The Mismatched Landscape:
Spatial approach to Renewable Energy Planning
A case study in Victoria, Australia

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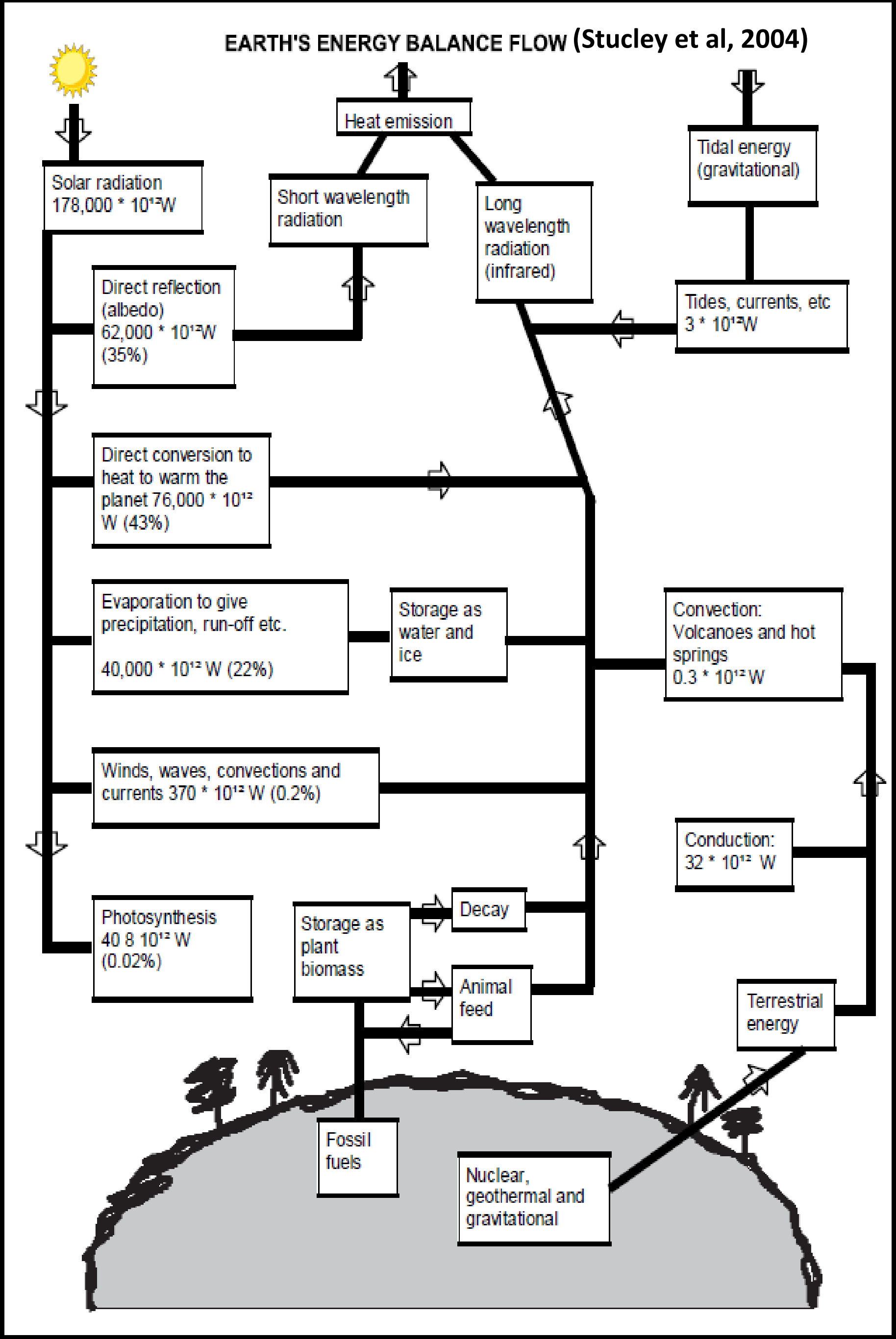
- How the energy landscape is mismatched?
- How spatial planning can help to achieve sustainable energy planning outcomes?

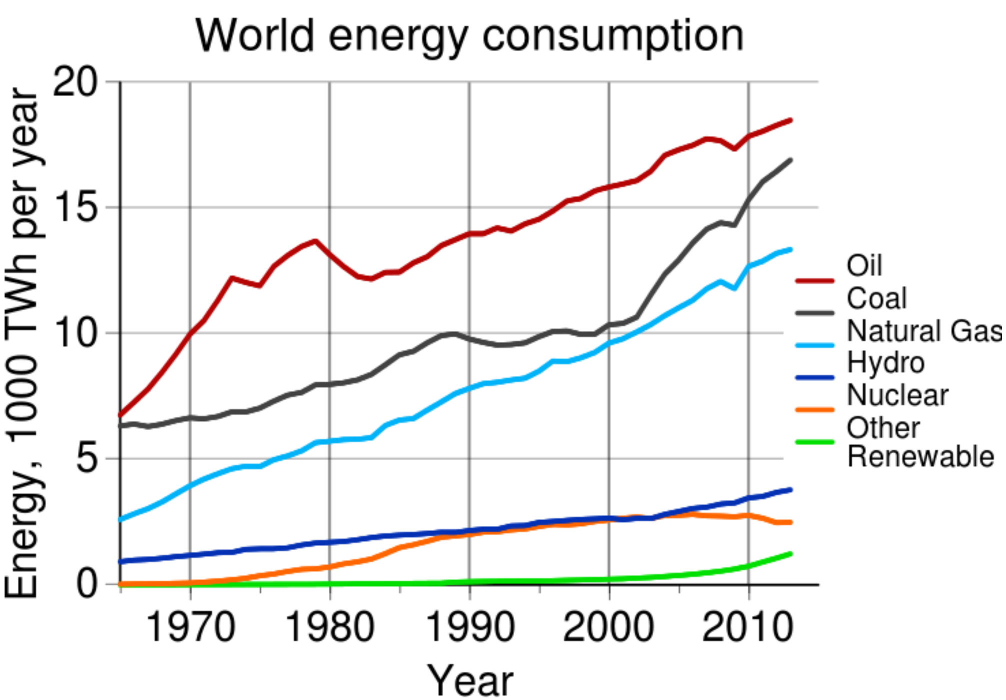


Renewable Energy Sources Are Set to Expand Rapidly

Renewable energy receives strong policy support, and is becoming more competitive.

- **Affordability**
  - The costs of solar PV and wind continue to fall as renewable technologies mature
  - Oil prices climbed above $80/barrel in 2018 for the first time in four years
- **Reliability**
  - Risks to oil and gas supply remain: shipping and distribution
  - So are the instabilities in renewable energy supply (better planning practice)
- **Sustainability**
  - GHG emissions rose by 1.6% in 2017
  - Emissions may continue to grow, far from a trajectory consistent with climate goals.
  - Energy-related air pollution continues to result in millions of premature deaths each year.

Background: Current Energy Mix

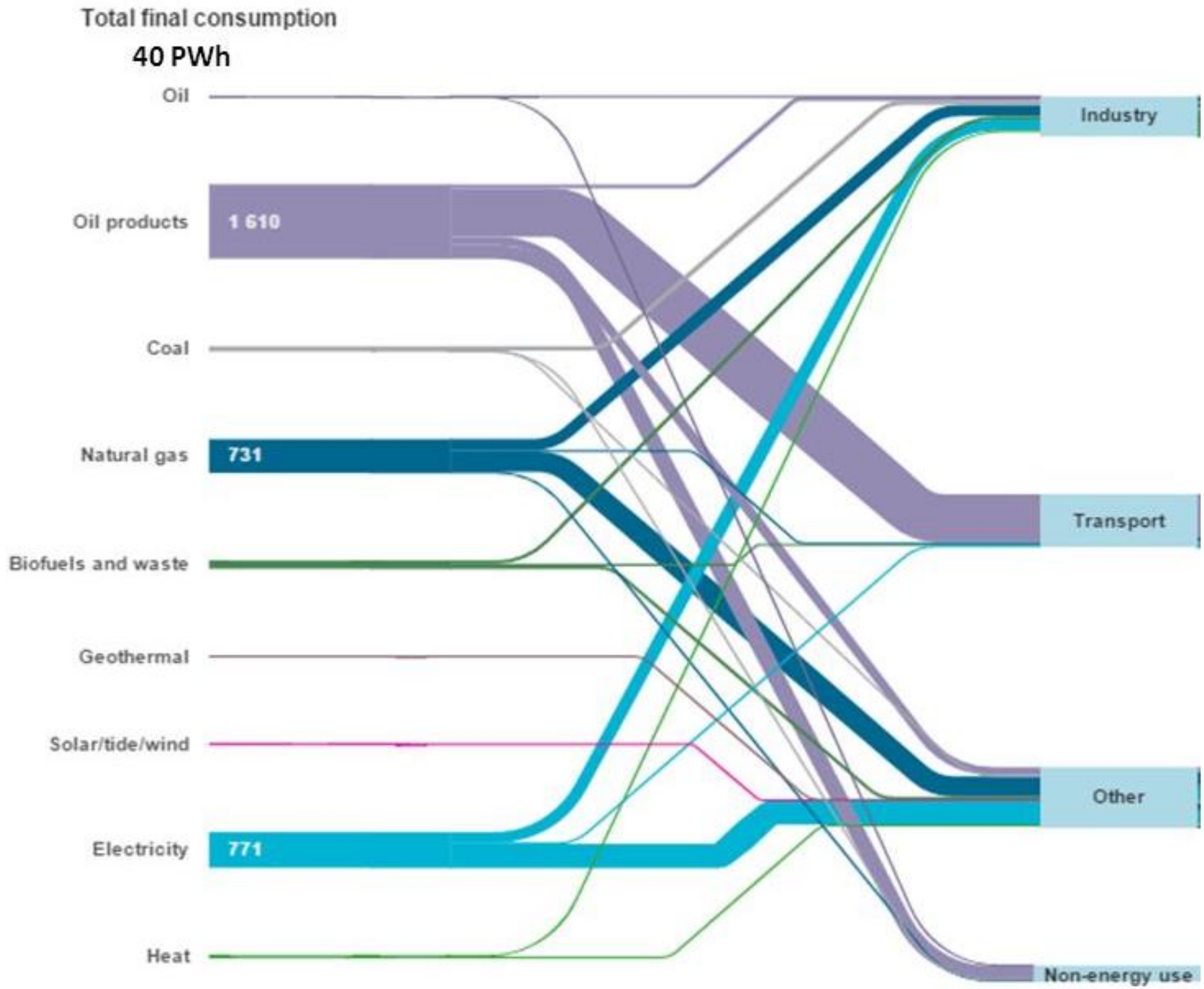


Renewable breakdown

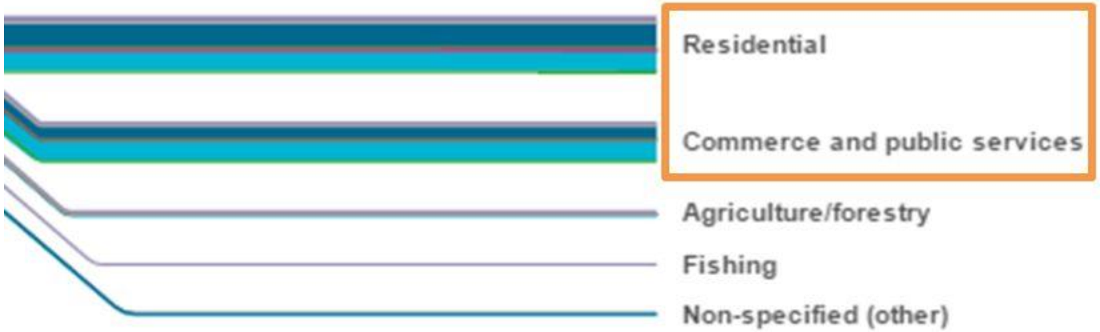
Solar hotwater	0.17%
Geothermal heat	0.12%
Hydropower	3.34%
Ethanol	0.50%
Biodiesel	0.17%
Biomass electricity	0.28%
Wind power	0.51%
Geothermal electricity	0.07%
Solar PV power	0.06%
Solar CSP	0.002%
Ocean power	0.001%

