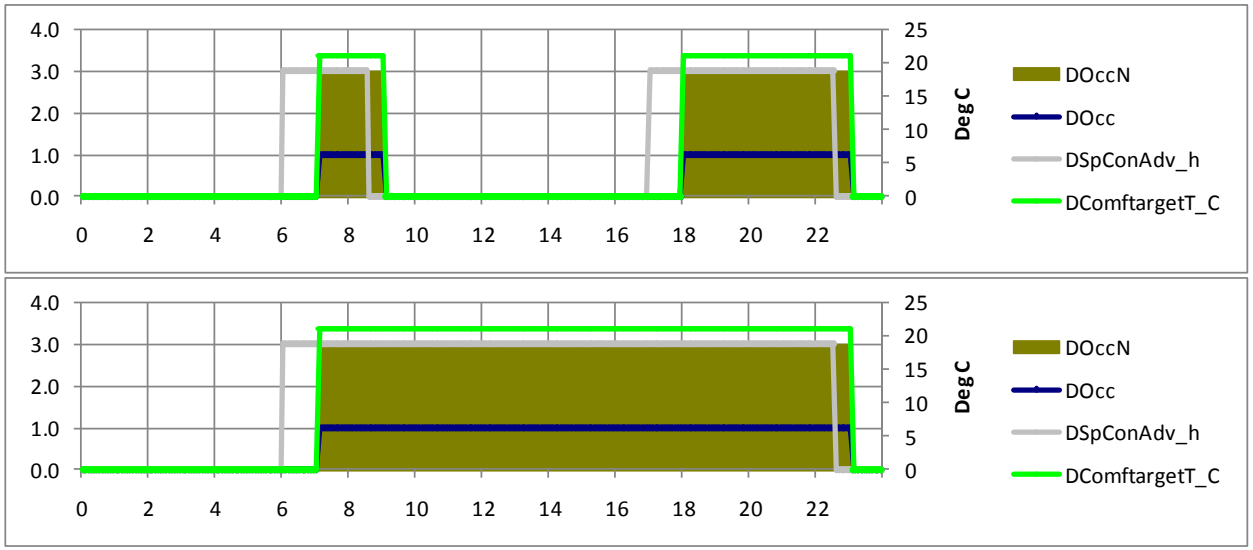
Load curves:
Lighting & appliances
and
occupants' patterns



