A Sustainable Scenario for Energy and Water in Bahrain

John Barton, j.p.barton@lboro.ac.uk

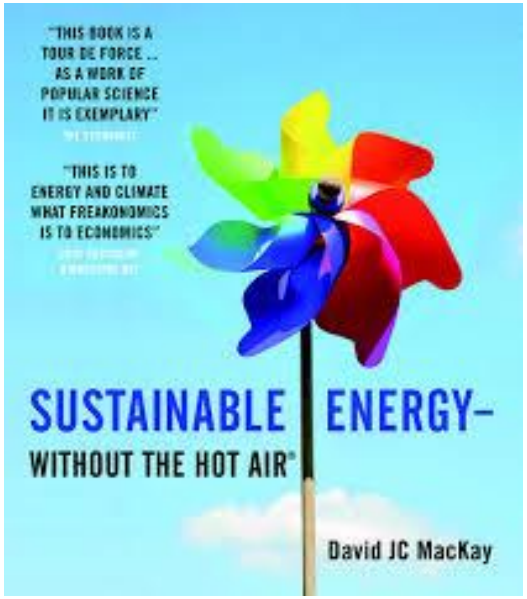
Murray Thomson, m.thomson@lboro.ac.uk

Centre for Renewable Energy Systems Technology (CREST),

Loughborough University

Can all of Bahrain's energy and water needs be supplied by renewable energy?

Inspired by the book:
" Sustainable Energy Without the Hot Air"



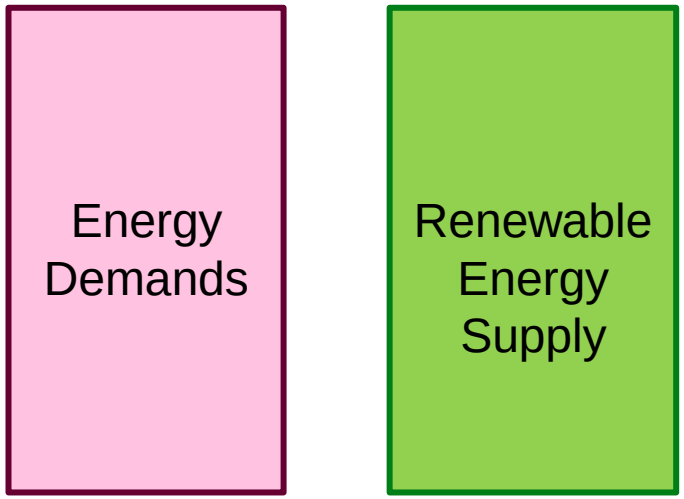
Sir David J. C. MacKay, 1967-2014. Professor at Cambridge University and Chief Scientific Adviser to the UK Department of Energy and Climate Change (DECC)

Why is this study needed?

- Knowing the end point helps us plan how to get there
- Makes the issues understandable on a human scale
- Helps all the stake-holders to get involved in the decision processes
- Helps us to focus on the big issues and identify where research can have the biggest impact
- This is just a ‘straw man’, a starting point for discussion

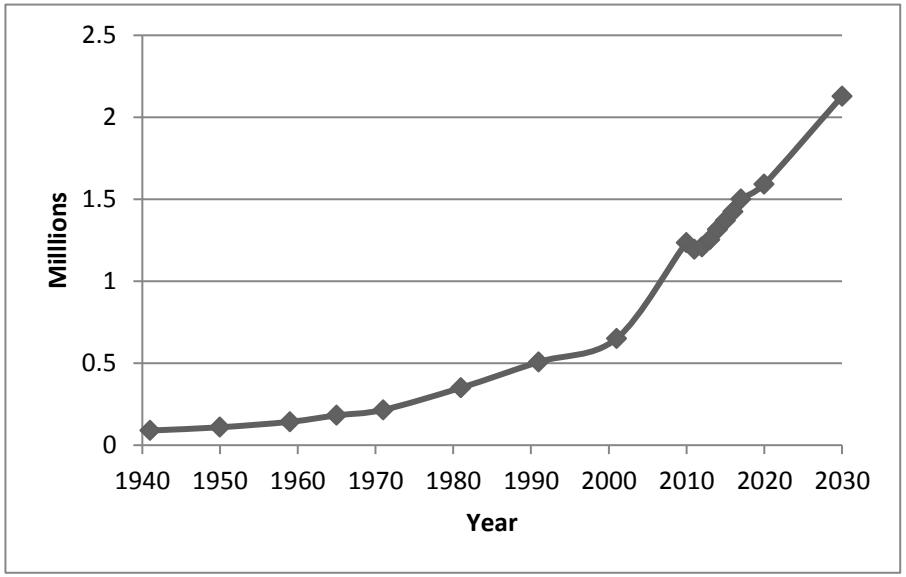
Energy Demand and Possible Energy Supply

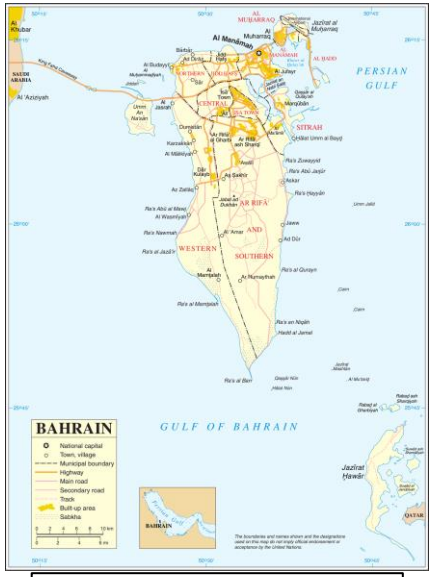
- Population: Energy in kWh per person per day
- Today's energy use in Bahrain
- Electrical appliances and lighting
- Water heating and cooking
- Water supply
- Air conditioning
- Wind power
- Solar power
- Non-domestic buildings
- Cars
- Industry
- Wave and tidal power
- Biogas and biomass



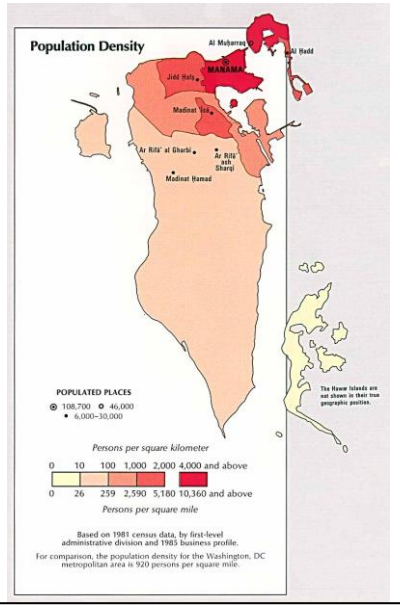
Do resources match demand?