Source: BP, Statistical Review of World Energy 2015

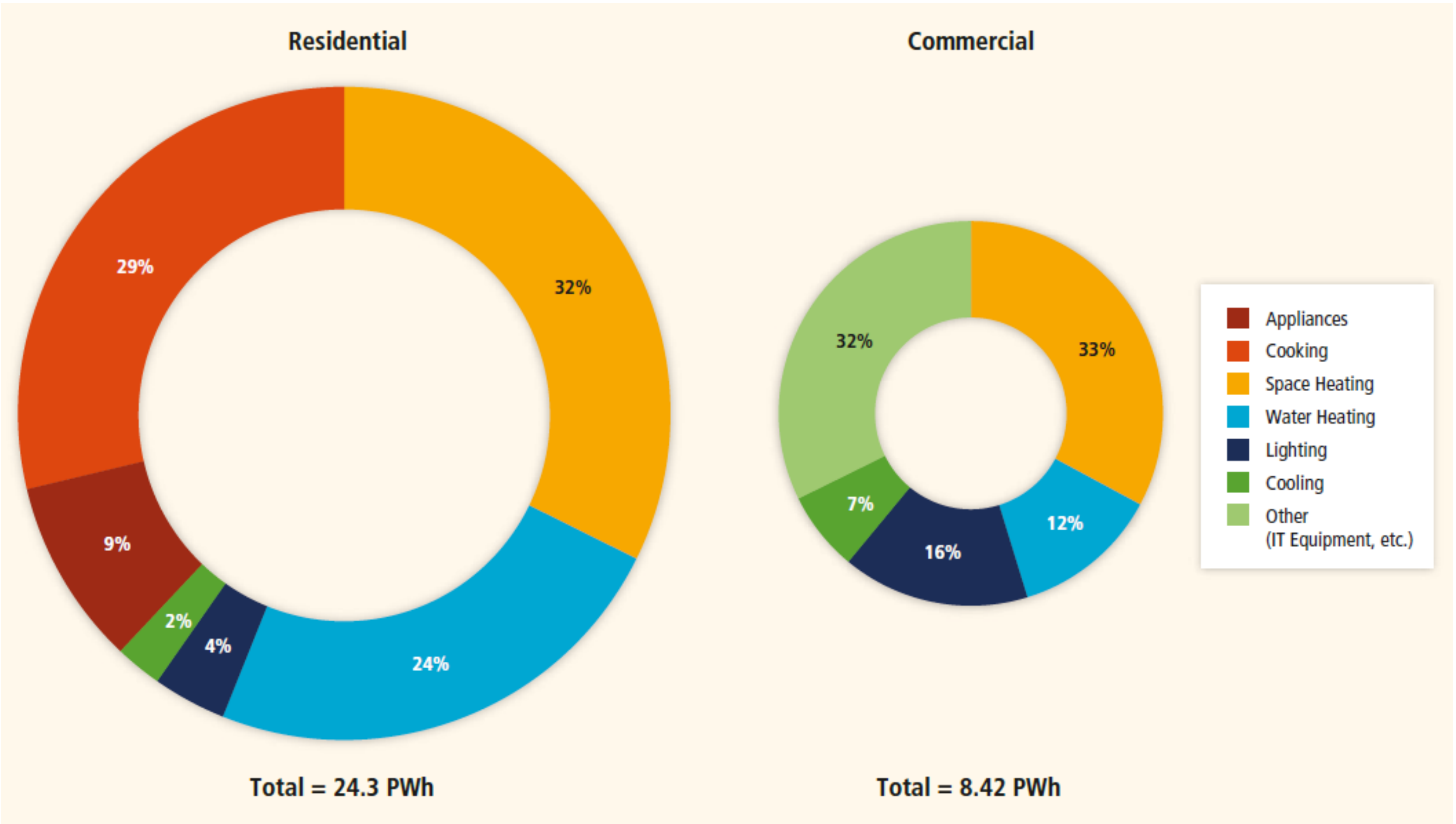
Global energy end-use



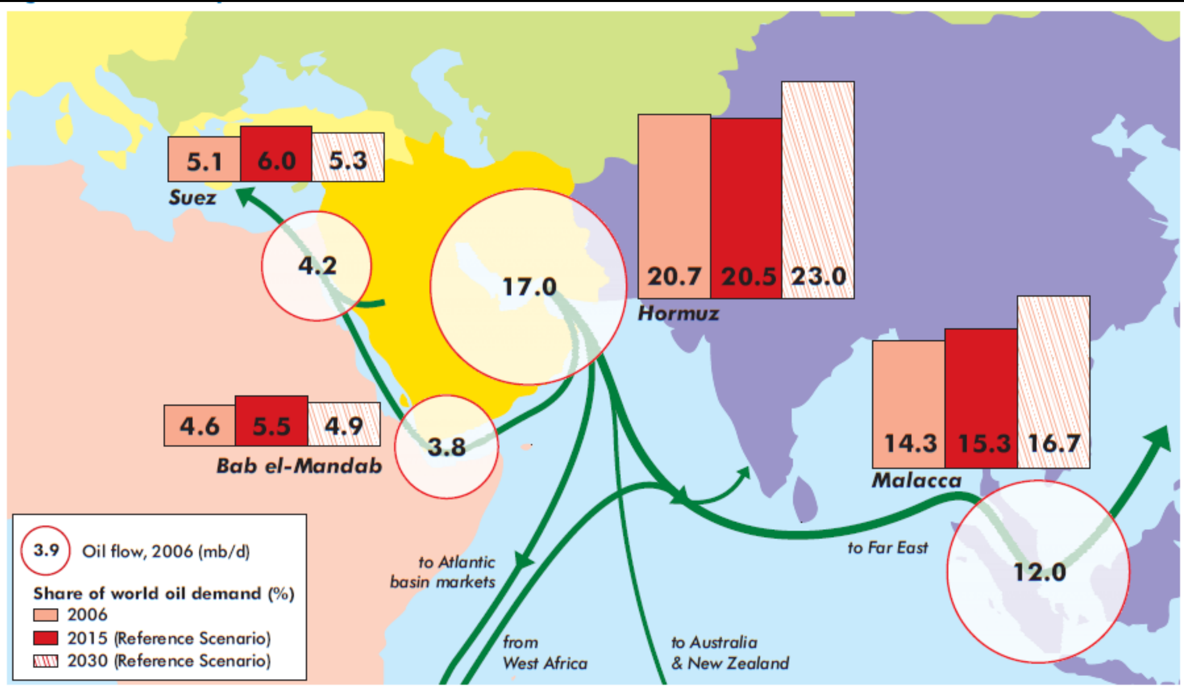
IEA 2013

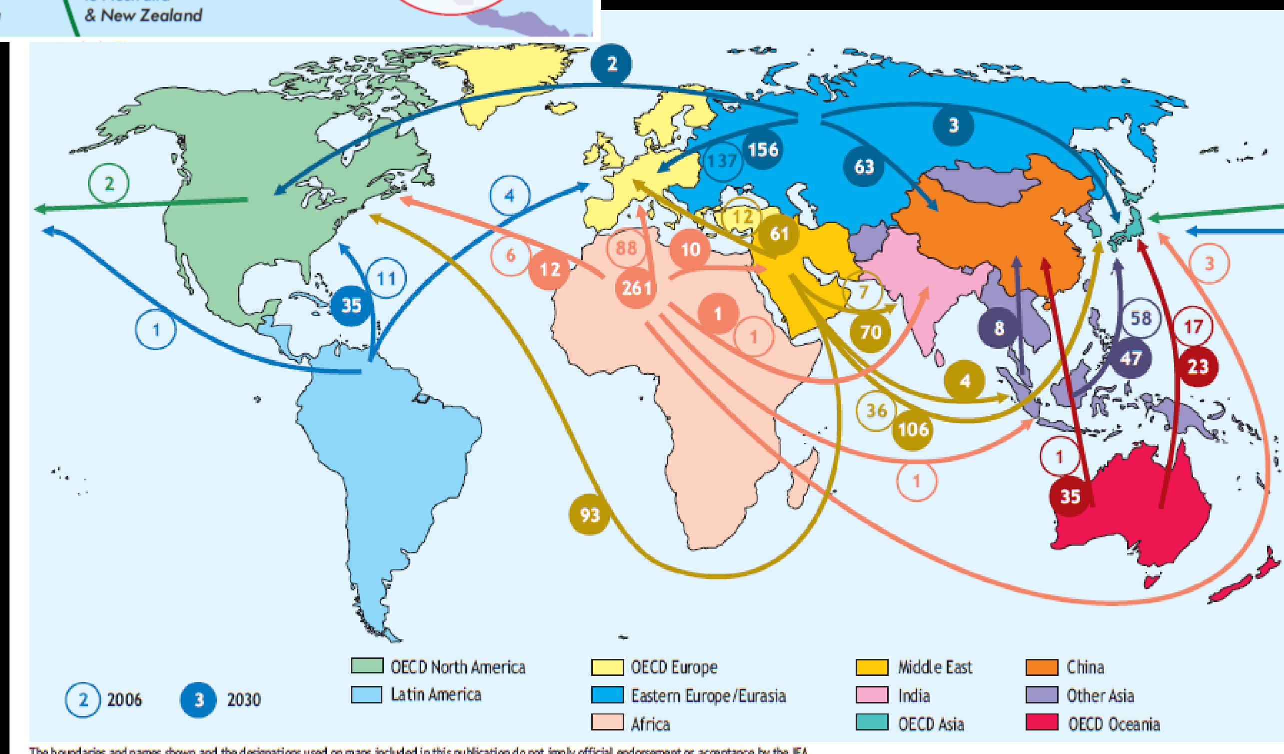

Residential
Commerce and public services
Agriculture/forestry
Fishing
Non-specified (other)

IEA 2013


Residential
Commercial
29%
32%
9%
2%
4%
24%
32%
33%
7%
16%
12%
Appliances
Cooking
Space Heating
Water Heating
Lighting
Cooling
Other
(IT Equipment, etc.)
Total = 24.3 PWh
Total = 8.42 PWh

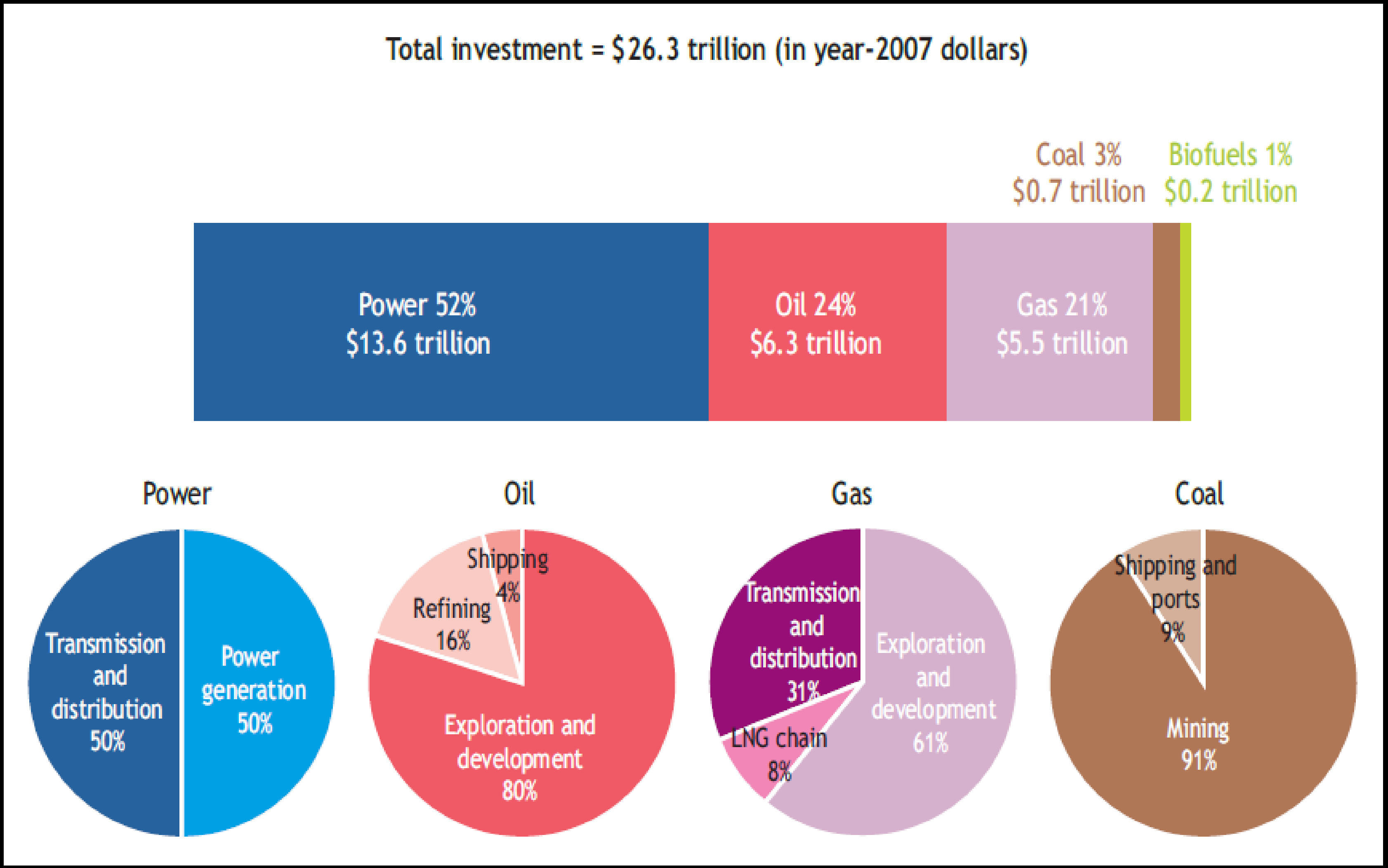
Oil export flows from the Middle East (IEA, 2008)





Main net inter-regional natural gas trade flows 2006 and 2030 (billion m^3 per year) (IEA, 2008)

Cumulative investment in energy-supply infrastructure 2007-2030 (IEA, 2008)



Smart Cities and Smart Regions?

What can we do as a landscape designer or planner?

$$E = mc^2$$

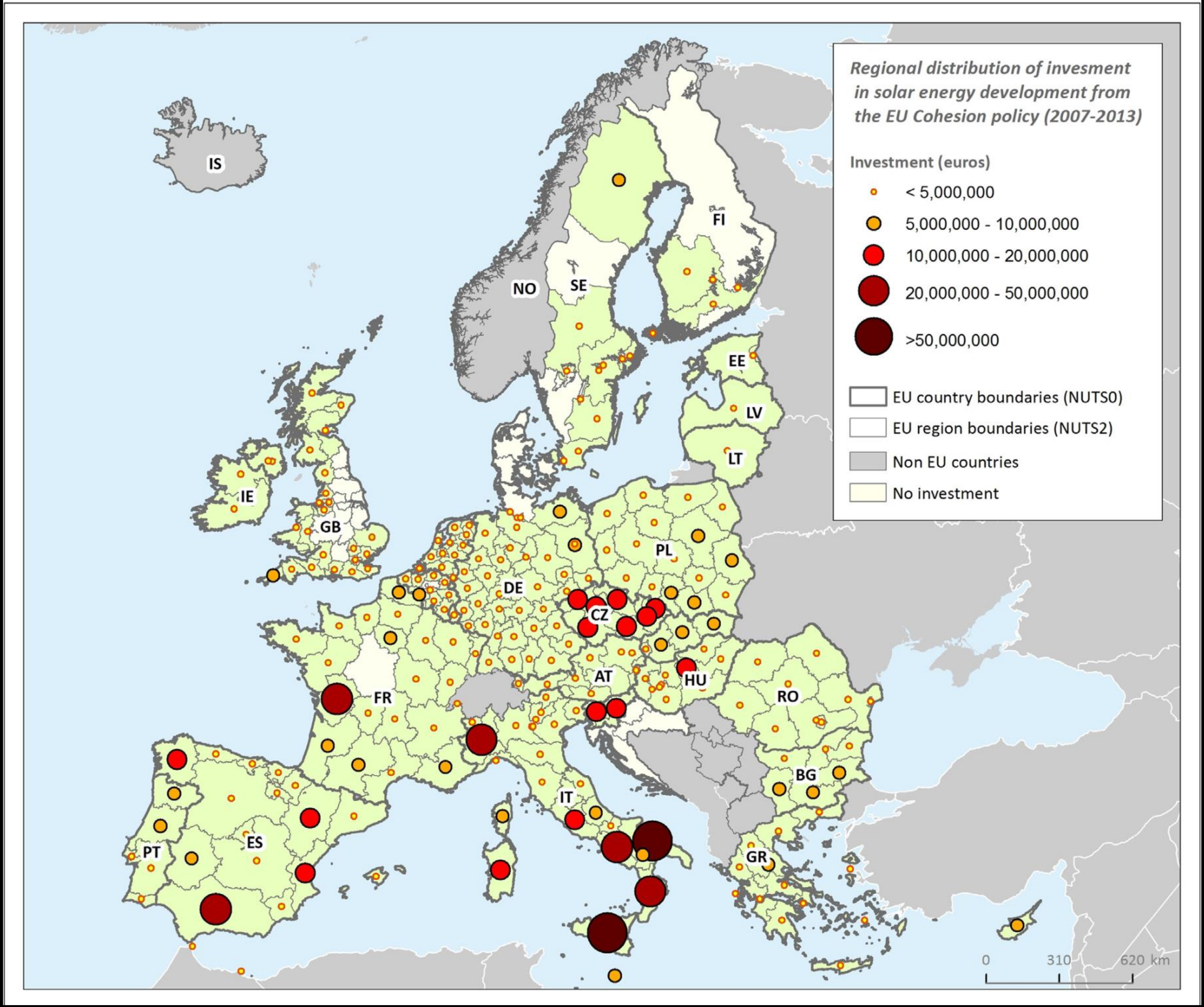
$E = f$ (Landscape: hydro, wind, solar, biomass, etc.)