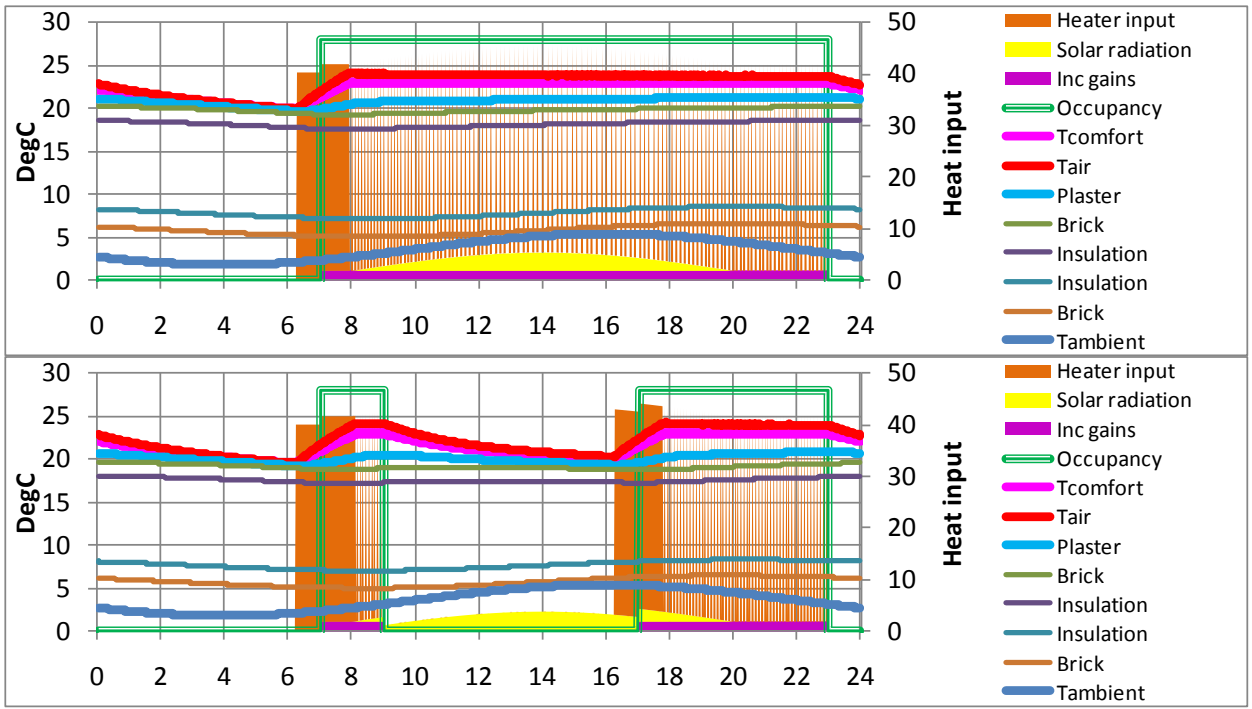


Building dynamics

Occupancy

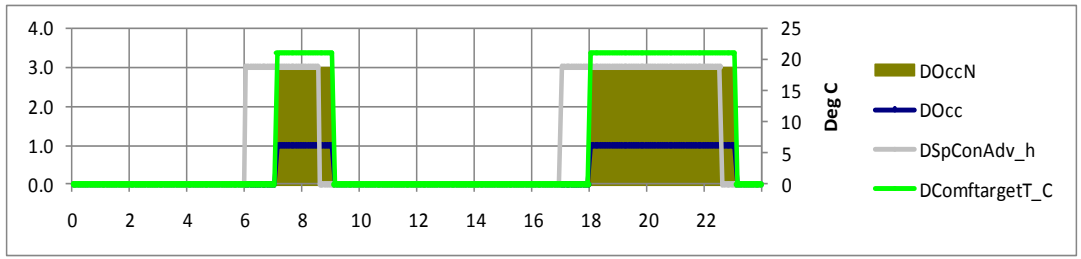


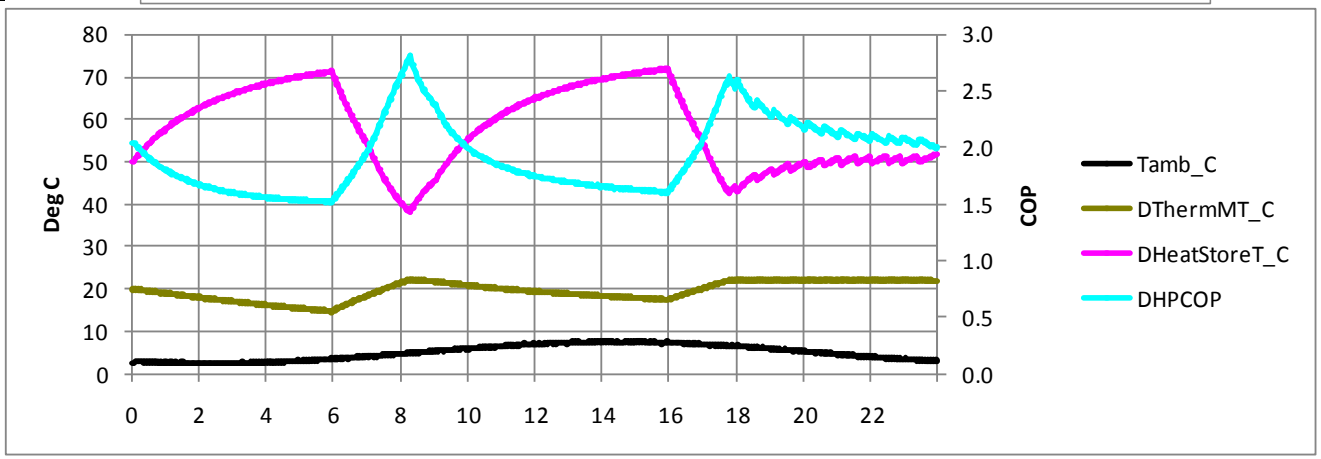
Walls

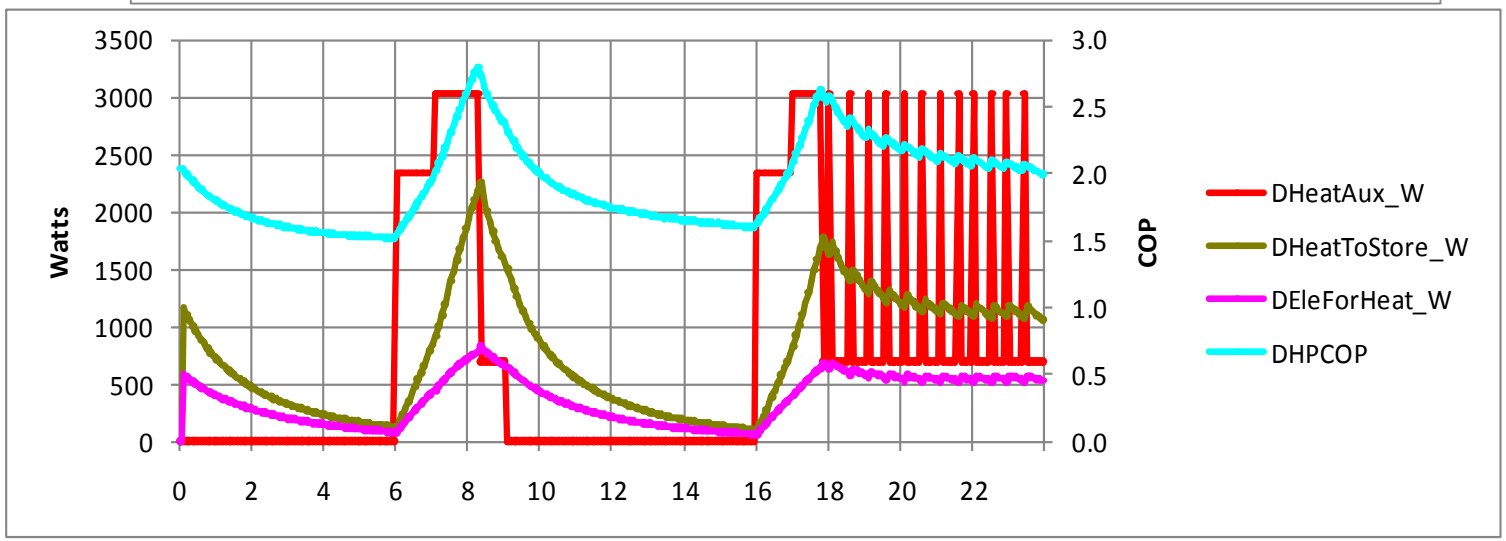