Population of Bahrain





United Nations Map (Wikipedia)



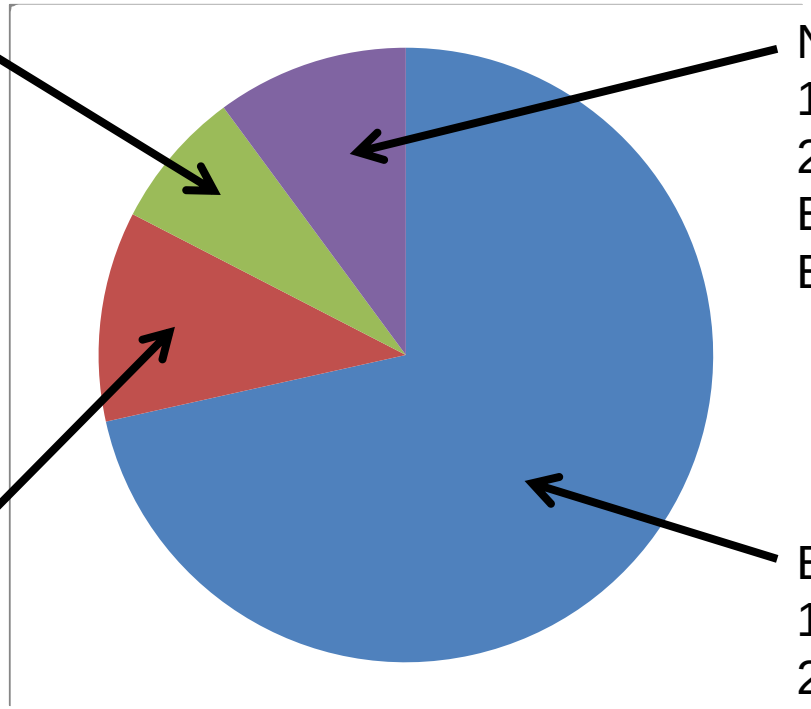
CIA Atlas of the Middle East 1993 (University of Texas)

Per capita energy use is estimated using 2017 numbers (1.5 million)
But generation per capita is based on the future population of 2030 (2.1 million)

Bahrain has the 7th highest population density of any territory in the world, but the Southern half of the country appears to have some empty space.

Natural Gas Use in Bahrain is Enormous!

Total = 157 TWh / year or 287 kWh / day per person, 2015 numbers (IEA)



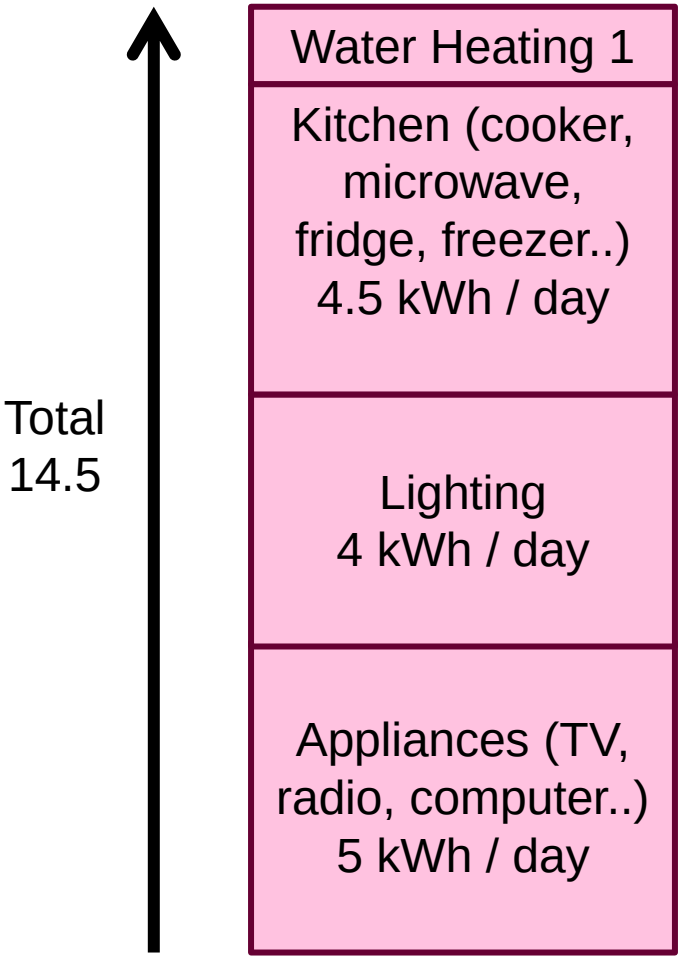
Other Industries
12 TWh / year or
21 kWh / day

Non-Energy Uses
16 TWh / year or
29 kWh / day
Exported?
Exclude from this study

Energy Industry
Own Use
17 TWh / year or
32 kWh / day
Gas reinjected for EOR?
Needs CCS

Electricity Generation
112 TWh / year or
205 kWh / day
Could be replaced by
renewable electricity

Appliances, Lighting, Water Heating and Cooking



- Lifestyle assumed to be similar to the UK
- Calculated as average kWh per person per day
- All numbers fairly approximate!

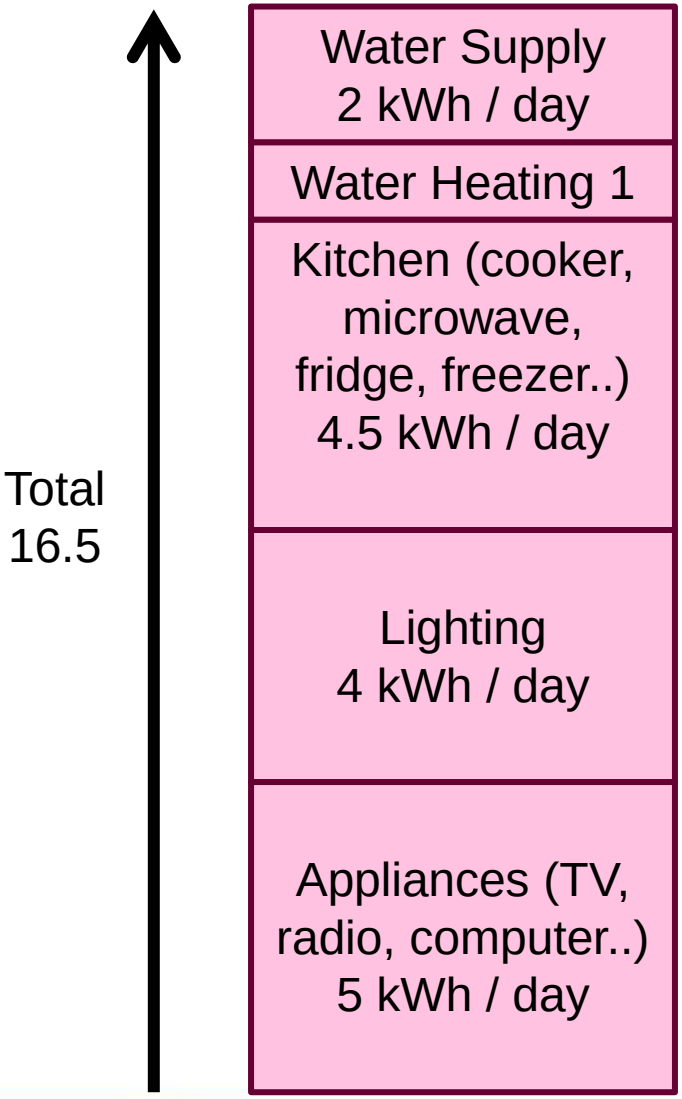
Water Supply

- For the purposes of the model, all water is produced by reverse osmosis using electricity
- Example: Al Dur Power and Water Company

The Al Dur power plant with RO water production
© Sheryl Williams, Loughborough University, May 2017

- 4 kWh per cubic metre of water
- Bahrain uses 700,000 cubic metres per day
- 1000 GWh per year of electricity!