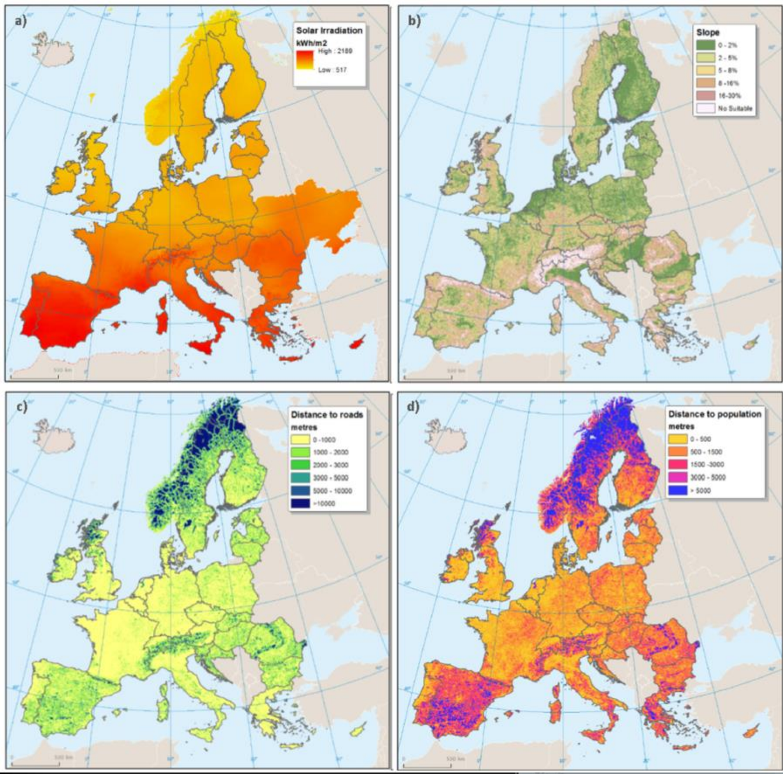
Energy and Landscape

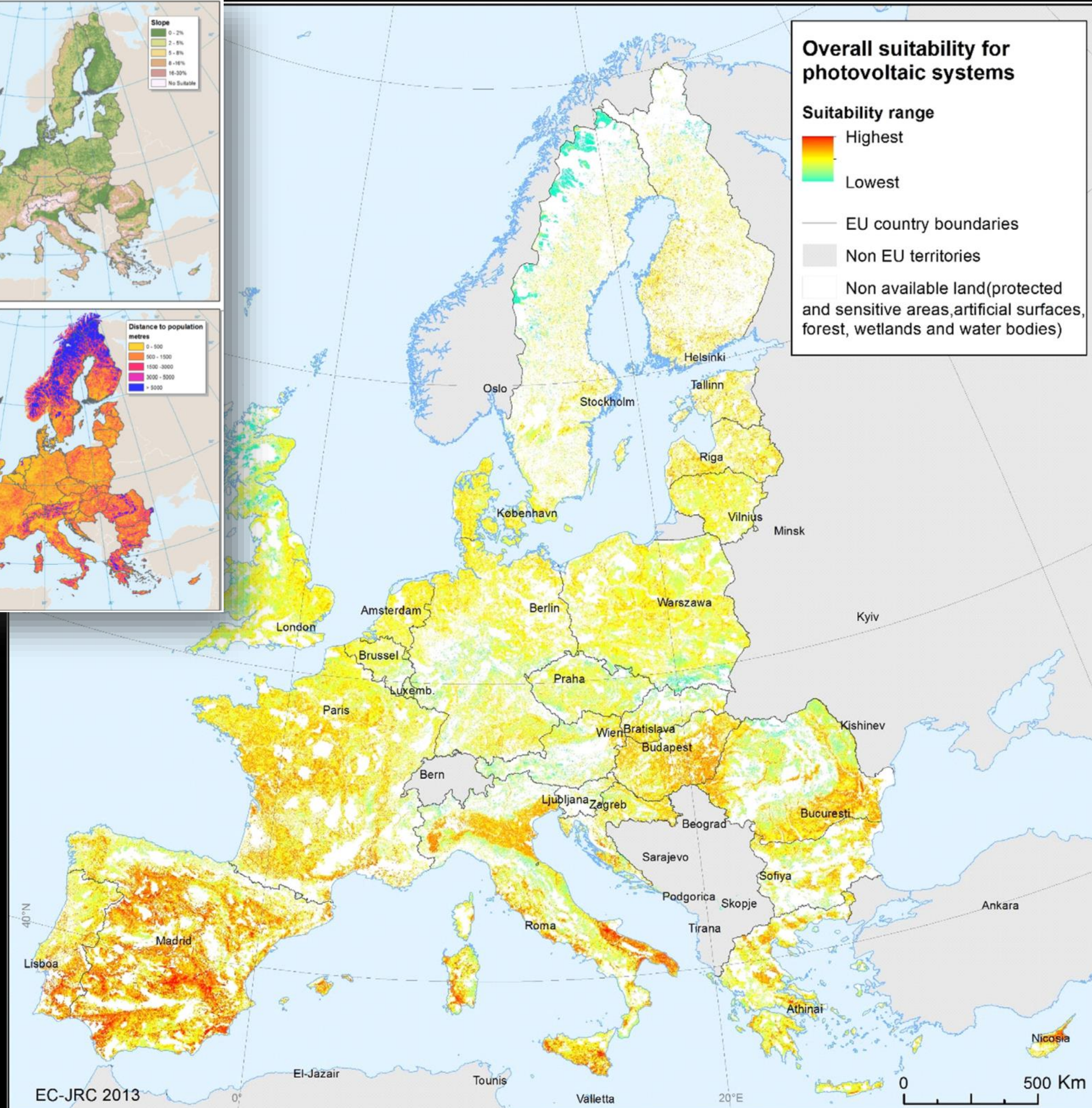
- Energy and landscape should be seen in relation to each other (Sijmons, 2014)

- Decision-making regarding energy infrastructure design for energy supply and distribution should be informed by the regional energy landscape.

Investment on solar energy development, EU-28 (Castillo et al, 2016)



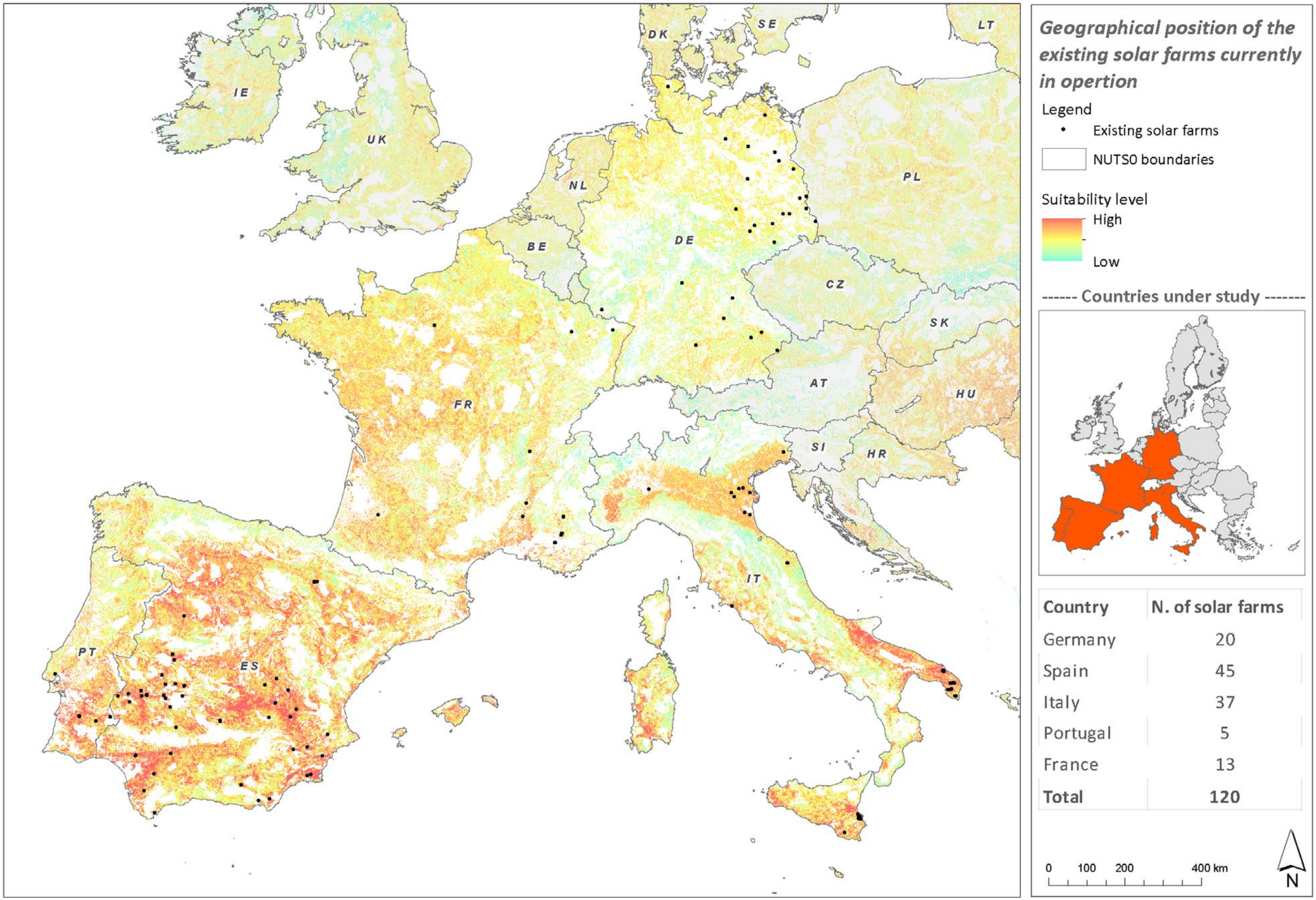




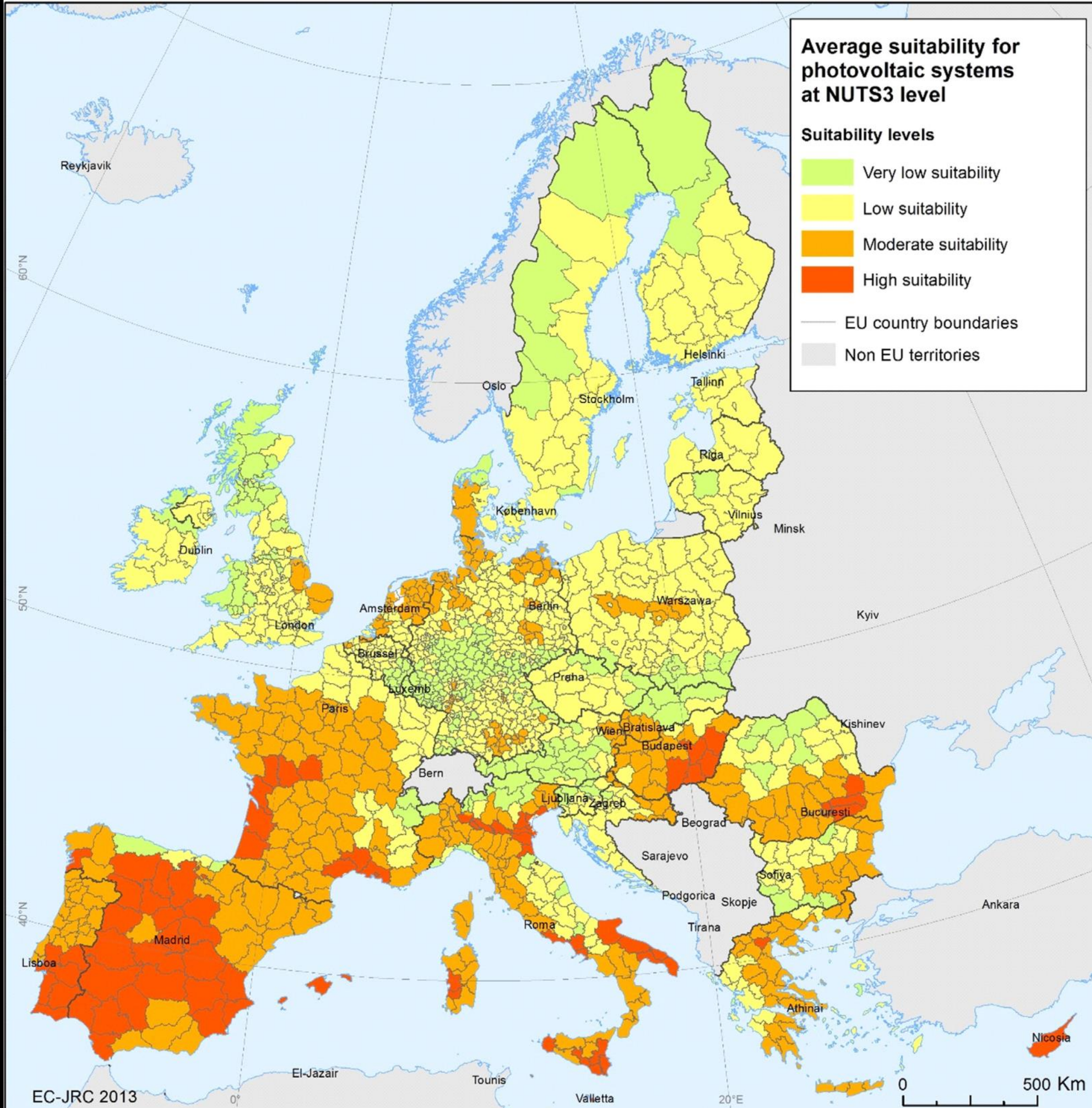
Some suitability factors for the development of PV energy systems at European scale (Castillo et all, 2016).

(a) solar radiation in (kW h/m^{2}).
(b) Slope in percentages
(c) Population potentially affected
(d) Proximity to roads and
(e) Proximity to the electricity grid.