Heat pump and storage dynamics

<u>Winter's day modelled at 5 min intervals</u>



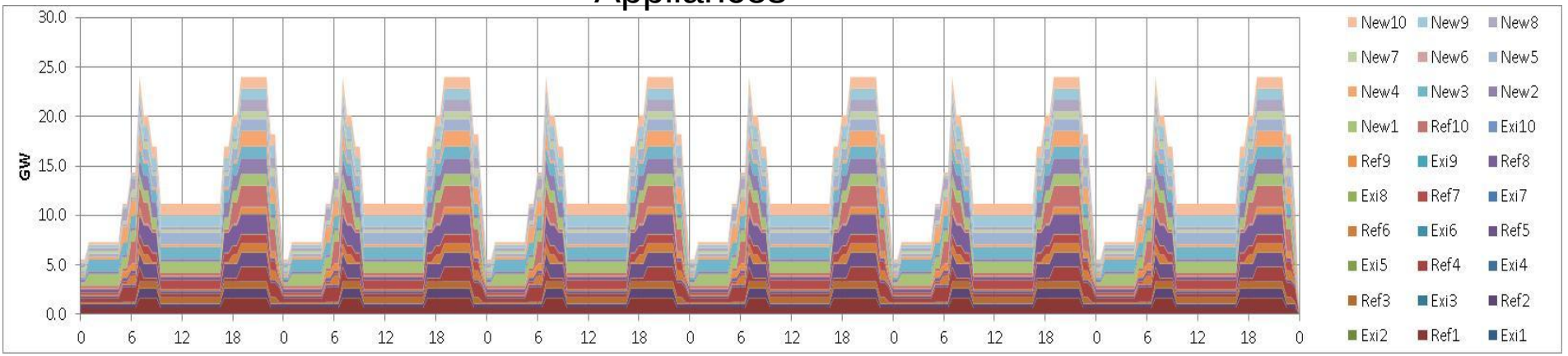




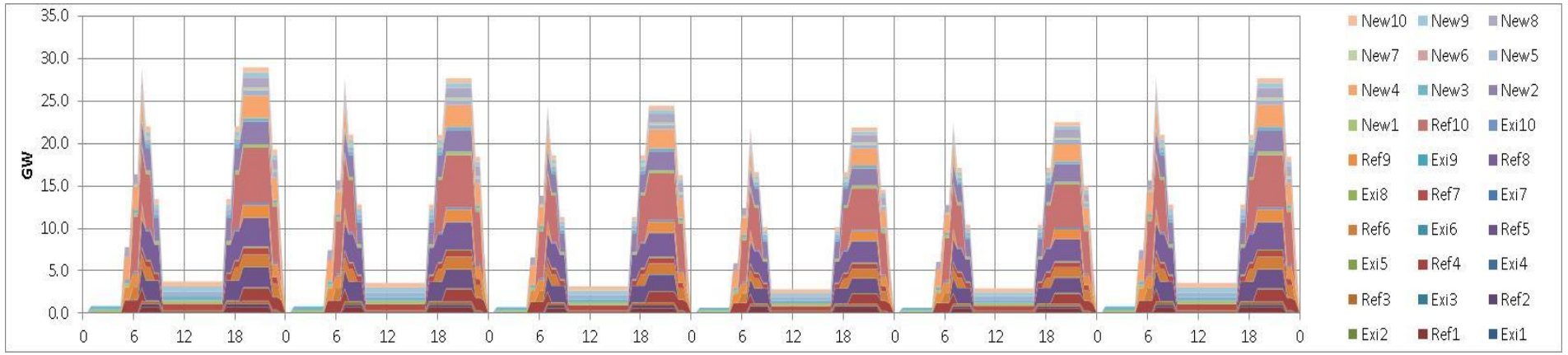
Load curves for Person-Dwelling Combinations