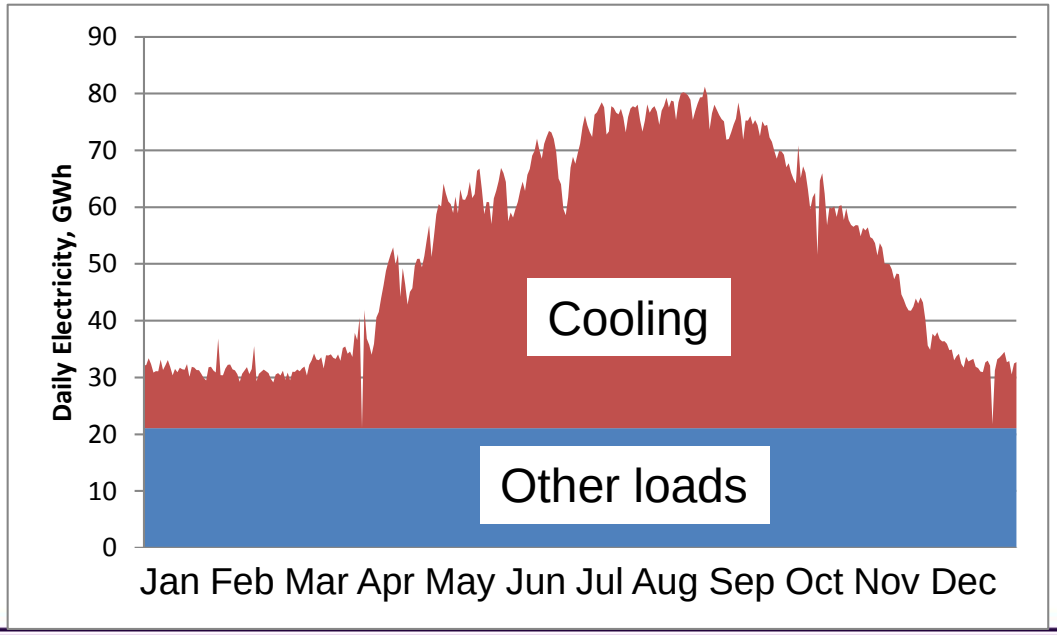
Water Supply



…But only 1.9 kWh per person per day

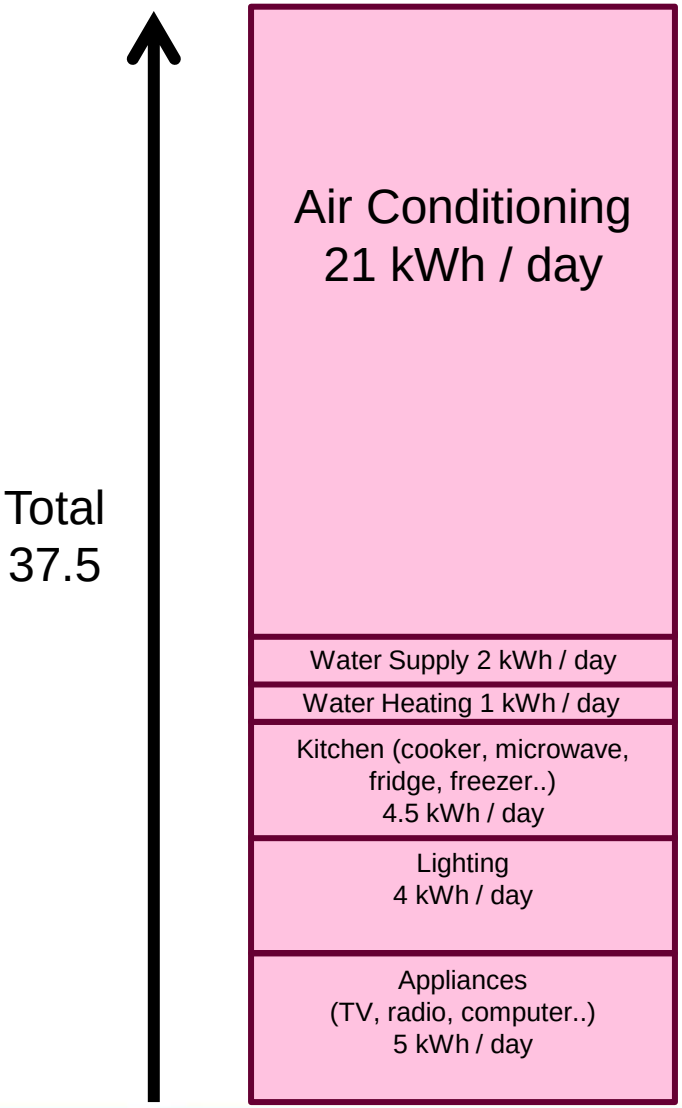
Air Conditioning

- Temperatures up to 46°C and high humidity
- Virtually all buildings are air conditioned
- Air conditioning is used mainly in summer but some is still used in winter (60% of grid electricity):



Daily Electricity Demand in 2017

Add in Air Conditioning (and Zoom Out)