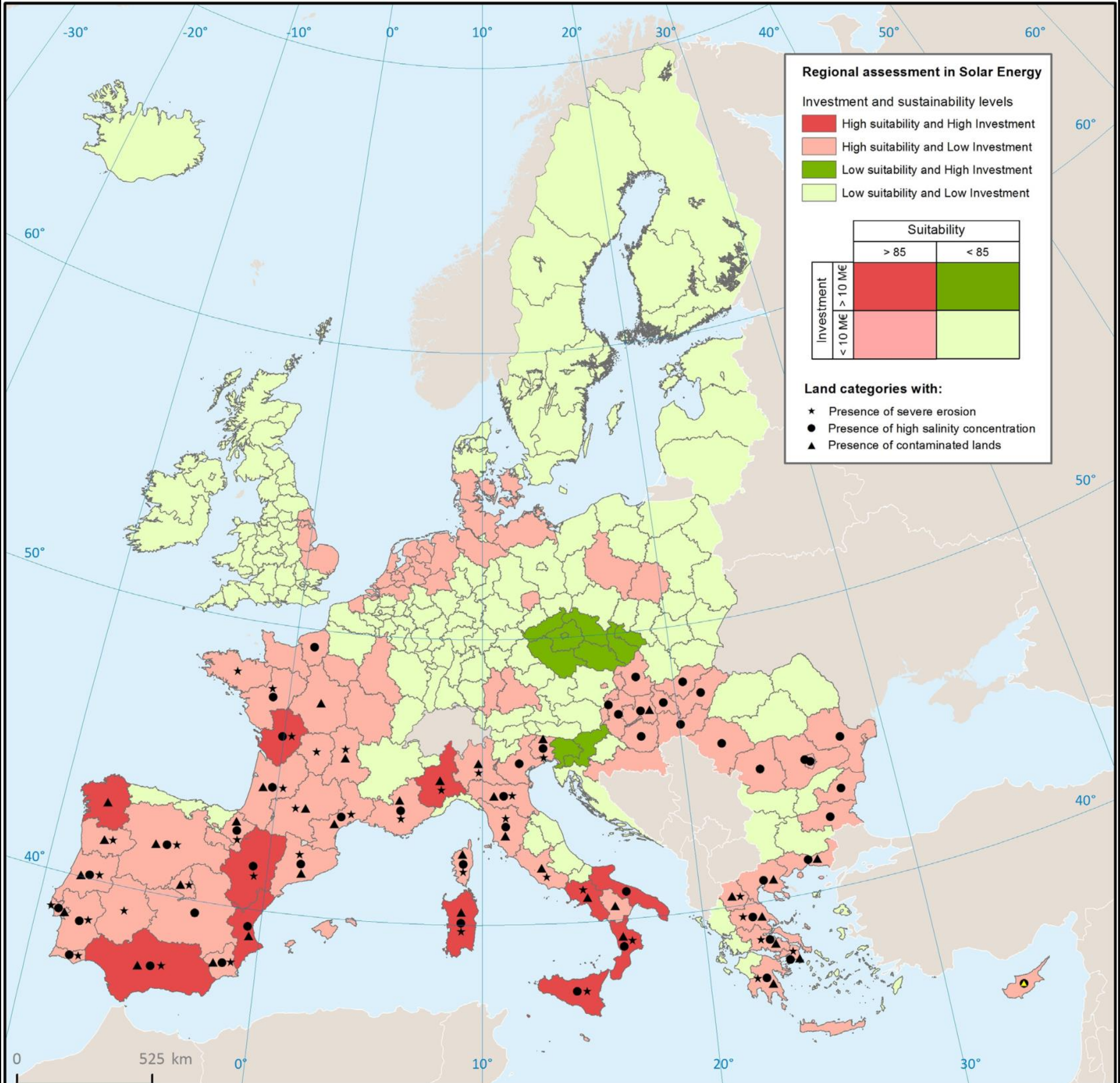
Geographical location of the existing solar farms currently in operation (Castillo et al, 2016)



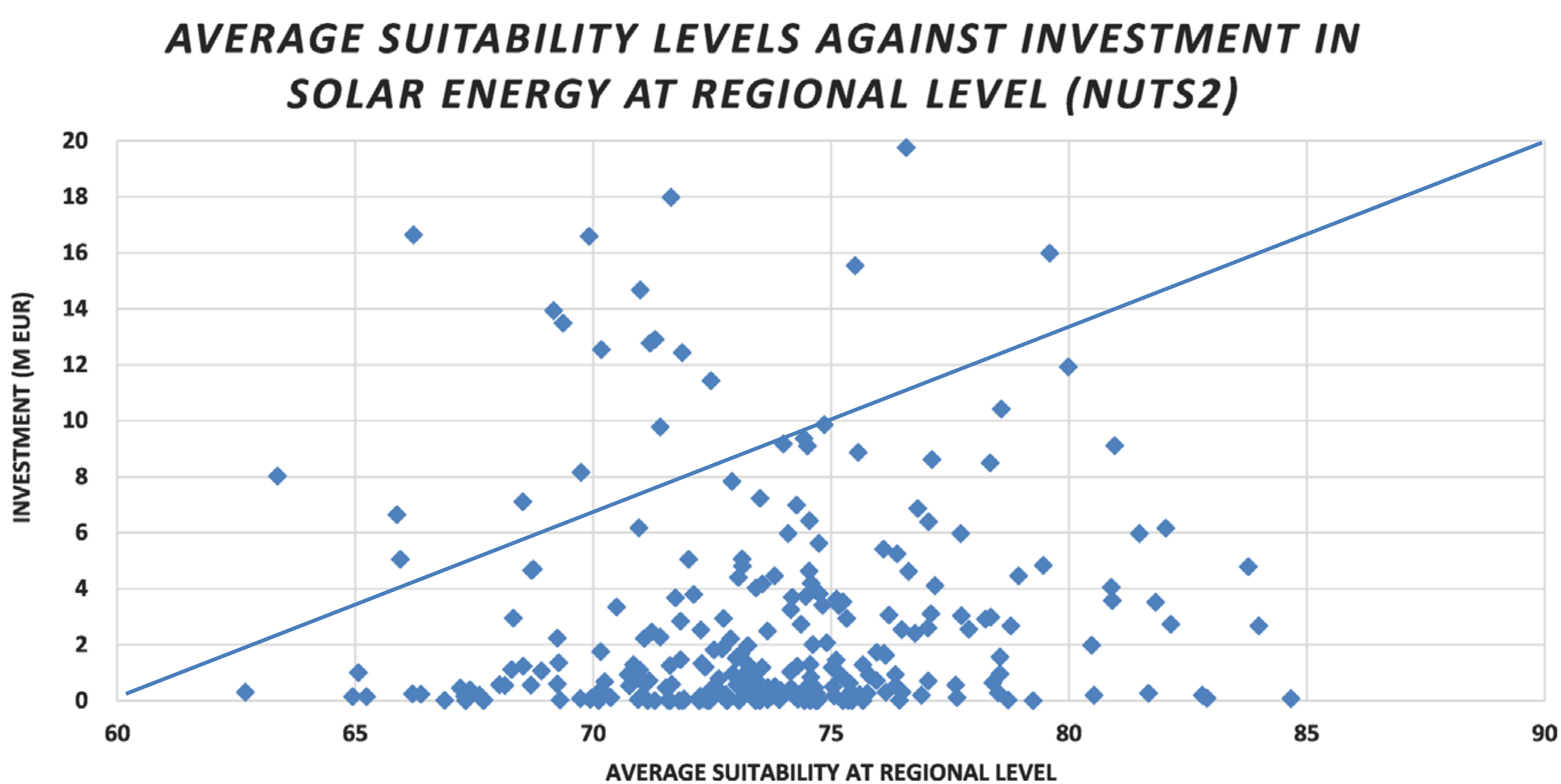
Country	N. of solar farms
Germany	20
Spain	45
Italy	37
Portugal	5
France	13
Total	**120**



Average suitability for photovoltaic systems at NUTS3 level
Suitability levels
Very low suitability
Low suitability
Moderate suitability
High suitability
EU country boundaries
Non EU territories
Reykjavik
Helsinki
Oslo
Tallinn
Stockholm
Riga
København
Vilnius
Minsk
Dublin
Amsterdam
Berlin
Warszawa
London
Kyiv
Brussel
Praha
Luxemb
Paris
Kishinev
Wien
Bratislava
Budapest
Bern
Ljubljana
Zagreb
Bucuresti
Beograd
Sarajevo
Sofiya
Podgorica
Skopje
Ankara
Roma
Tirana
Madrid
Lisboa
Athinai
Nicosia
El-Jazair
Tounis
Valletta
60°N
50°N
40°N
0°
20°E
0
500 Km
EC-JRC 2013



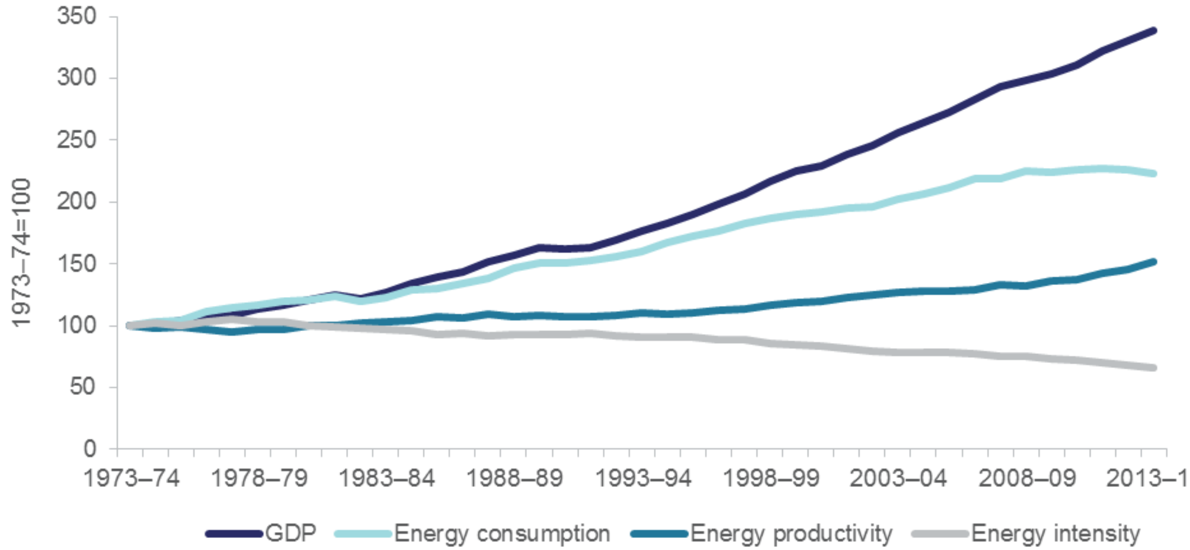
Regional assessment in Solar Energy
Investment and sustainability levels
High suitability and High Investment
High suitability and Low Investment
Low suitability and High Investment
Low suitability and Low Investment
Suitability
> 85
< 85
Investment
> 10 M€
< 10 M€
Land categories with:
Presence of severe erosion
Presence of high salinity concentration
Presence of contaminated lands
0
525 km


AVERAGE SUITABILITY LEVELS AGAINST INVESTMENT IN SOLAR ENERGY AT REGIONAL LEVEL (NUTS2)
INVESTMENT (M EUR)
0
2
4
6
8
10
12
14
16
18
20
60
65
70
75
80
85
90
AVERAGE SUITABILITY AT REGIONAL LEVEL

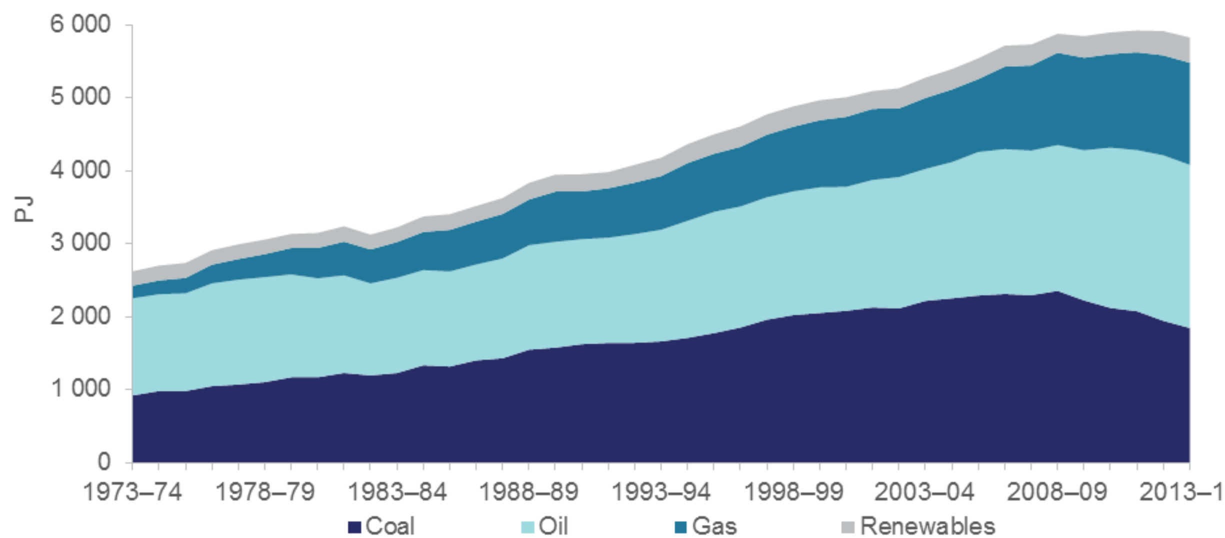
Australia

- Unsustainable nature of current patterns of energy supply
  - Oil 38%; coal 32%; 24% natural gas; 6% renewable (DOIS, 2015)
- Total final energy consumption keeps increasing in Australia (1%: 2013-2014)
- **Australia** is the largest emitter per capita (30t CO_2-e in 2005)
- 10 August 2015, Australian Government has agreed a new target of 26-28 per cent below 2005 levels by 2030 (14.7-15.1 t CO_2-e)
- CSIRO predicts that by **2050** around **30%** of Australia's energy supply will come from **solar power** (CSIRO, 2010)
  - Australia has the highest average solar radiation per sqm of any continent in the world (Zahedi, 2010)
  - Annual solar radiation falling on Australia is 10,000 times Australia's annual energy consumption (DOAFF, 2011)
  - Australia has been internationally criticized for producing very little of its energy from solar power, despite its vast resources and overall high potential (Byrnes et al, 2013)
  - Wind resource is abundant in Australia (Yusaf et al, 2011)

Australian energy intensity and energy productivity (DIS, 2015)



Australian energy consumption, by fuel type (DIS, 2015)