– one day for months 1,3,5,7,9,11

Appliances

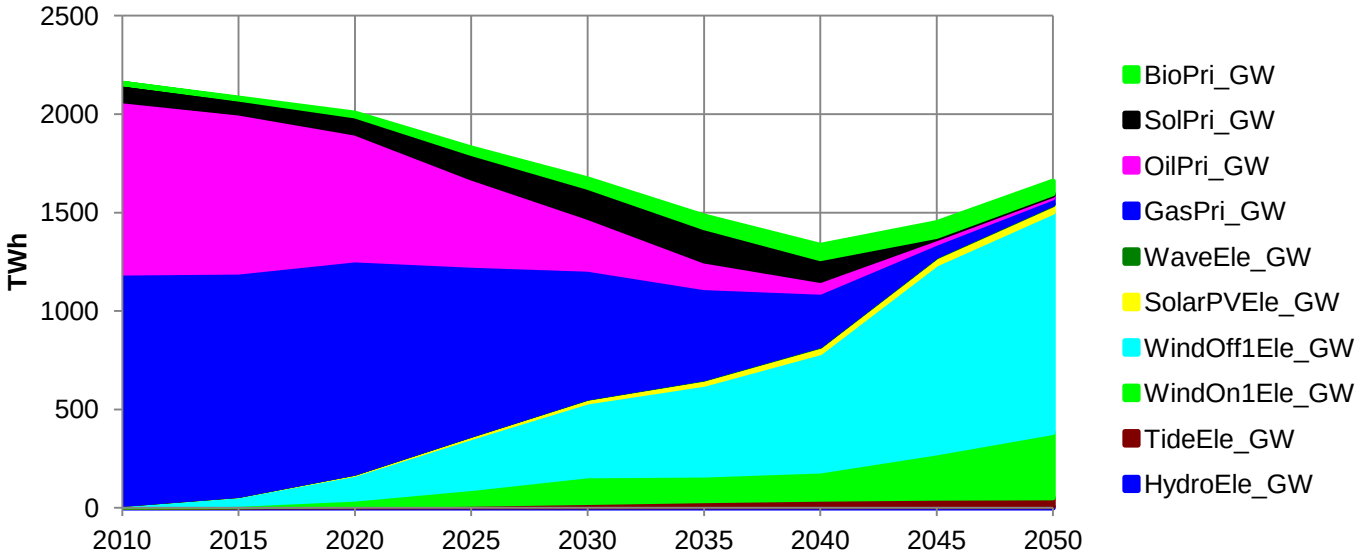


Water heat demand

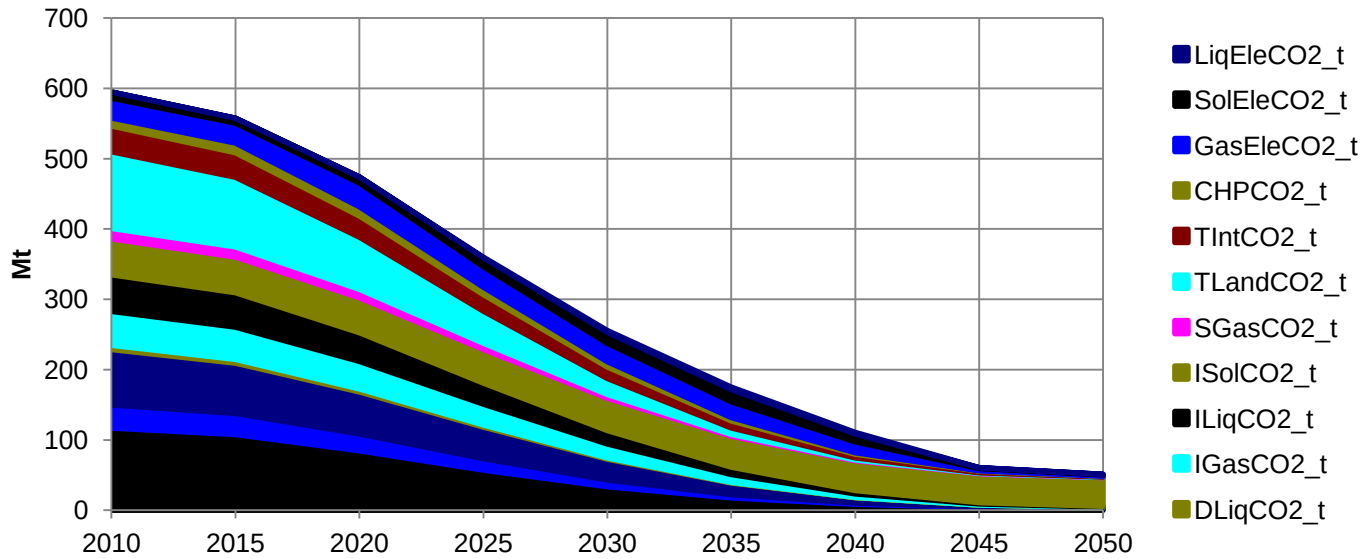


National system scenario

Primary



CO2



District heat – economics and developing the market

Central problem:

•High capital cost and long development times means DH suppliers need long contracts and high take-up of consumers.

- This **restricts consumer choice in end use energy supply** type (e.g. gas or DH), and frequency with which fuel switches can be made (say, increasing from 1 month to 15 years); **but it increases consumer flexibility and security in primary fuel mix**

Economics of DH must be comparative;

•What are capital costs compared to alternatives? E.g. increasing the capacity of dispatchable generation and low voltage electricity distribution to accommodate individual heat pumps in dwellings.

•What are the variable fuel and operating costs of alternatives? E.g. individual heat pumps or gas boilers?

•What are the economic benefits of DH in terms of:

- multi-fuelling (CHP+HPs+…) that may be adjusted instantly or in long term with no consumer impact?
- lower carbon emissions?
- Role in the energy system with dynamic fuel mix changing and storage, so as to integrate, for example, a large wind component?

To overcome problem

•What financial incentives?

•What changes to regulation of energy market, buildings, planning, etc. are required?

District heat development – possible drivers

- Building regulations: zero carbon, energy supply
- Planning regulations: e.g. Merton type rule
- Energy supply drivers.
  - E.g. offshore wind->HP+DH, **renewable target** to absorb wind (inc. CHP, HPs?)
  - RHI etc
- Energy system coherence. Role of DH as system balancer.
- Carbon target.
- Power stations; old and new. CHP mandate. IPPC. LCPD.

District heat : foreign success

60% Danish houses have DH

Stockholm has DH with inputs from CHP, waste heat, large heat pumps using sea heat

Gothenburg DH:
•offers consumers the choice between DH and ground source HPs
•extends its DH system to very low density housing on rocky terrain
•has inputs from waste incineration, fossil plant etc.

http://www.worldenergy.org/documents/dhchp.pdf

How do they do it?
Organise seminars to bring successful practice to the UK. Advice on technical, economic, regulatory, local political, social aspects of DH. Attendees: DECC, LAs, industry, consultants etc.

Aim for lead demonstration UK DH systems small/medium scale with Scandinavian aid. New schemes and/or extensions of existing (from nuclei) e.g. Southampton, Woking, Pimlico. Build on existing initiatives. Consider dominant building/industrial loads, proximity to heat sources such as existing power stations.