Adds 21 kWh per person per day

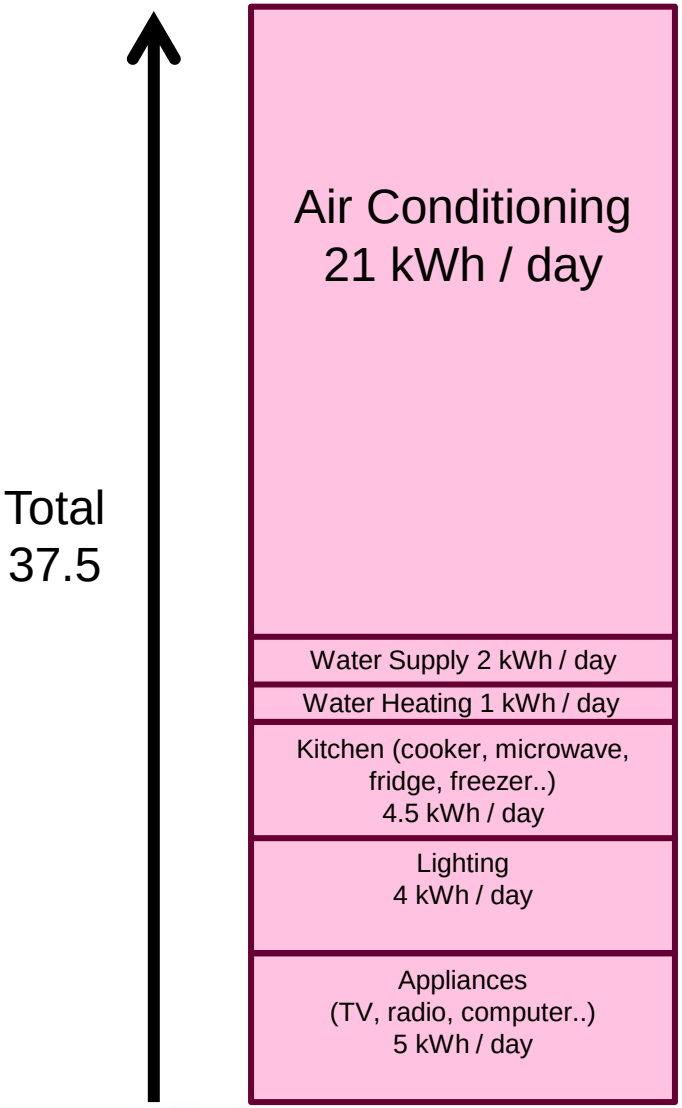
So let's look at possible sources of renewable energy to meet this demand:

Onshore Wind Power

- Average wind speed 6.9 m/s
- 60 m diameter, 60 m hub height
- Average power of 223kW per turbine
- Turbine spacing of 10 diameters (600m)
- 10% of land area is suitable
- Annually 0.4 TWh
- 0.5 kWh/day per person in 2030

Wind turbines, pxhere.com

Demand vs. Onshore Wind



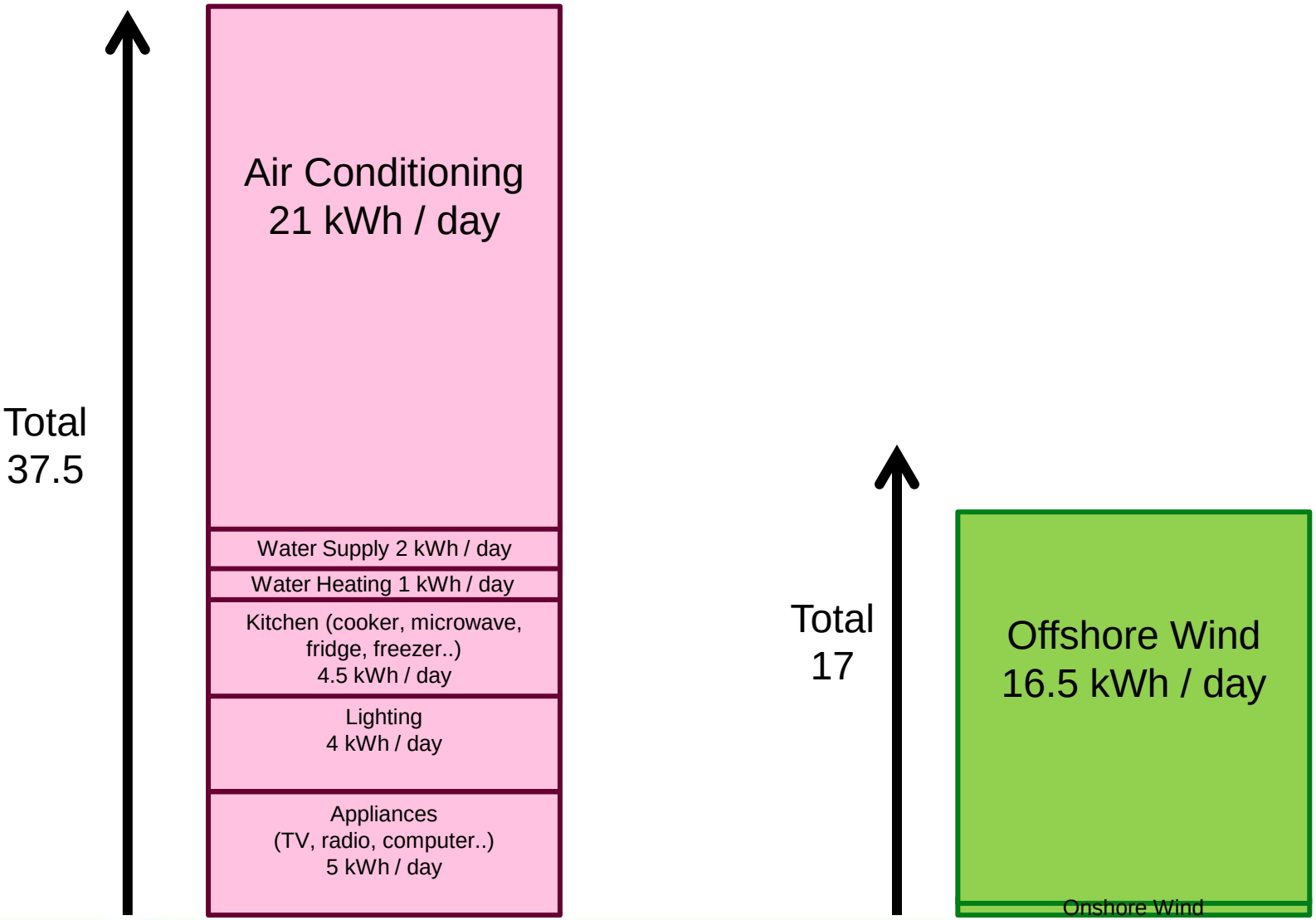
Onshore Wind < 0.5

Offshore Wind Power

- Average wind speed 7.3 m/s
- 100 m diameter, 100 m hub height
- Average power of 733kW per turbine
- Turbine spacing of 10 diameters (1000m)
- 8000 square km of territorial waters
- Sea depths < 50 m
- 25% of sea area is suitable
- Annually 12.8 TWh
- 16.5 kWh/d per person in 2030