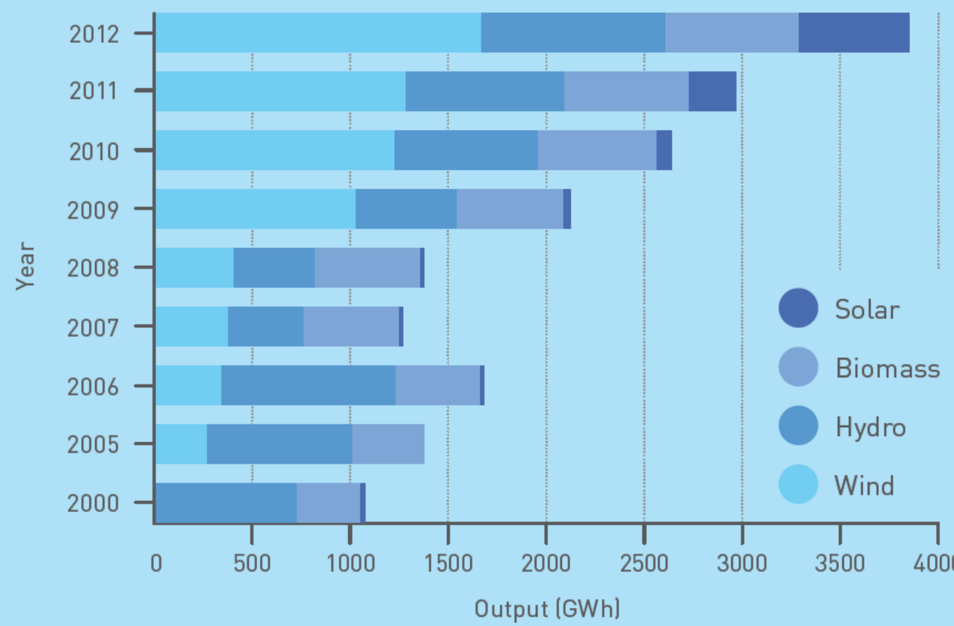


Victoria, Australia

Victorian renewable energy generation output by calendar year

Output (GWh)

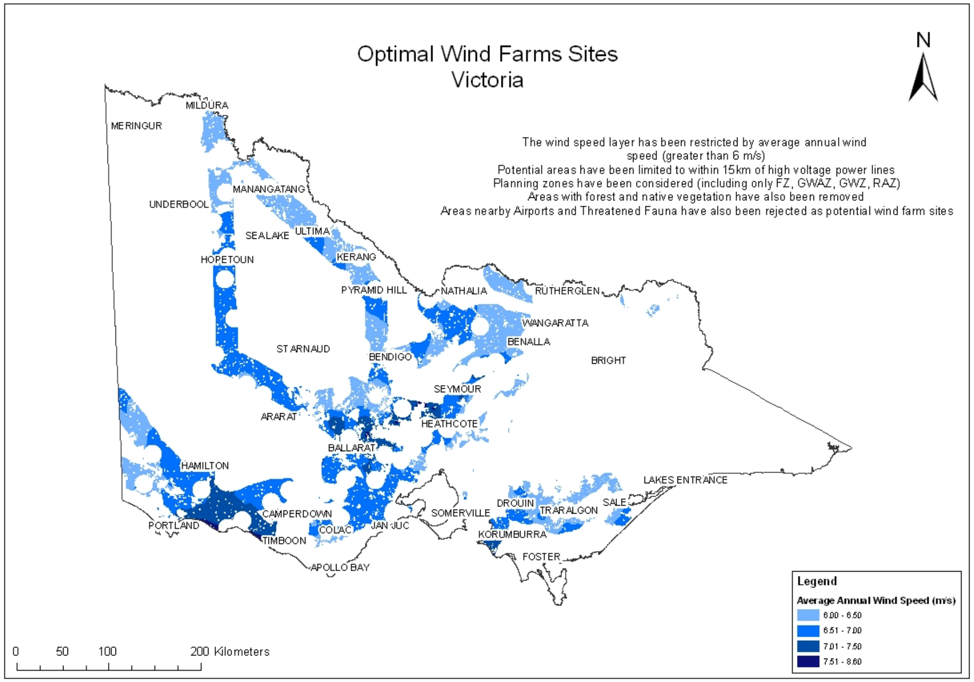
Fuel type	2009	2010	2011	2012
Bioenergy	554	605	633	651
Hydro	506	748	813	950
Solar	18	61	225	550
Wind	1028	1217	1280	1674
Total	**2106**	**2632**	**2951**	**3825**



In 2012, renewable energy generation produced from Victoria met around **7.7%** of the state's total electricity demand (CEC, 2012)

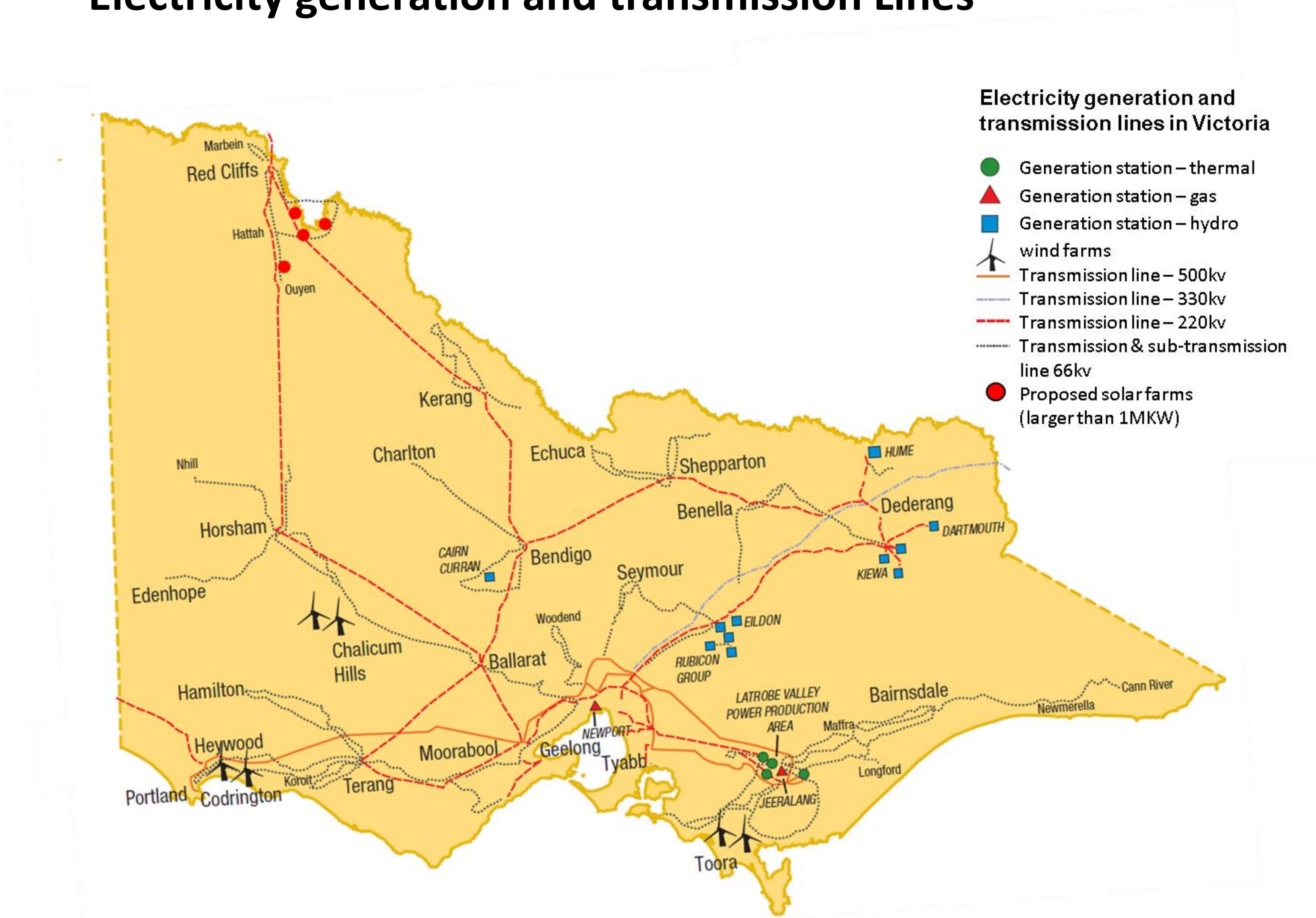
Wind Farm Suitability

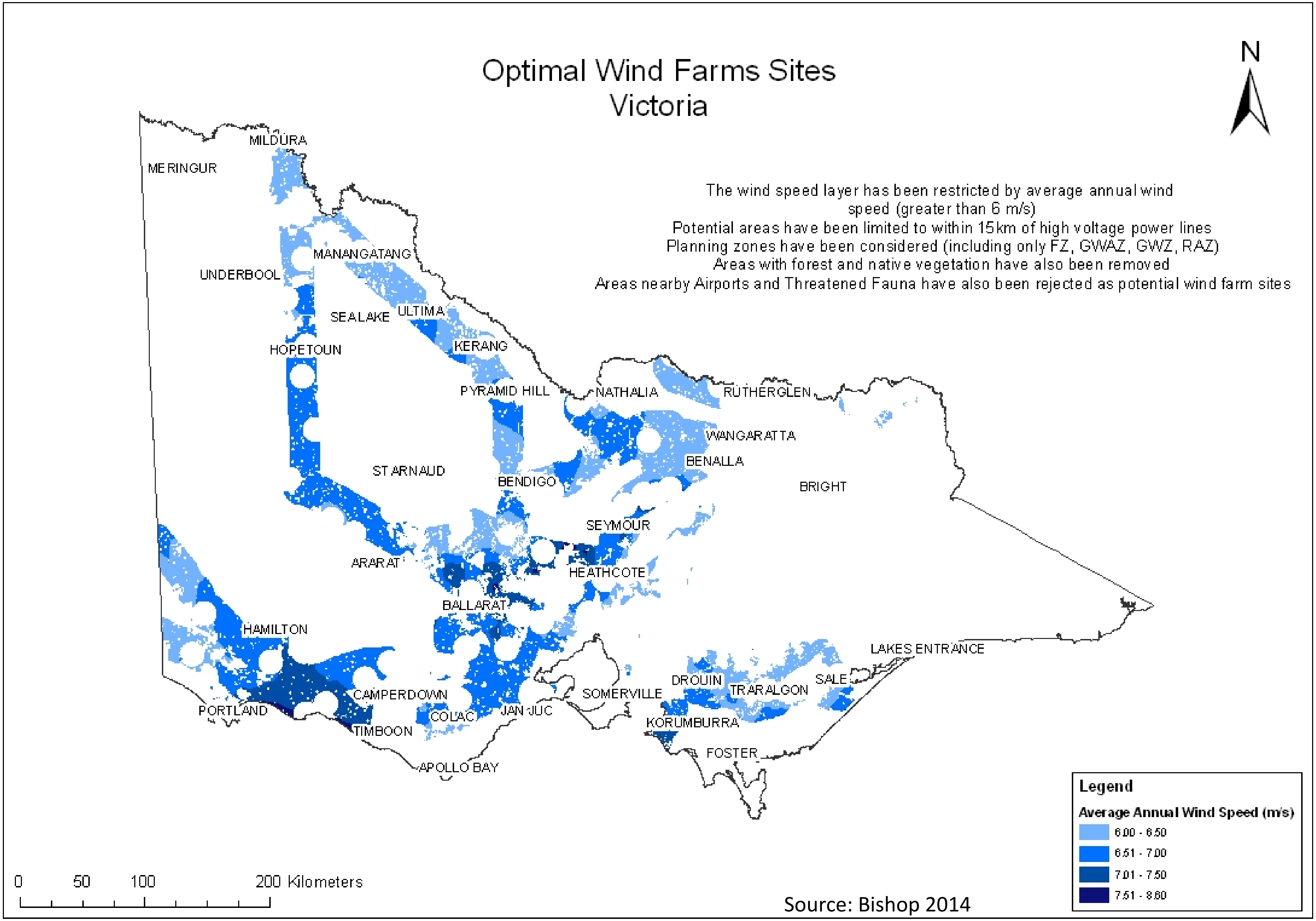
- **Sufficient Energy Resources:** Only areas with an average annual wind speed greater or equal to 6m/s are considered suitable for wind farms.
- **Planning Zone Considerations:** The potential site locations were limited to the following planning zones: Farming Zone (FZ), Green Wedge Zone (GWZ), Rural Conservation Zone (RCZ), Rural Activity Zone (RAZ), Mixed Use Zone (MUZ) and Industrial Zones (IN*)
- **Land Use – Protection of Flora:** It was necessary to ensure that the proposed sites were not located in areas of dense vegetation.
- **Distance from Townships:** A one-kilometre buffer was placed around towns to minimise aesthetic disturbance to communities.
- **Threatened Fauna:** Potential site areas were then limited to areas more than five kilometres from sightings of threatened fauna.
- **Airports:** Potential sites were greater than ten kilometres from any airport.
- **High Voltage Power lines:** To facilitate the connection of power plants to the State electricity grid, potential sites were preferred within 15 kilometres of high voltage power lines.



Source: Bishop 2014

Electricity generation and transmission Lines





Source: Bishop 2014

Case study: To design with the Mismatch

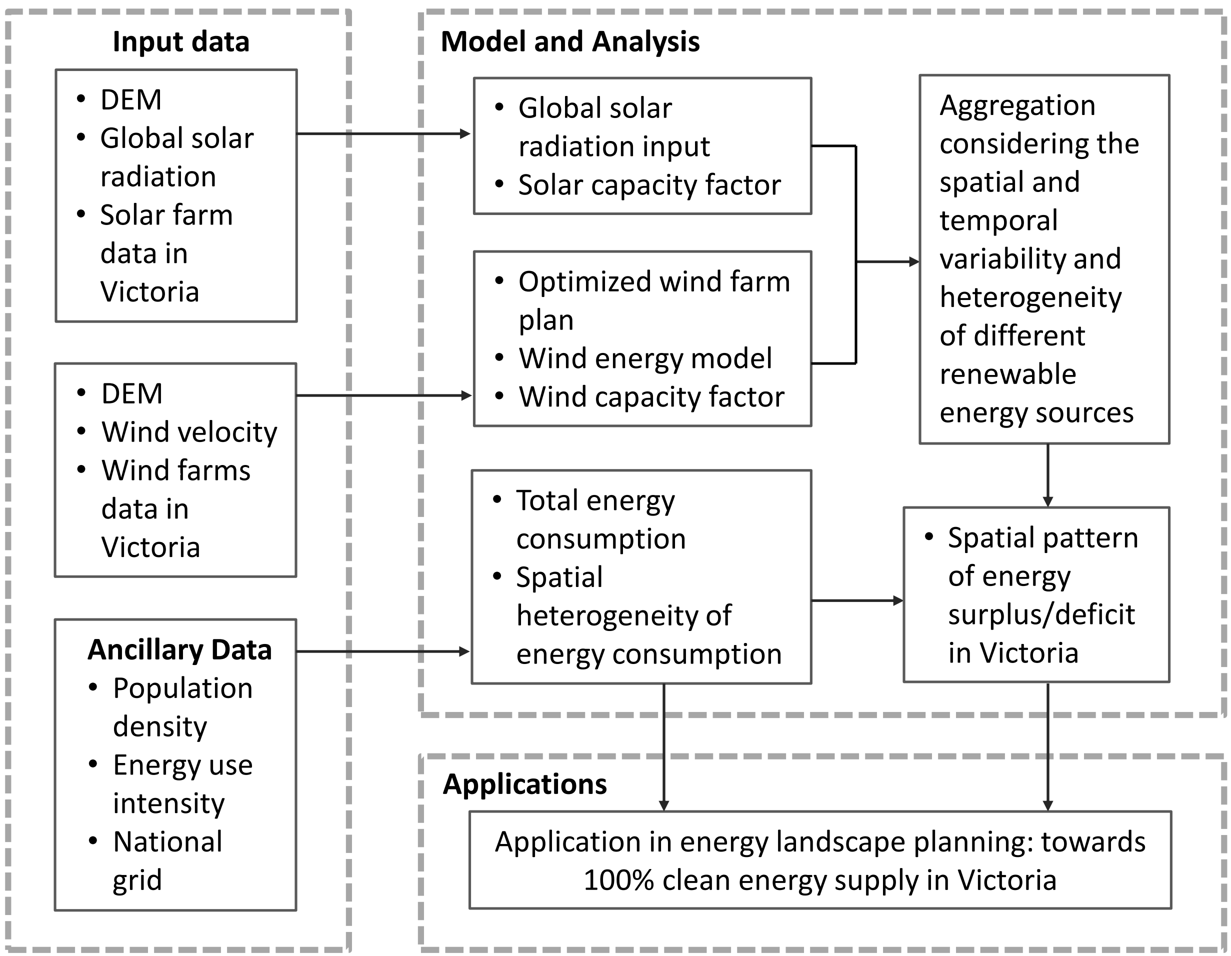
1. Understand the spatial/temporal variations of renewable energy