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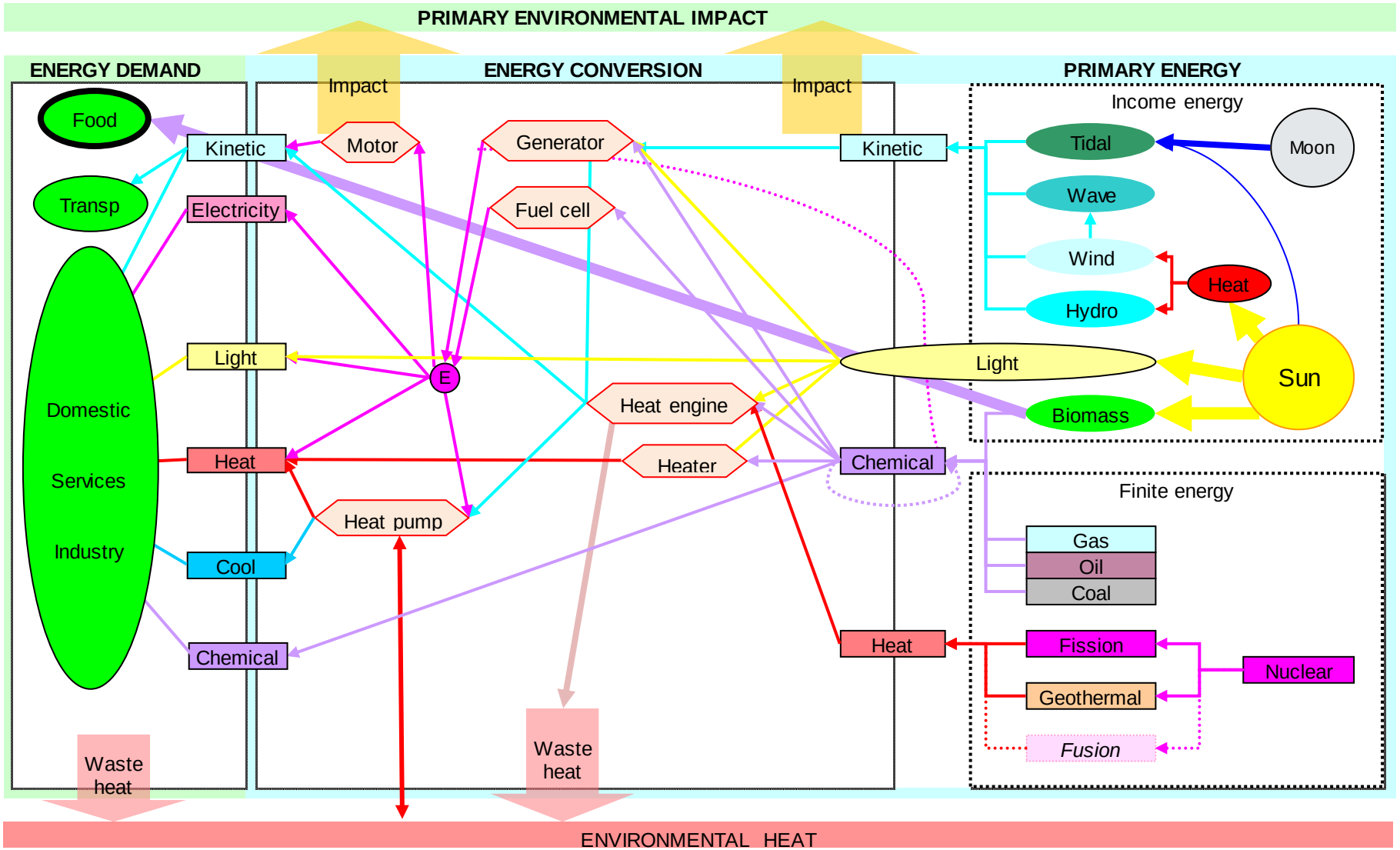
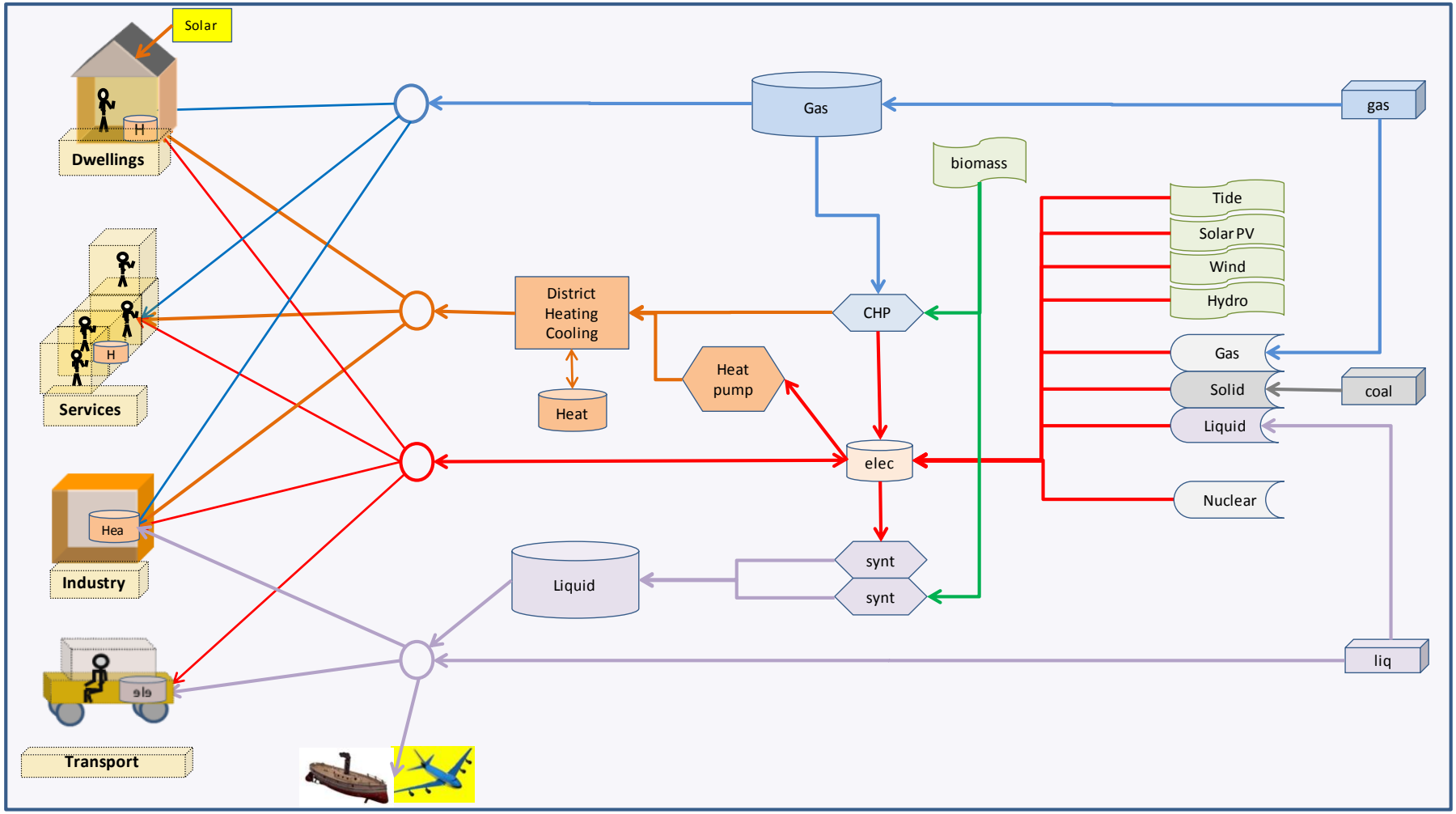
Smart grid