Offshore turbines, pxhere.com

Add in Offshore Wind

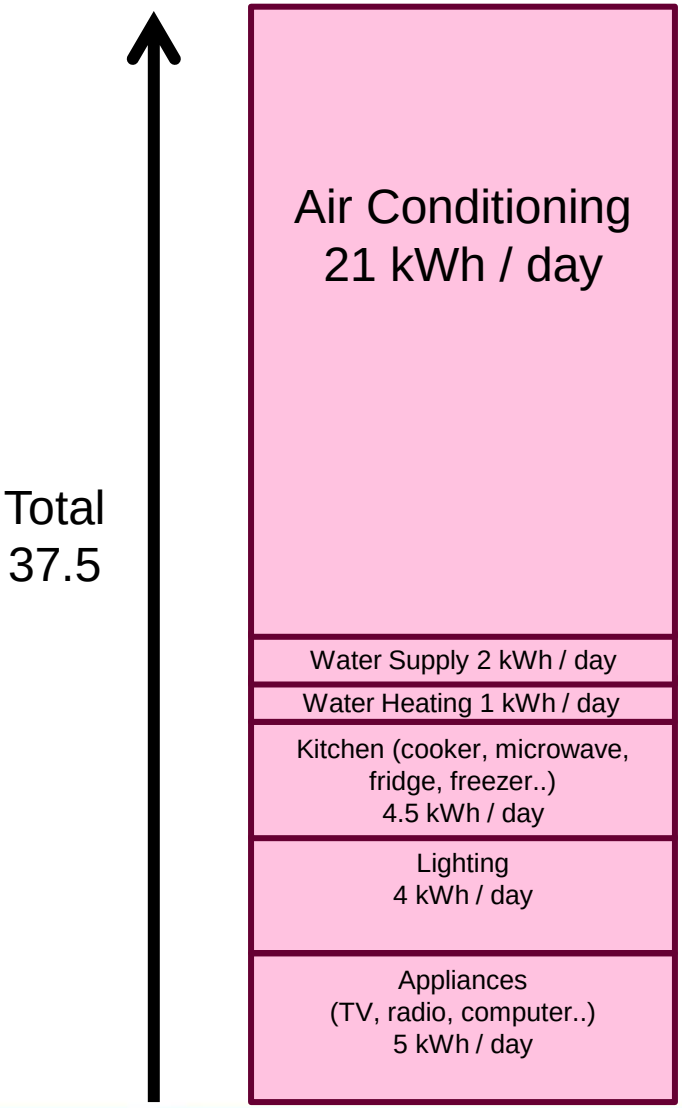


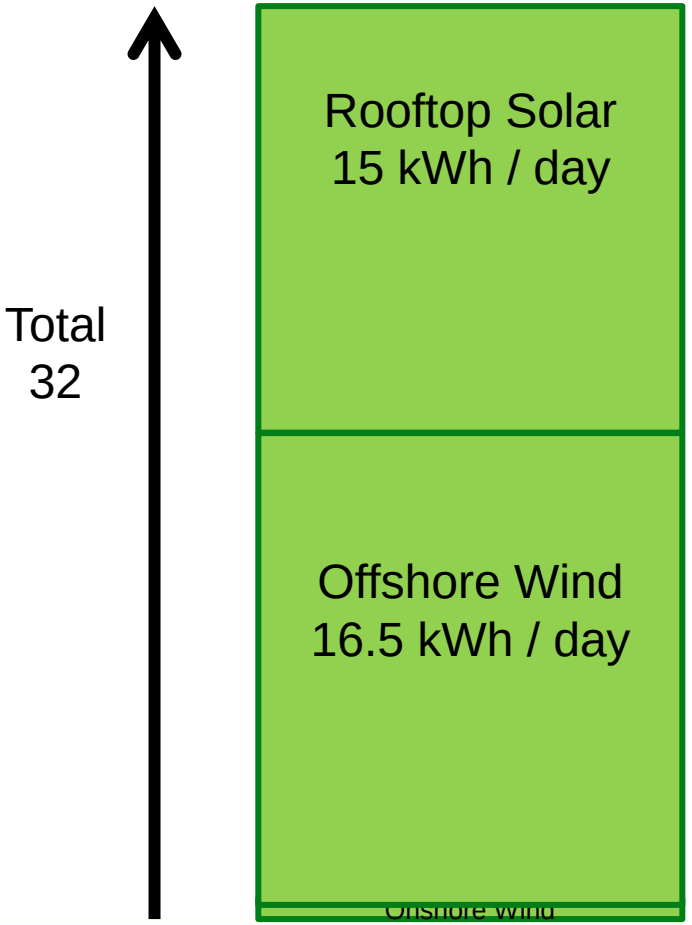
Rooftop Solar Power

- Urban land in 2030 will be 400 sq. km
- 30% of urban land suitable for photovoltaics
- 16 sq. metres per kWp capacity
- Yield of 1600 kWh / kWp
- Annually 12 TWh
- 15 kWh / day per person in 2030

Rooftop solar PV, pxhere.com

Add in Rooftop Solar Power



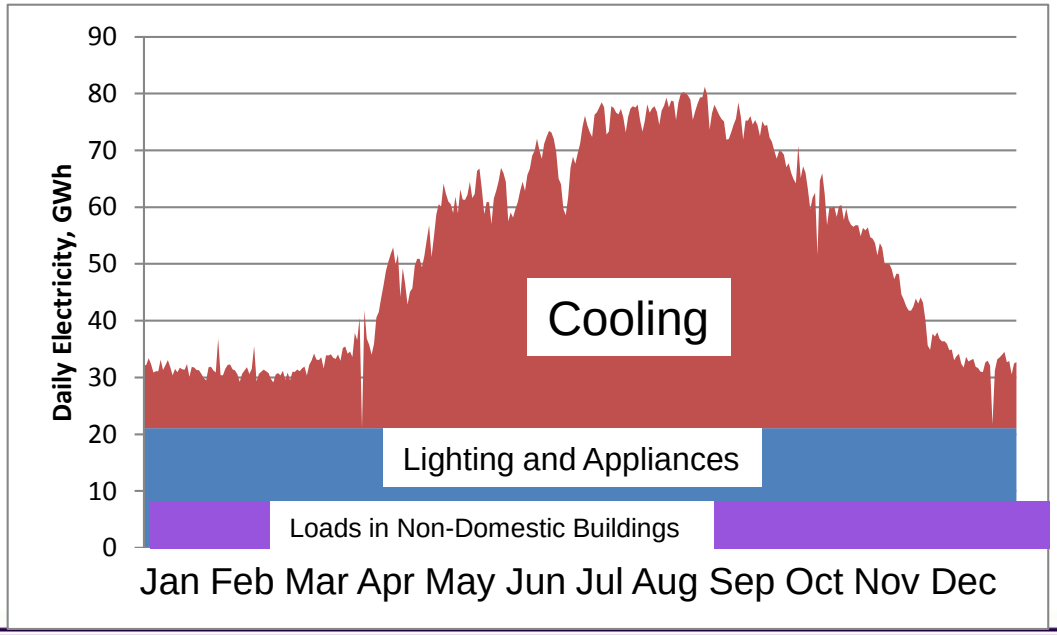


We have a small shortfall for domestic electricity, but what about…

- Cars?
- Non-domestic buildings?
- Industry?