2. Spatial planning

Data

	Datasets	Attributes	Resolution/Format	Data Source
Solar	Solar radiation	Monthly average	1990-2011, 2km raster	BOM (Bureau of Meteorology)
Wind	Wind speed	Daily average	1975-2006, 2km raster	CSIRO Land and Water, 2008 McVicar, 2008
Ancillary datasets	SRTM DEM	--	30m raster	Geoscience Australia, 2014
	Population density, 2016 Australia Census	Annual	1km raster	LandScan, 2016; ABS, 2017
	Energy Intensity (Secondary)	Annual	1km raster	LandScan, 2016; ABS, 2017; CEA, 2016
	National grid	--	Vector data	Geoscience Australia, 2012; 2013

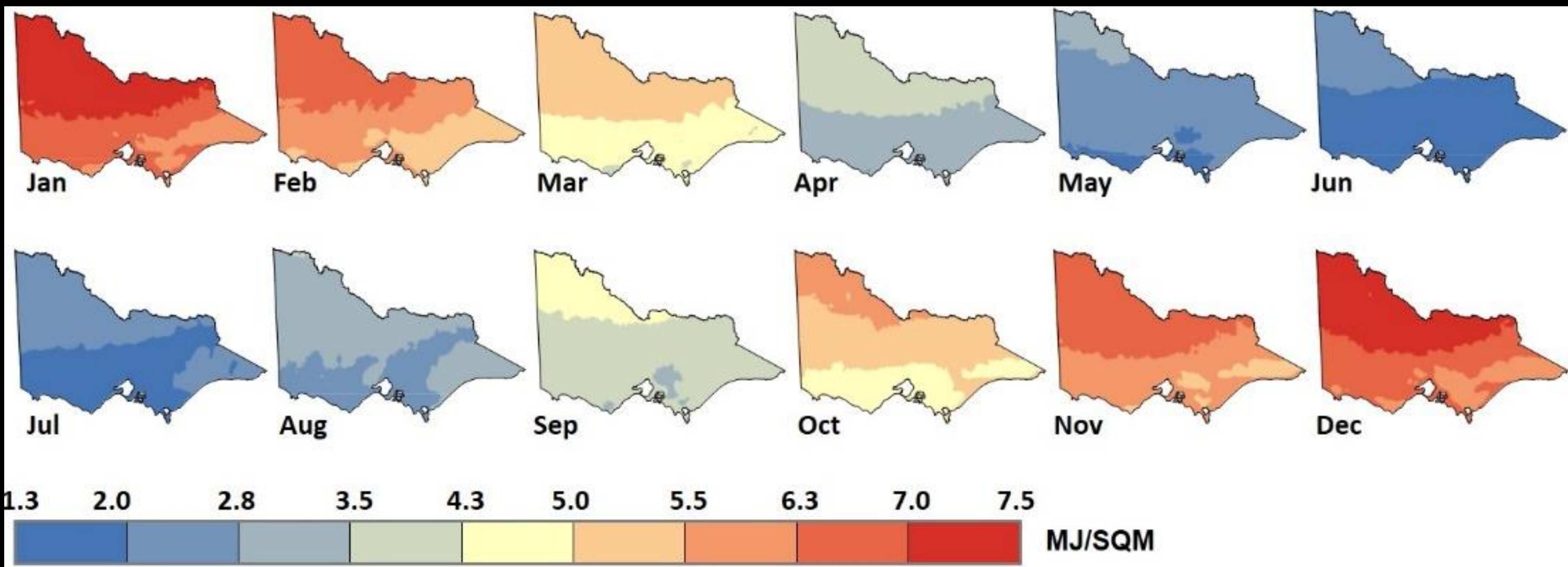
Methods



- Installed Capacity x Capacity Factor = Actual Production
- Installed capacity are on the daily term
- Actual production are generally on annul term

Results

Spatial and temporal variation of solar energy



Solar energy capacity (per m^2 per day) in Victoria (1990-2011 average); based on Capacity Factor = 25% (DELWP, 2016)

Mapping Wind Energy Capacity

$$E_{wind} = ½\, m_{air} \times v^2 = ½\, (\rho_{air} \times A \times v \times t) \times v^2 = ½\, \rho_{air} \times A \times t \times v^3 \qquad (1)$$

where E_{wind} is wind energy; m_{air} is the mass of air; v is wind speed (KISSELL 2010); ρ_{air} is the density of air, which varies with the altitude and time, and depends on the temperature and pressure. However, since the variations are very small, average air density at ground level (1.225 kg/m^3) is widely accepted as the air density in the hub height of wind turbines (CARRILLO ET AL. 2013).

Power is energy per unit time, so the wind power is

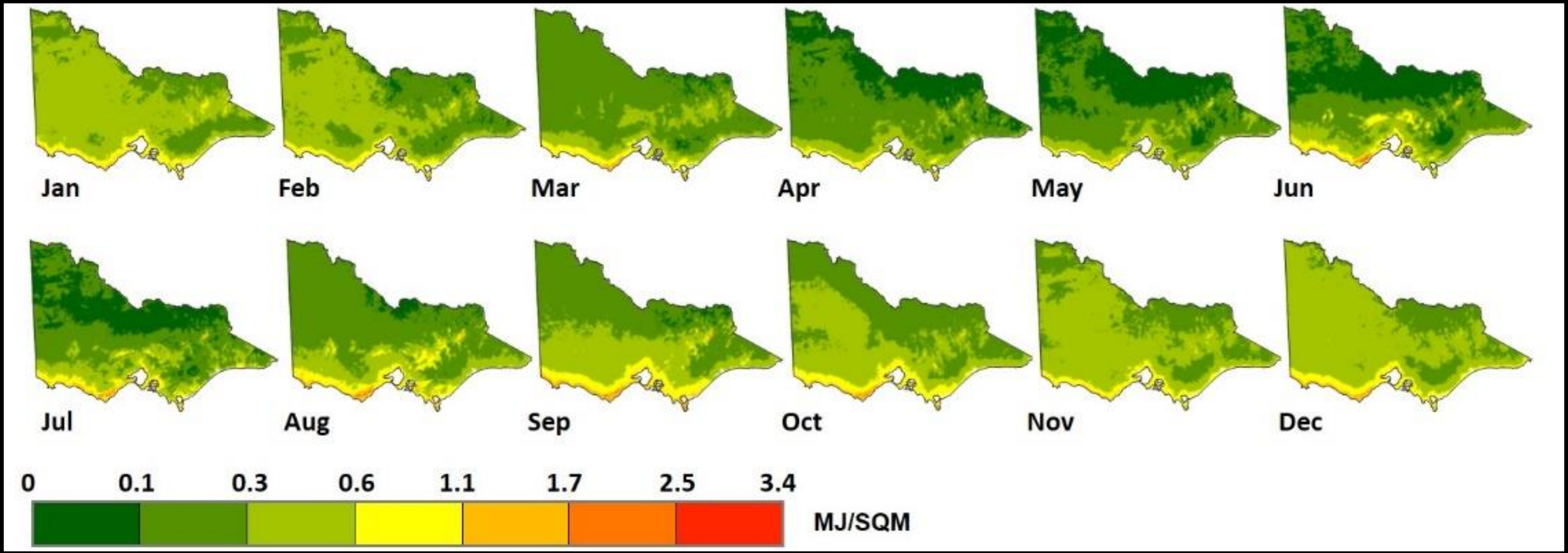
$$P_{wind} = E_{wind} / t = ½\, \rho_{air} \times A \times v^3 \qquad (2)$$

P_{wind} is total wind energy capacity per second.

Considering *A* (or the blades of a turbine) is often perpendicular to ground, the total maximum possible *A* is calculated using the total land area in Victoria, the rotor diameters, and spacing between wind turbines are used to estimate the wind energy capacity. The outputs from the model display distinct seasonal and spatial variations of solar energy capacity in Victoria.

Results

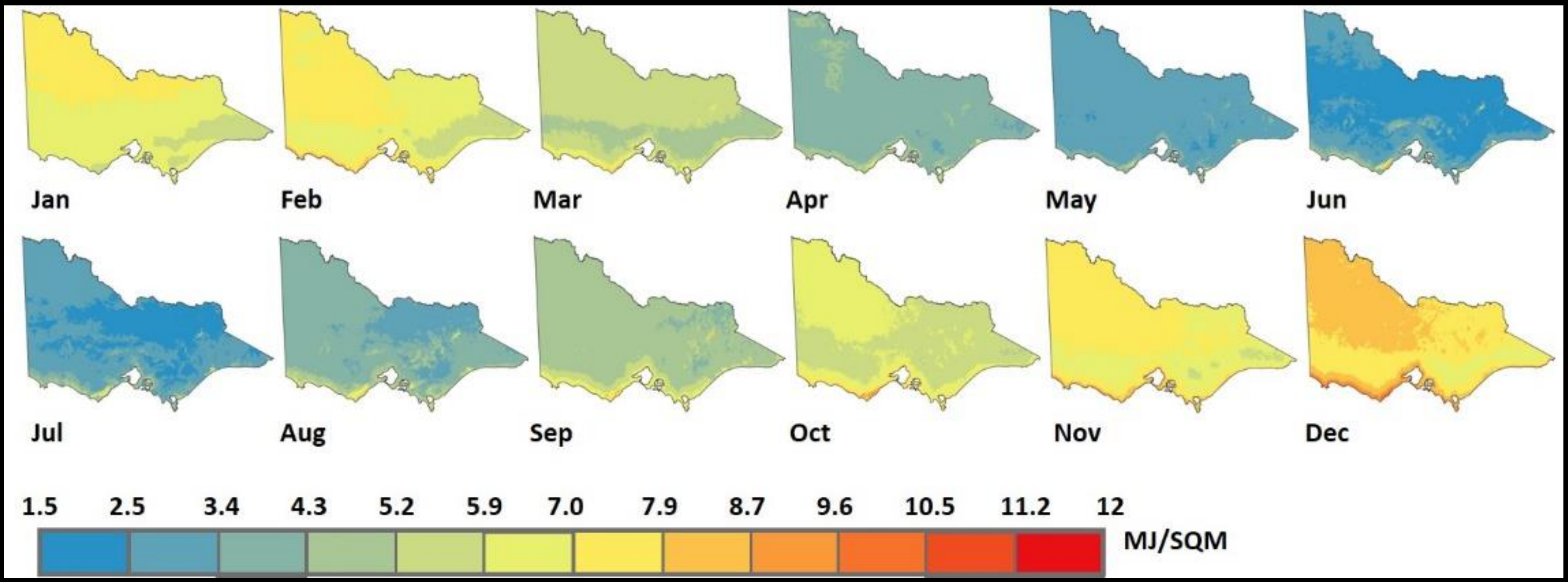
Spatial and temporal variation of wind energy



Total daily wind energy in Victoria (1975-2006 average), based on Capacity Factor = 34%; rotor diameter = 60m, spacing between wind turbines perpendicular to wind = 120m; parallel to wind = 180m

Results

Aggregation of solar and wind energy



Total daily wind and solar energy in Victoria, based on multiple years solar and wind energy data

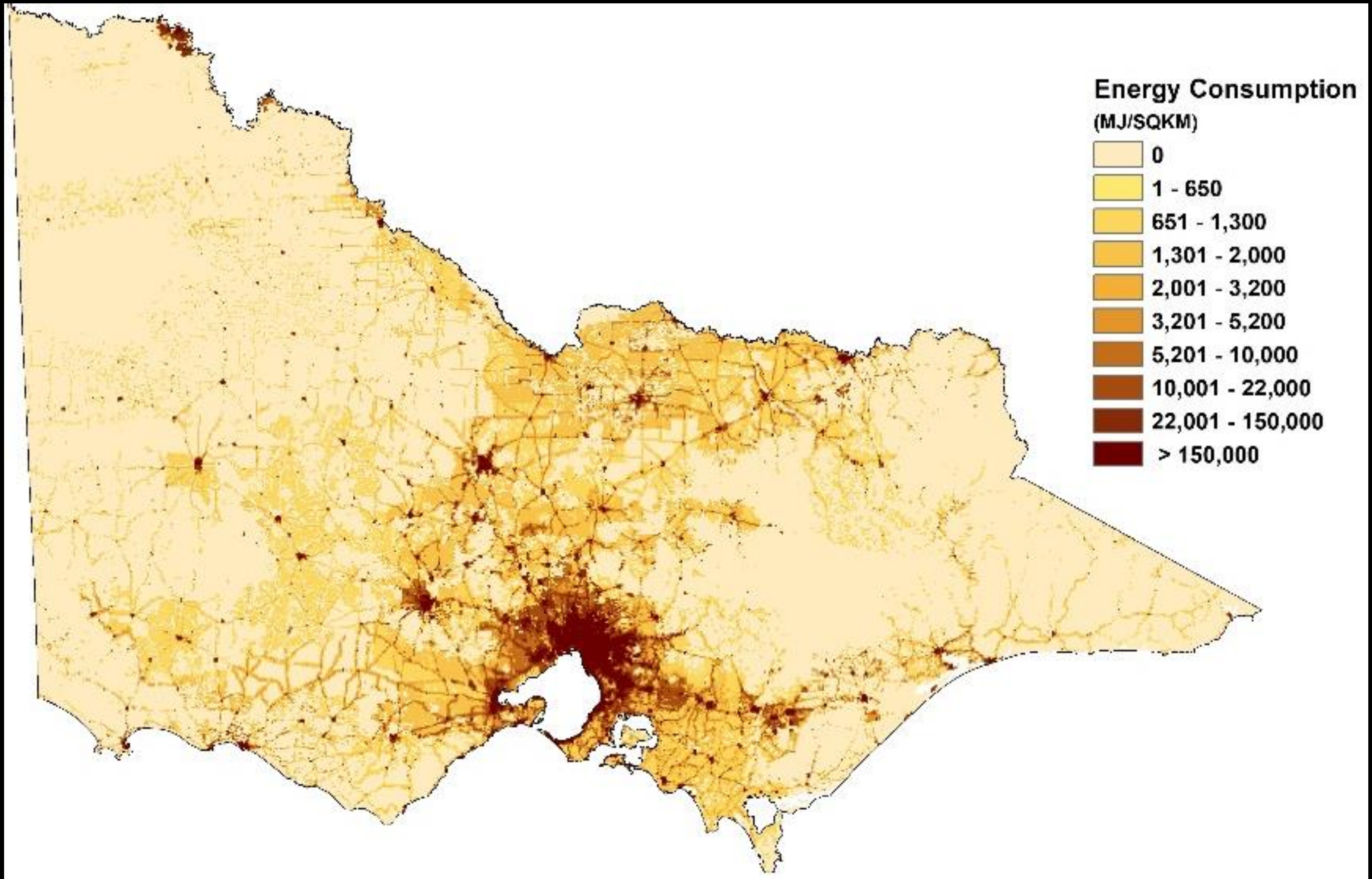
Outcomes from the aggregation analysis

- **Alleviation of uneven spatial distribution of wind and solar energy**.