PRIMARY ENVIRONMENTAL IMPACT
ENERGY DEMAND
ENERGY CONVERSION
PRIMARY ENERGY
Impact
Impact
Food
Transp
Domestic
Services
Industry
Kinetic
Electricity
Light
Heat
Cool
Chemical
Motor
Generator
Fuel cell
E
Heat engine
Heater
Heat pump
Kinetic
Light
Chemical
Heat
Income energy
Tidal
Moon
Wave
Wind
Heat
Hydro
Sun
Biomass
Finite energy
Gas
Oil
Coal
Fission
Nuclear
Geothermal
Fusion
Waste heat
Waste heat
ENVIRONMENTAL HEAT

Smart grid


Solar
Dwellings
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Services
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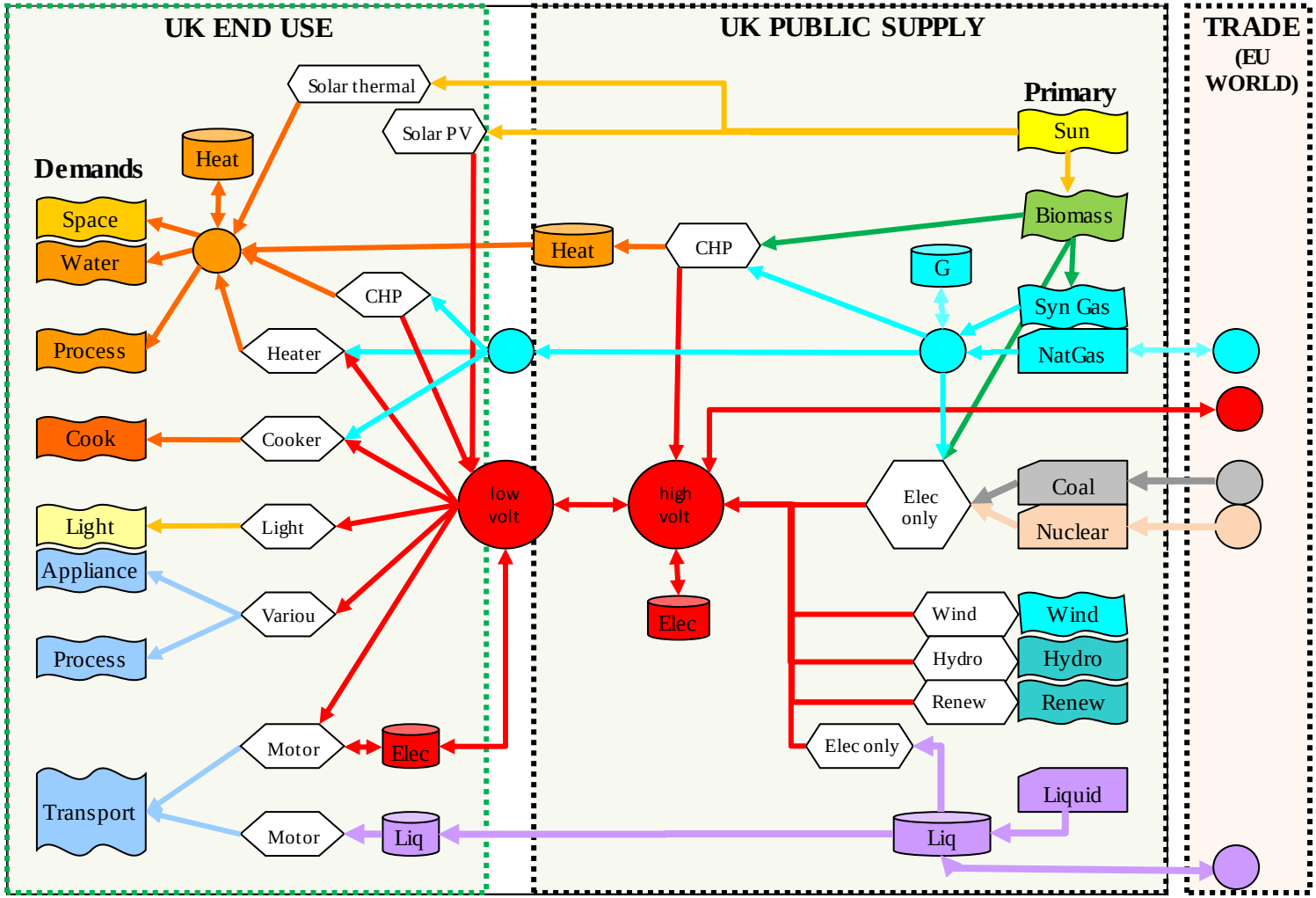
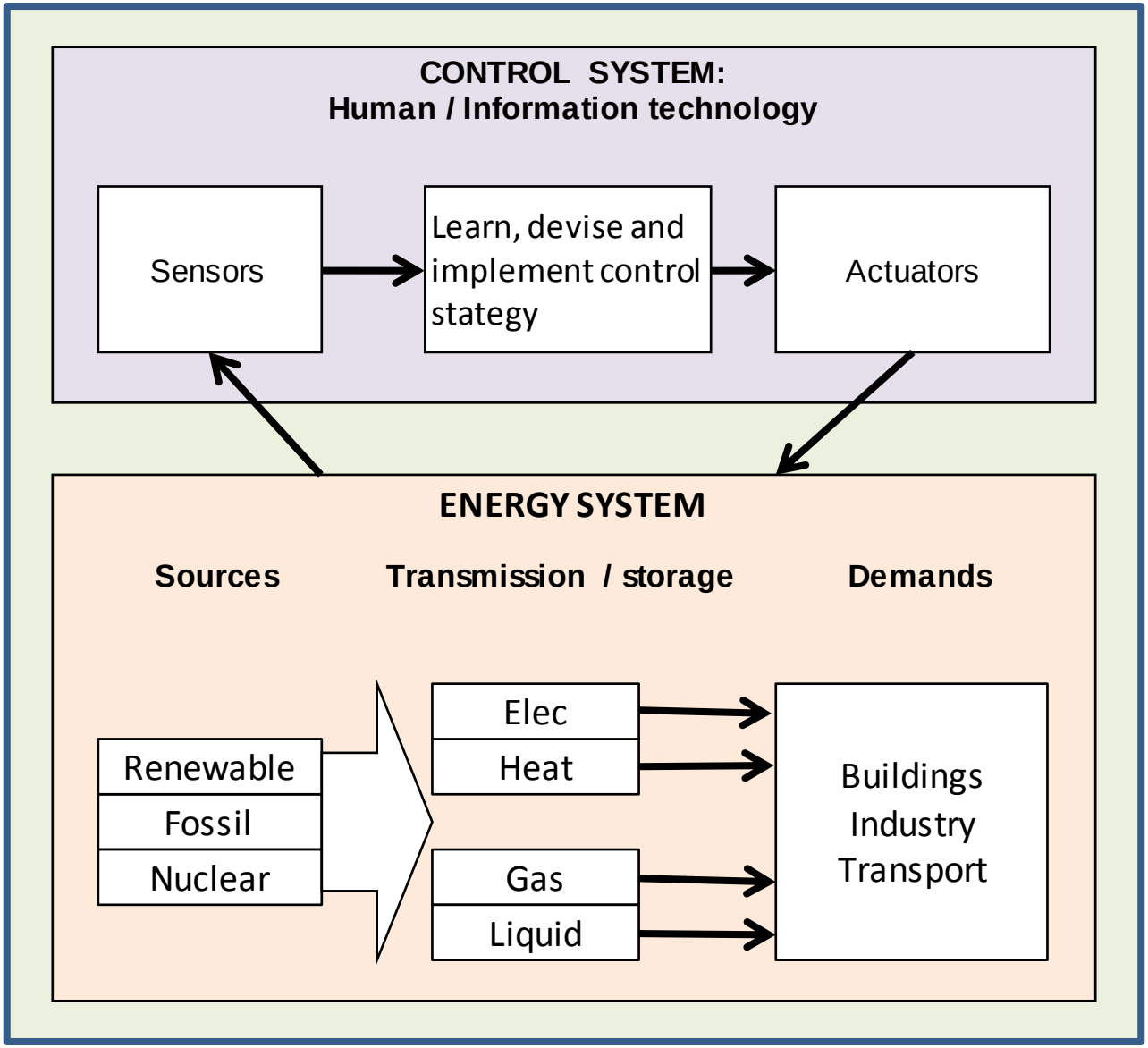
Hea
Industry
Transport
Gas
gas
biomass
Tide
Solar PV
Wind
Hydro
District
Heating
Cooling
CHP
Heat
pump
Heat
Gas
Solid
Liquid
coal
elec
Nuclear
synt
synt
Liquid
liq

Smart grid



Social patterns & weather

Smart grid


CONTROL SYSTEM:
Human / Information technology
Sensors
Learn, devise and implement control stategy
Actuators
ENERGY SYSTEM
Sources
Transmission / storage
Demands
Renewable
Fossil
Nuclear
Elec
Heat
Gas
Liquid
Buildings
Industry
Transport