Appliances Within Non-Domestic Buildings

- Grid electricity demand excluding cooling, lighting and domestic appliances
- 8 MWh / day in 2017
- 5 kWh / day per person



Cars

Pxhere Toyota SUV

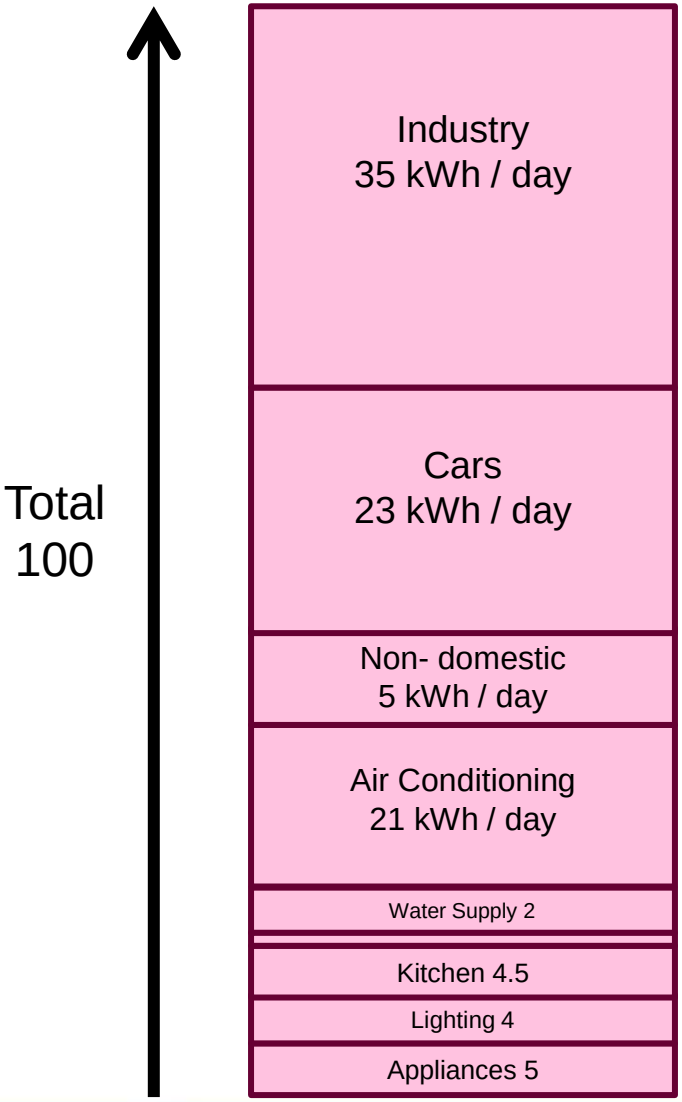
- 537 cars per 1000 people
- Assume this remains constant?
- Energy of fuel is 12.8 TWh / year
- Current total petrol and diesel use is 1.1 million tonnes per year
- Population of 2.1 million by 2030
- 1.1 million cars by 2030
- 23 kWh / day per person

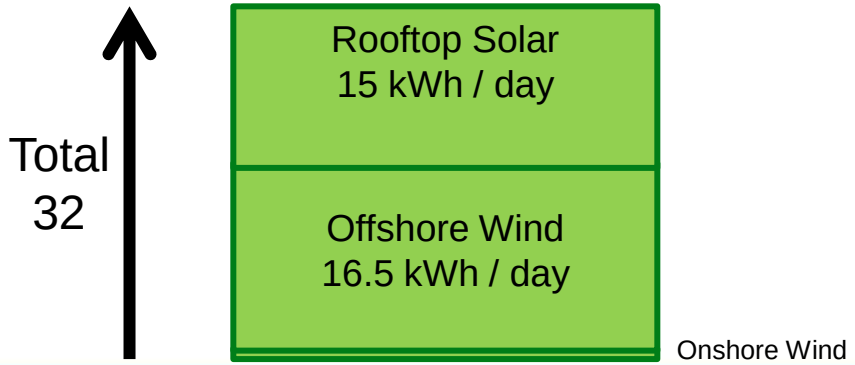
Industry

- Excluding…..
  - Grid electricity generation
  - Own-use by the oil and gas industry
  - Plastics and chemical uses of natural gas
- Bahrain industry generates 9.9 TWh / year of electricity for its own use
- And also uses 11.5 TWh / year of natural gas directly for heat ≈ 9 TWh / year of heat
- Total industrial energy ≈ 19TWh / year
- Or 35 kWh / day per person

(Zoom out a bit more…)

We have a bigger shortfall of supply





Ground-Mount Solar Power

- Non-Urban land in 2030 will be 365 sq. km
- Assume 50% suitable for solar power
- 16 sq. metres per kWp capacity
- Yield of 1600 kWh / kWp
- 18 TWh / year available
- 23.5 kWh / day per person
- PV or Solar Thermal?
- Concentrating solar power generates electricity continuously with molten salt storage but it is dusty!

Pxhere Saudi Arabia PV farm

Pxhere solar towers

Wave Power

- Wave fetch (distance) is similar to that of the North Sea coast of the UK
- Energy density of 5 kW / metre length
- Width of sea facing the Arabian Gulf 60 km
- Energy efficiency of conversion 25%
- Average power available 0.65 TWh / year
- 0.85 kWh / day per person in 2030

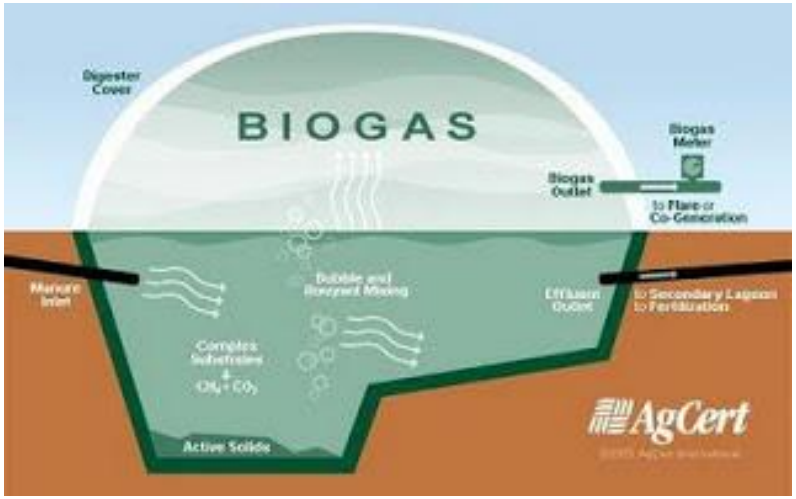
Worldatlas.com

Tidal Power?