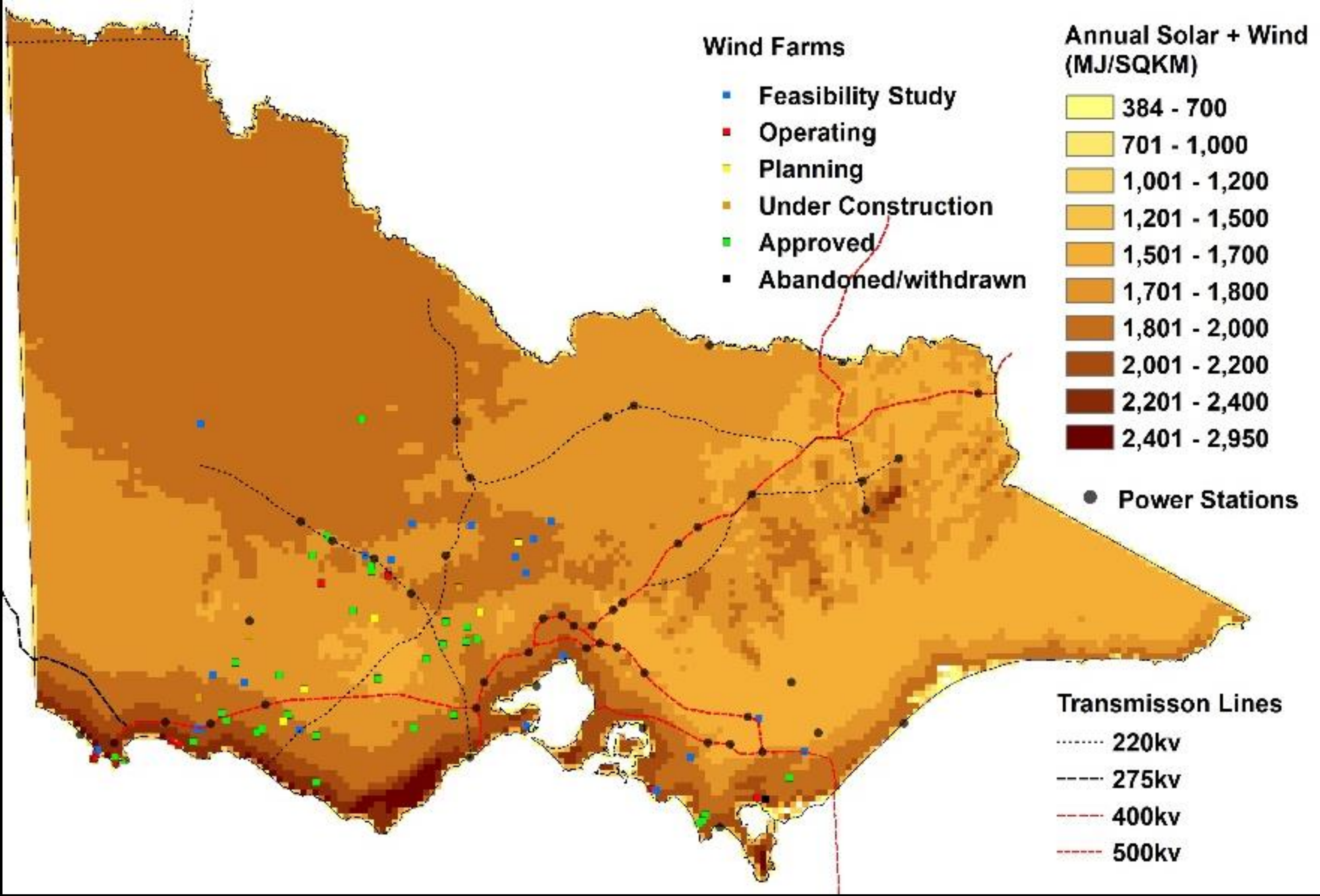
  Thanks to contrary spatial patterns of solar and wind energy potential in Victoria (i.e. solar power capacity decreases from inland to the coastal areas, while the wind power capacity increases from inland to coastal areas), the aggregation serves to alleviate the uneven spatial distribution of wind and solar energy in Victoria.

- **Seasonal polarisation of total solar and wind power**

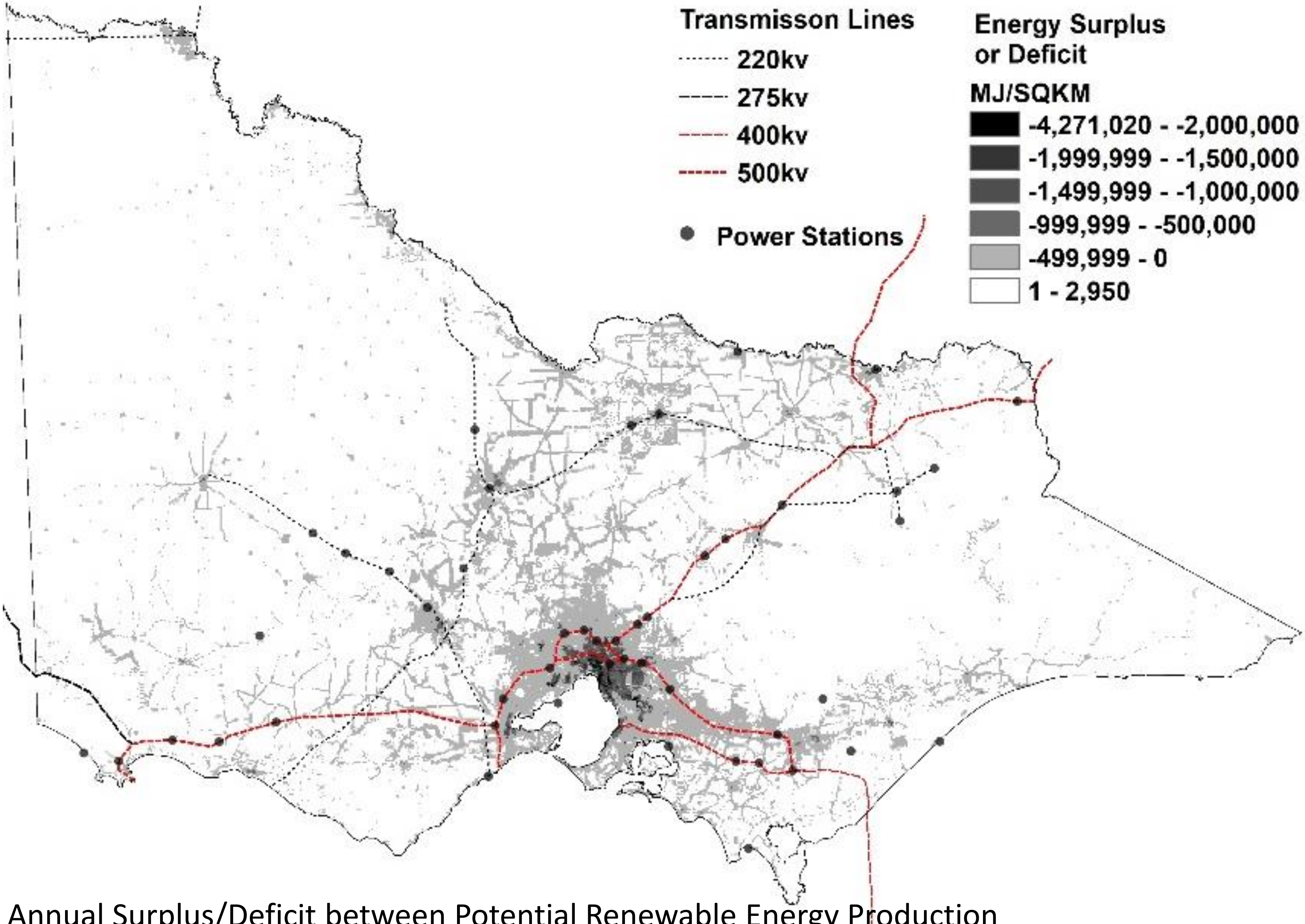
  The energy potential for both solar and wind are higher in hot seasons and lower in cold seasons. The aggregation exacerbates the seasonal renewable energy variations. This requires planning strategies that can precisely handle the risks of polarisation in energy production.



Spatial heterogeneity of total annual energy consumption in Victoria

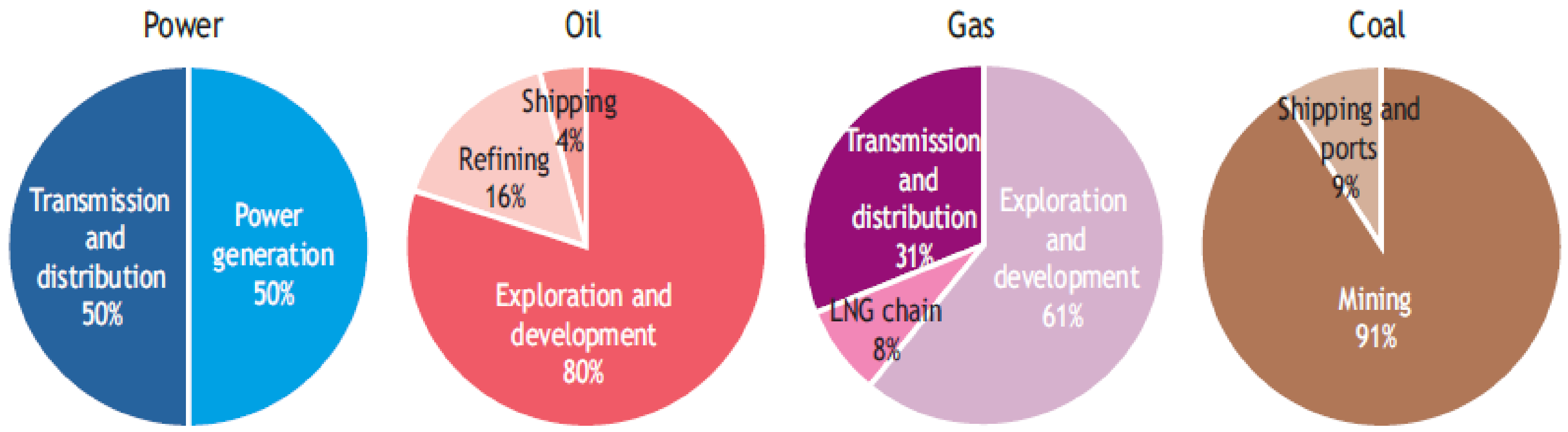


Spatial heterogeneity of annual renewable energy (solar + wind) and energy infrastructure in Victoria



Annual Surplus/Deficit between Potential Renewable Energy Production and Total Energy Consumption in Victoria

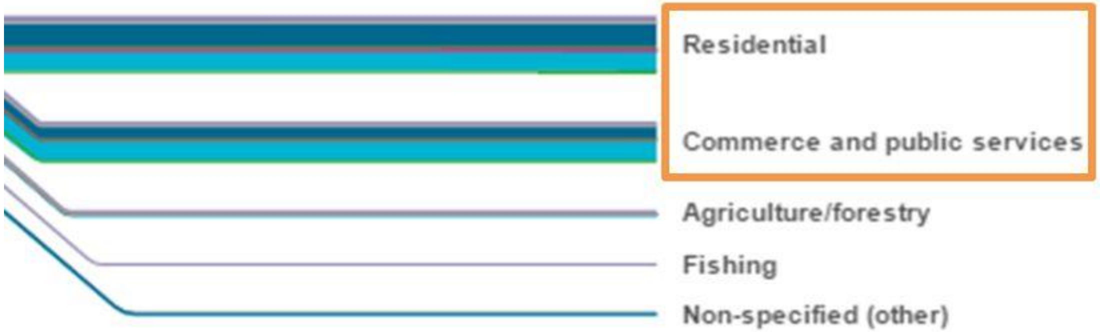
- Energy production should be as local to its consumers as possible, so that the energy transmission cost and loss could be minimized (Chen, 2018)



Investment on energy supply infrastructure (IEA, 2008)

Discussion

- The mismatch between energy capacity (production) and demand (consumption)
  - Spatial
  - Temporal
- Aggregation
  - Alleviation: when patterns of production are positively related with demand
  - Aggravation or polarisation
  - Could be in spatial or temporal terms
- Aggregation/Dis-aggregation combining multiple forms of renewable energy to inform allocating resources where/when needed