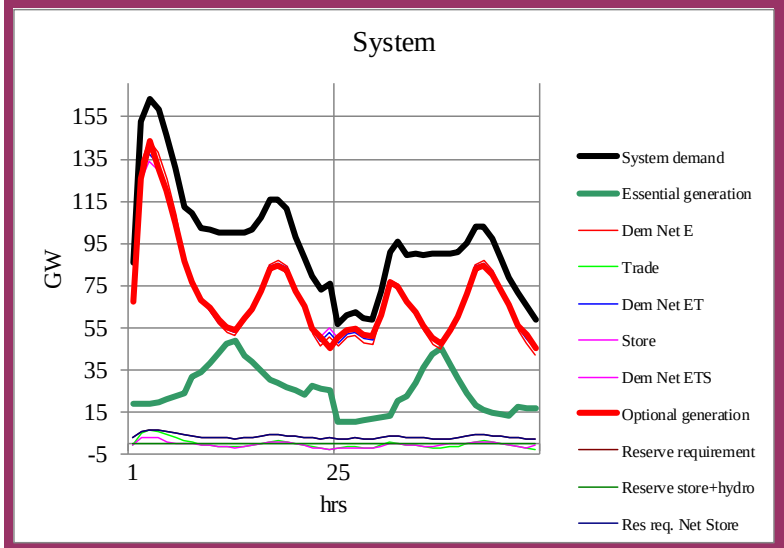
Smart grid

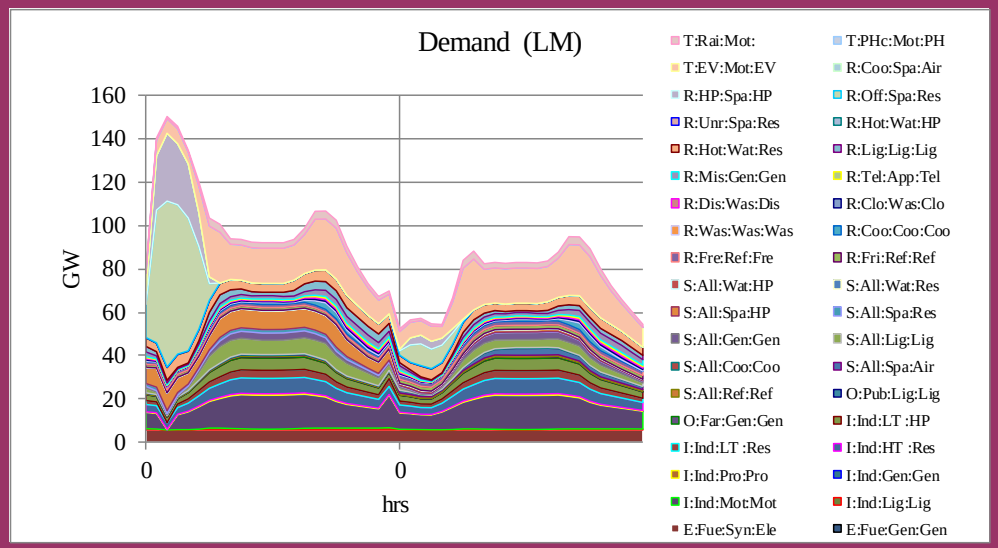
				Current	Projected
Demand	**Service demand**	weather dependent	space heating		input
			lighting		input
		independent	water heating		input
			appliances		input
Stores	storage levels	heat stores	end use	input	output
		electricity stores	system		output
Supply	**Thermal stations**	elec only		input	output
		CHP		input	output
	Renewables	uncontrolled	wind		input
			wave		input
			solar		input
		with storage	biomass	input	output
			hydro	input	output
			tidal	input	output
			geothermal	input	output
	Trade				output

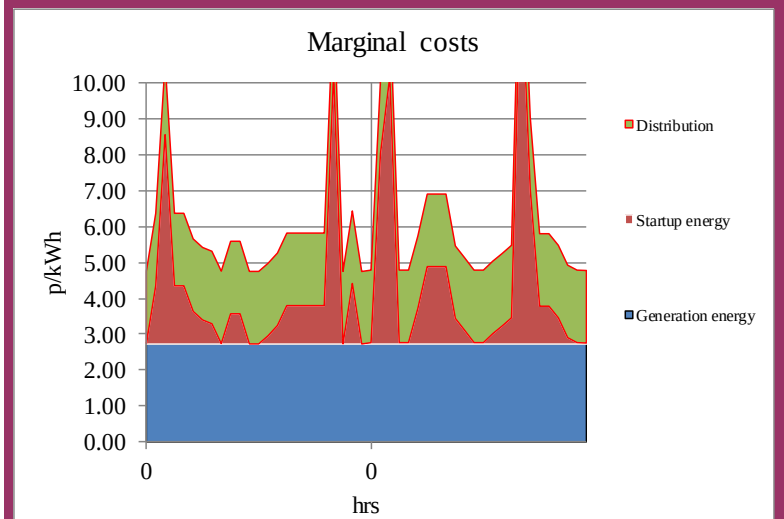
Smart grid

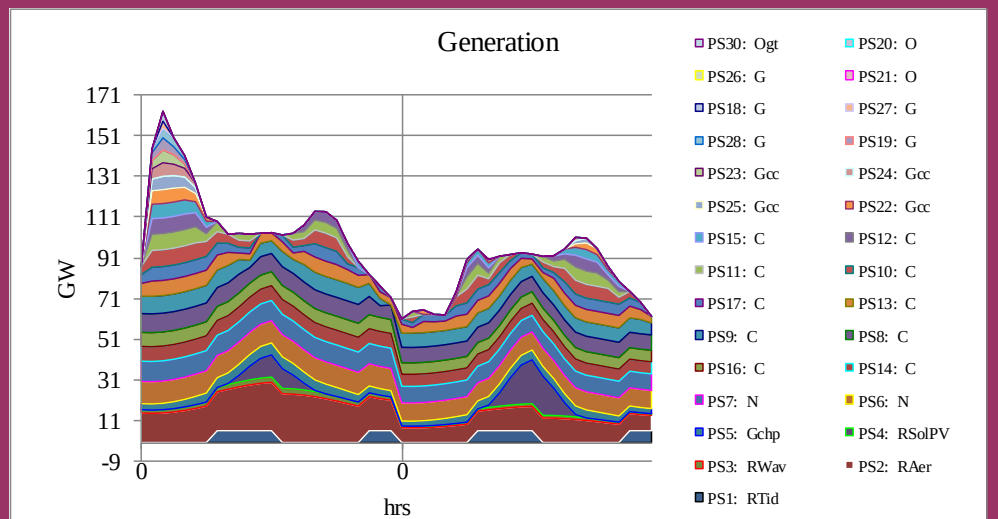
System before load management

EleServe Scenario: Efficiency + CHP + renewables 2030 Winter day : Summer day









Smart grid

System after load management

EleServe Scenario: Efficiency + CHP + renewables 2030 Winter day : Summer day