- Tidal range is 1 metre or less
- Much less tidal power available than in the UK
- Tidal stream speed estimated < 0.1 m/s
- Probably only a very small tidal resource
- Ignore for our study

Biogas

- Biomass sources in Bahrain:
  - Sewage sludge
  - Fish waste
  - Sorted food waste
- Potential of 190 million m^3 of biogas per year
- 65% methane
- 11 kWh per m^3 of methane
- 1.4 TWh per year
- 1.8 kWh / day per person

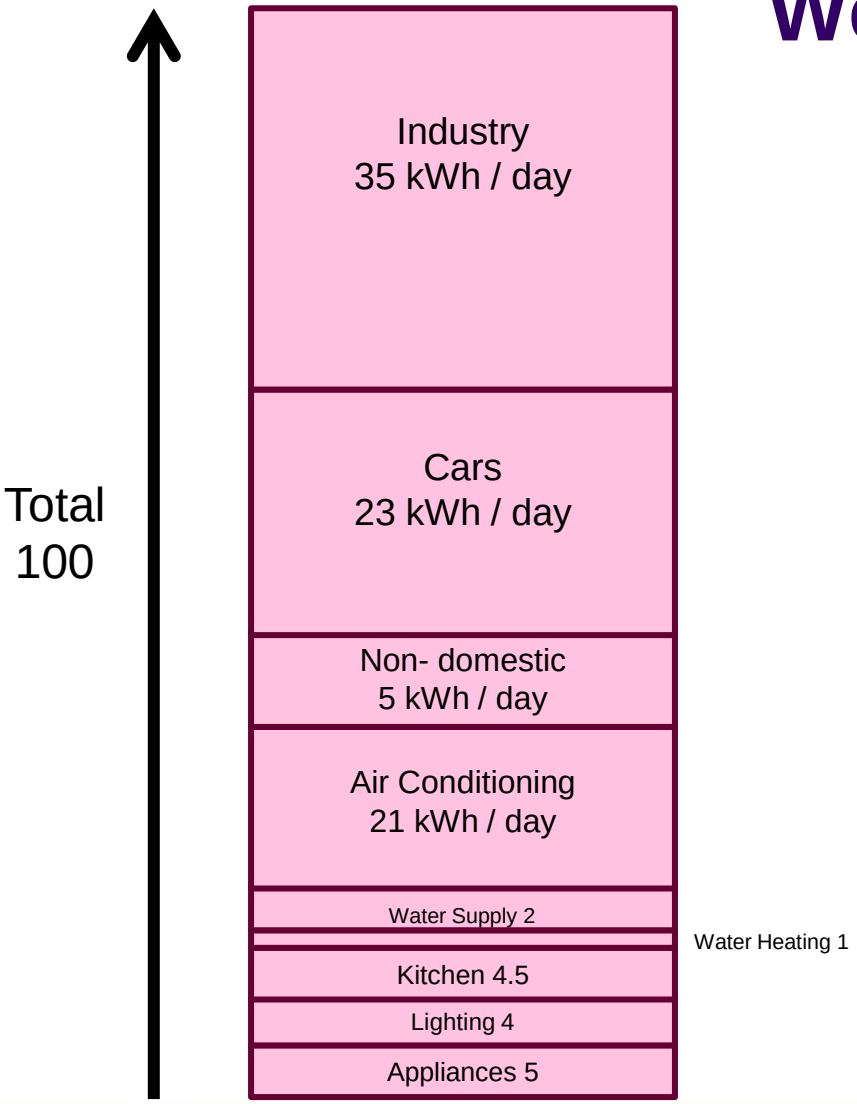


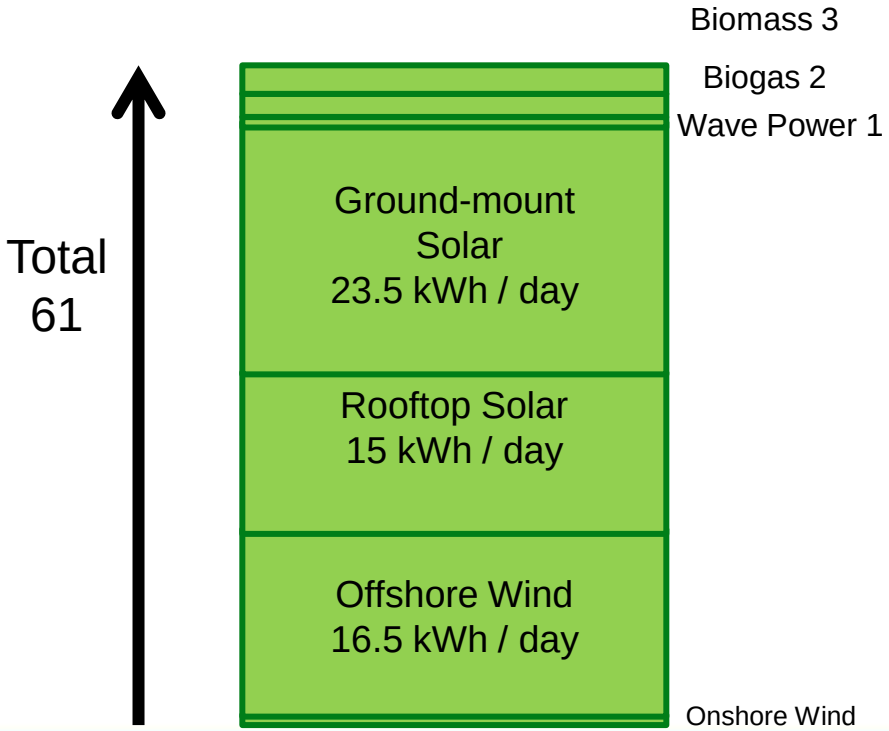
Can we do something with waste water?

- Obviously, clean it up and sterilise it first
- 700,000 cubic metres per day
- 365 sq. km of non-urban land in 2030
- Equal to 700 mm of rainfall per year
- Elephant grass (miscanthus)
- Yield of 13 dry tonnes per hectare (between the solar panels)
- 500,000 dry tonnes per year
- 2.2 TWh per year or 2.8 kWh / day in 2030
- Could grow much more biomass with more land

Miscanthus New Zealand Ltd

We still have a shortfall



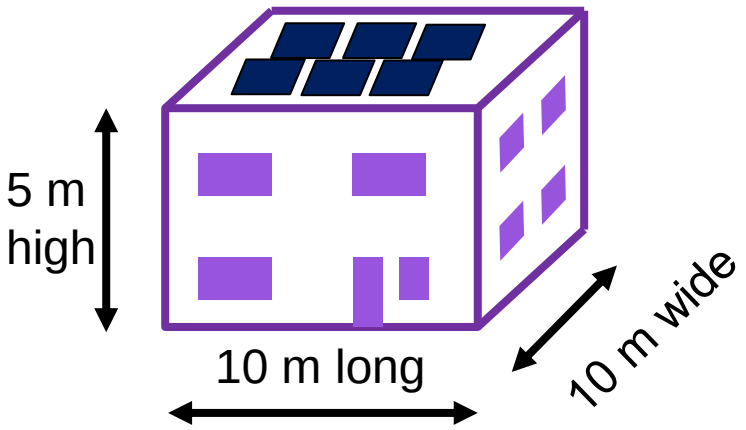


Can We Save Energy?