Residential
Commerce and public services
Agriculture/forestry
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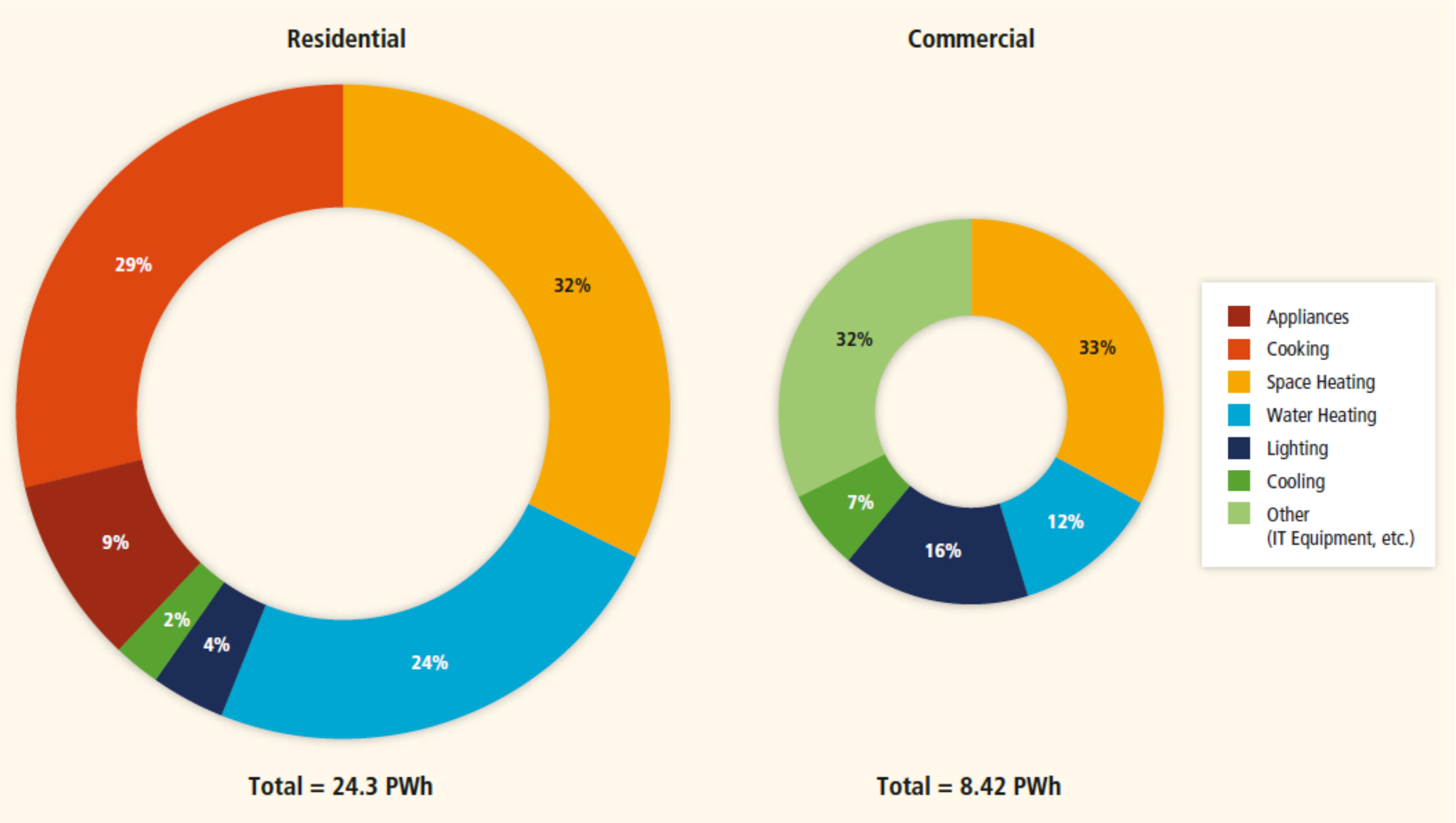
IEA 2013


Residential
29%
32%
9%
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4%
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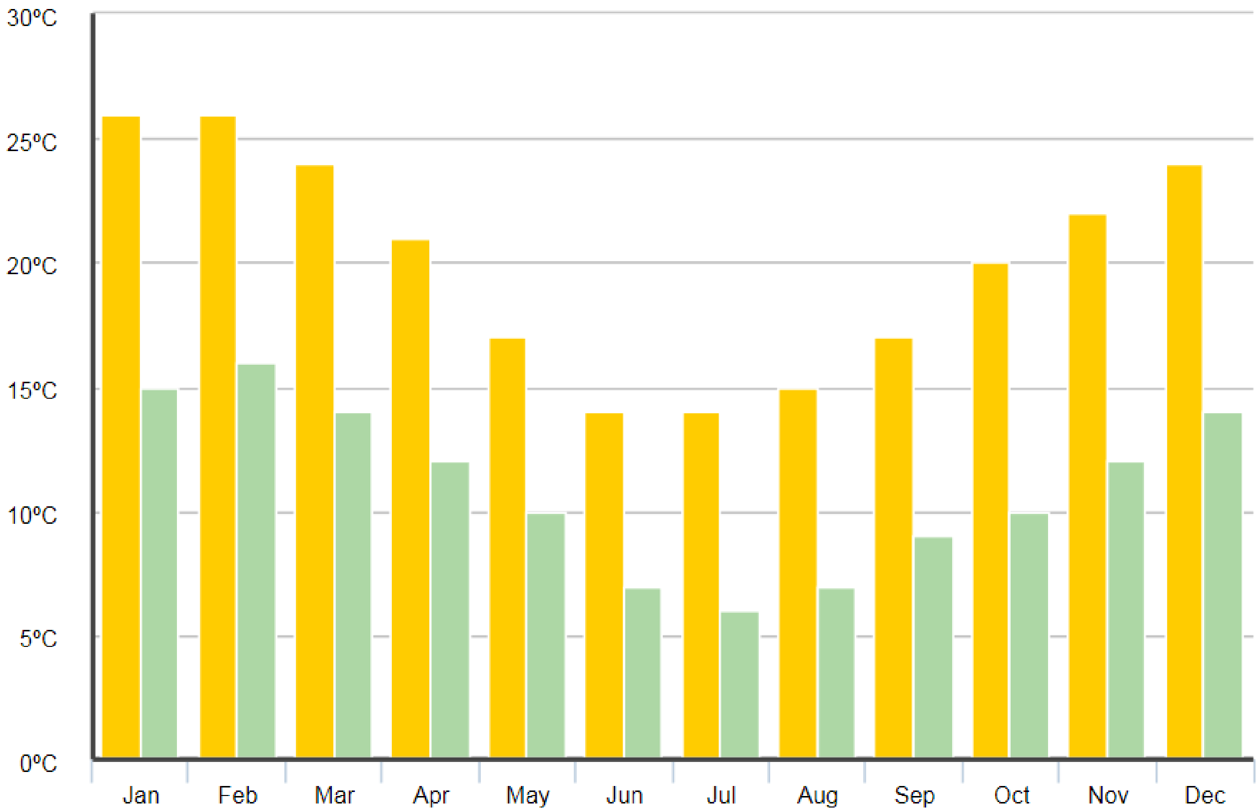
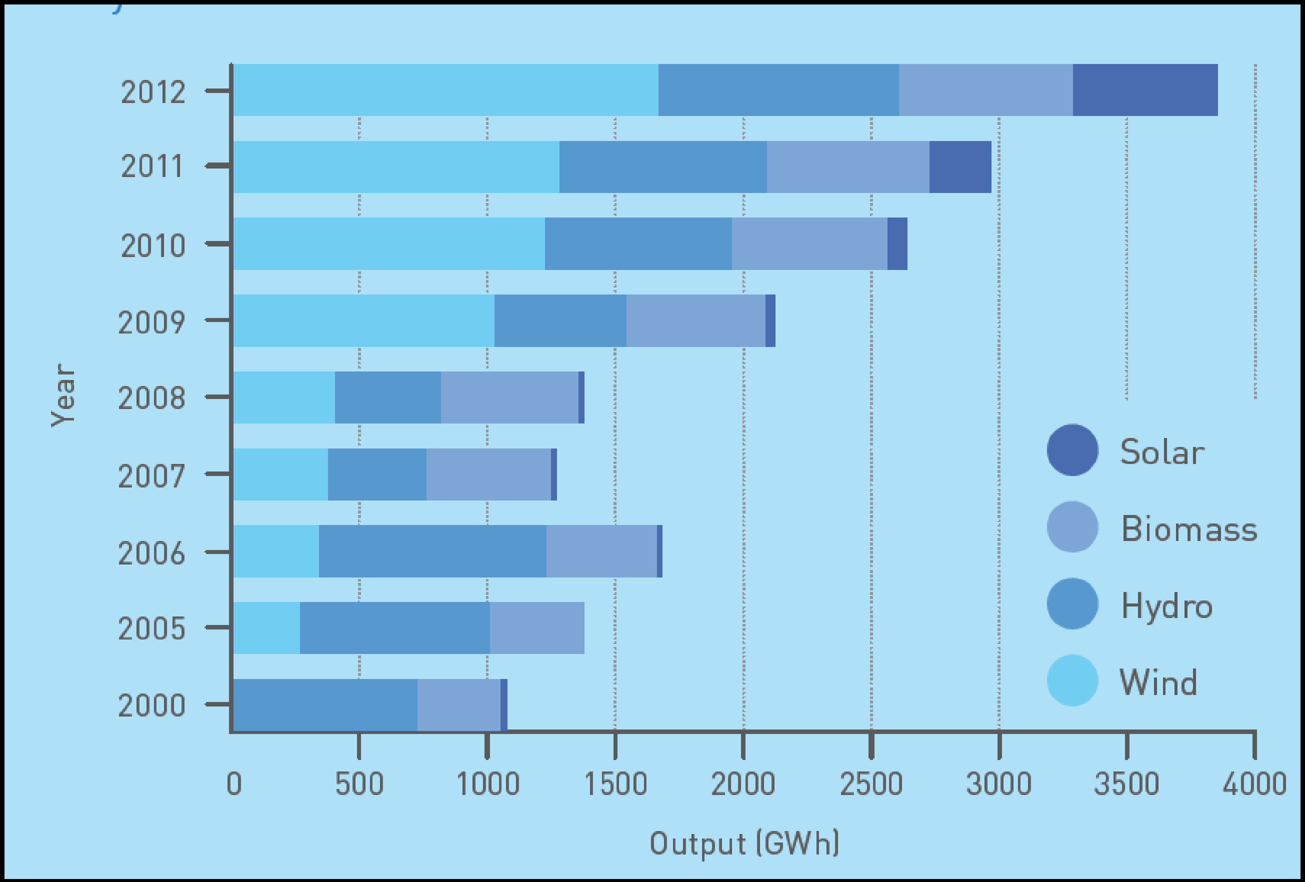
Total = 24.3 PWh
Commercial
32%
33%
7%
12%
16%
Total = 8.42 PWh
Appliances
Cooking
Space Heating
Water Heating
Lighting
Cooling
Other
(IT Equipment, etc.)

Melbourne and most areas in Victoria have a long cold winter. The number of hot days (30°C or above) is 35, while the number of cold days (18°C or below) is 159.

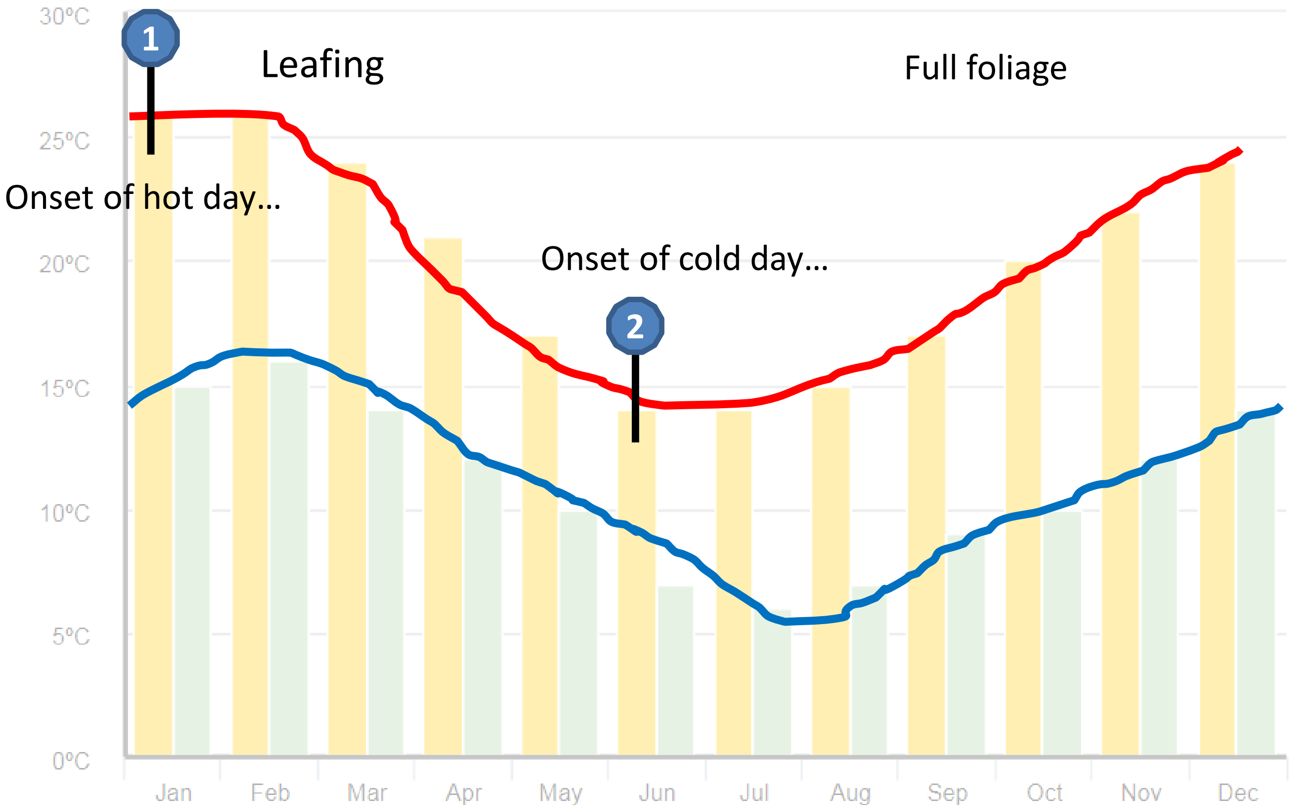


Source: http://www.bom.gov.au/

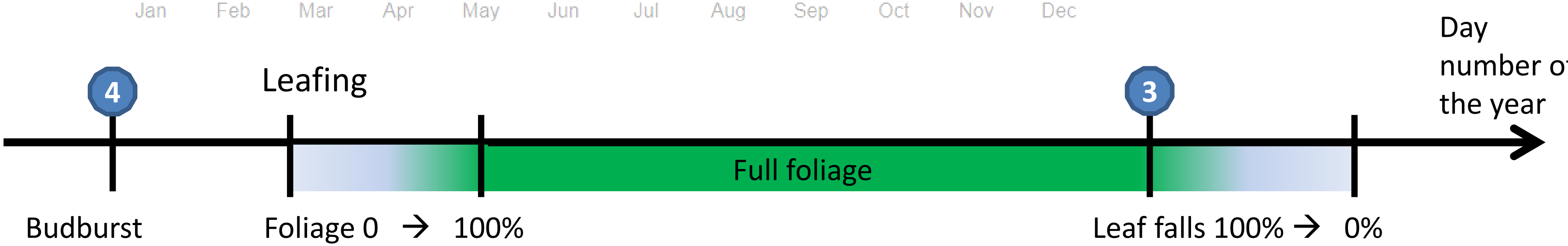


Renewable energy generation in Victoria

Phenology of Foliage Biomass



The variations of natural rhythms or spatial patterns in the landscape in both spatial and temporal terms) must be understood as design or planning opportunities



Outlook and Future Work

- Spatial aggregation combining multiple forms of renewable energy at multiple scales is promising
  - Large scale solar farms
    - Off-grid: remote mining industries, etc.
    - Grid connected
  - Medium scale solar farms
    - Off-grid: commercial operations
    - Grid connected
  - Small scale solar farms
    - Off-grid: remote settlements
    - Grid connected: households
- Towards 100% clean and renewable energy supply for all uses by combining with other forms of renewable energy sources (wind, biomass, geothermal, etc.)
- Smart energy city case study