- A+ rated electronics: save 2 kWh / day
- Convert lighting to LED: save 2 kWh / day
- A+ rated kitchen appliances, especially the cooker, oven and freezer: save 2 kWh / day
- Water heating and water desalination: Already small users of energy.
- Similar savings in appliances in non-domestic buildings

Air Conditioning – idealised model of a house

- 0.5 air changes per hour
- 10 square metres of window
- Inside 20°C, outside 30°C
- Add 20 cm of insulation
- Double glaze windows



- Average 6 people per household (600W of heat)
- Appliances and electronics: 6 x 7.5 kWh / day = 1875W
- Heat leaking in through walls, roof and windows: 830W
- Ventilation heat gain 825 W
- Total 4.1 kW of heat or 16.6 kWh / day per person
- Cooling ratio of 3 so only 5.5 kWh / day of electricity
- But same again for non-domestic buildings, 11 kWh / day

Cars

- Currently petrol powered, 10 litres / 100km (Ref: CEDARE 2015)
- ≈ 100 kWh / 100 km

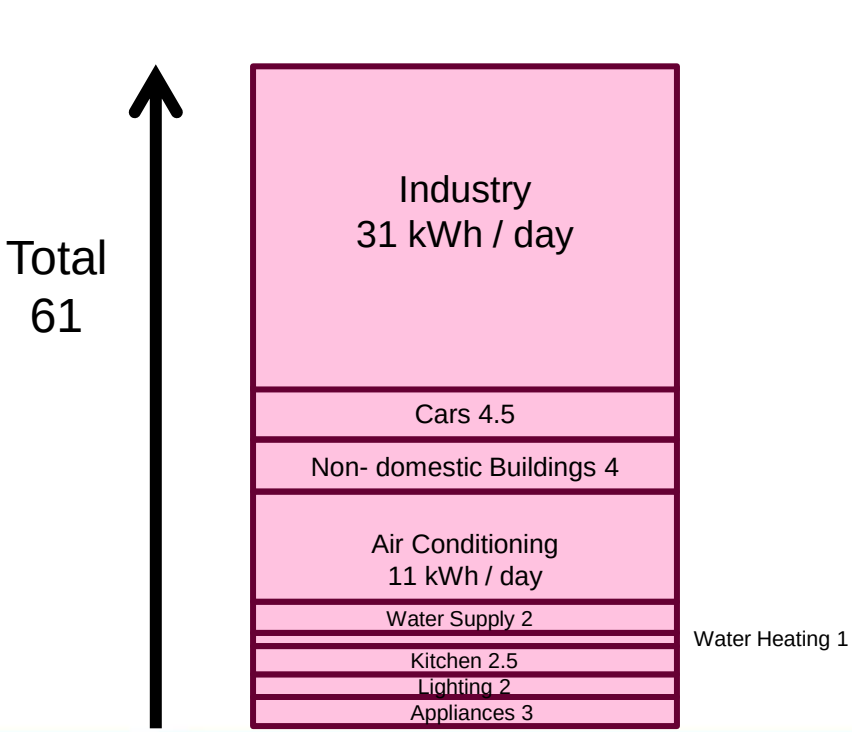
Pxhere Tesla battery electric car

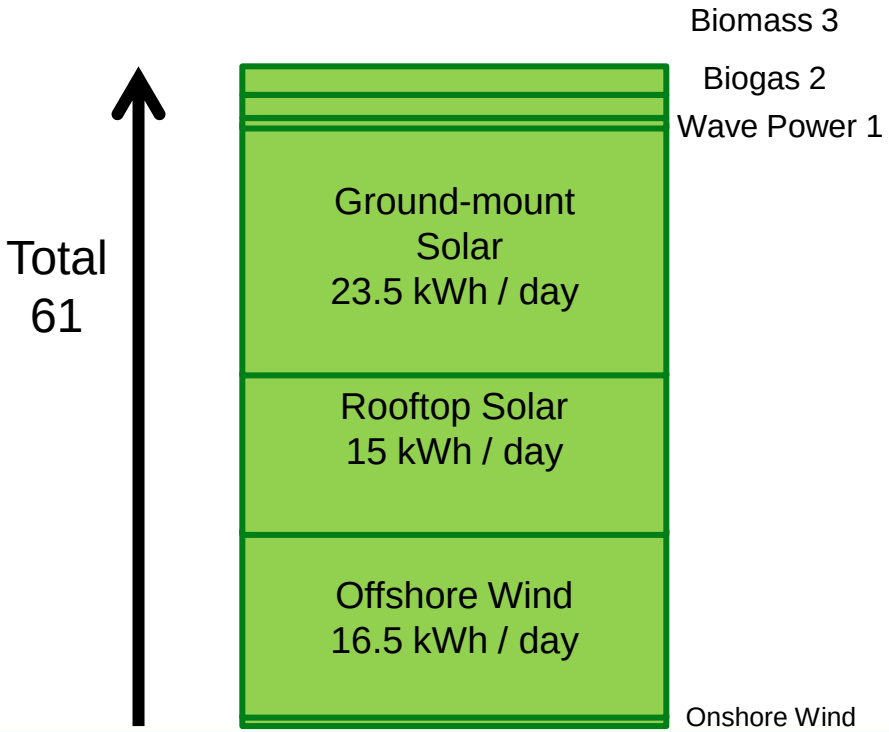
- Electric cars:
- Tesla or equivalent,
  3 miles / kWh or 20 kWh / 100 km
- Per capita energy used is reduced
  from 23 kWh / day to 4.5 kWh / day
- Range > 300 km, anywhere within Bahrain

Industry

- A bit of process efficiency improvement….
- Reduce energy use from 35 to 31 kWh / day per person

We have just achieved a balance!





Some issues I have not addressed

- Food production
- Imported goods
- Aviation
- CO_2 produced directly by aluminium smelting, $Al_2O_3 + 3/2\ C \rightarrow 2Al + 3/2\ CO_2$
- Perflurocarbon compounds (other greenhouse gases) made by aluminium smelting .
- The fossil fuel industry itself
- Time-dependent grid balancing
- Interconnections with other GCC countries

Conclusions

- There's a long way to go to achieve energy sustainability.
- Renewable energy resources are enough for Bahrain's own energy needs using today's technology, if used more efficiently
- Efficiency improvements in air conditioning and road transport would have huge benefits.
- Treated wastewater is a very large, valuable, unused resource.

Thank you

Dr John Barton

Acknowledgment

This work was conducted within ‘Technical Integration of Sustainable Energy and Water (TISEW)’, supported by the UK-Gulf Institutional Links Programme, which is part of the UK Government’s strategic commitment to strengthening partnerships with the Gulf countries and is coordinated by the British Council (Application ID 279332548).

CREST
Centre for Renewable Energy Systems Technology

Loughborough University