IEooc_Application1_Exercise1: The end of area? Sociometabolic regimes and their area demand

Goal: *Develop a simple engineering model, learn about the physical distance and population constraints in the agricultural society, and estimate the area yield of modern renewable energy technologies*

Part 1, agricultural societies) Biomass (wood or grain) is the main source of energy in agricultural societies. On land, biomass also serves as transportation fuel. Bairoch (1993) estimates that in the 18th century, the transport costs of one tonne for 1 km on land were equivalent to 3.9 kg grain. Area yields for grain in France in the 18th century were about 50 tonnes per km^2 (Sieferle et al., 2006). Imagine a large country where all land is used to farm grain. 80% of the grain is used to feed the rural population, and the remaining 20% are transported to the capital using horse carriages, and the draft horses are fed from the grain they transport, consuming 3.9 kg grain for each tonne-km of transport.

Questions:

1) What is the functional relationship between the original mass of grain loaded on the carriage and the mass arrived at the city after a transport distance r?

2) Imagine that grain from all provinces is transported to the capital using a radial road network with the capital at the centre. How much grain arrives at the city if the country is a) circular with a radius of 400 km, and b) very, very large? This formula might be of help:

$$\int_0^R r \cdot e^{-a \cdot r} dr = \frac{1}{a^2} - \left(\frac{R}{a} + \frac{1}{a^2} \right) \cdot e^{-a \cdot R}$$

3) With an energy content of the grain of 15 GJ/ton and a typical energy need of a agricultural citizen of 50 GJ/cap/yr (Haberl et al., 2011), what would be the maximum population of the city for the cases a and b? Assume that grain is the only energy source this country has.

4) Are these values realistic or do they represent under- or overestimates and why?
On the one hand these numbers are overestimates because not all land can be used for farming and the draft animals also need to eat even when they do not transport anything. For example, the area needs of the road network were not accounted for. On the other hand, more energy-efficient modes of transport, especially transport on canals, can reduce costs by a factor of up to ten (Sieferle et al., 2006).

Part 2, future society) During the industrial revolution the area constraint set by the agricultural yields and transport energy costs was overcome. With the coming energy technology revolution a massive switch back to area-constrained technologies is bound to happen. A set of different renewable energy technologies is available. Imagine a circle-shaped country or region with a diameter of 200 km. Assume that the entire area can be covered with renewable energy installations.

Questions:

1) How much electricity can be supplied by that area with the three primary energy carries sunlight, wind, and biomass? (Rough values), use area yields by MacKay (2008) or other sources:
   + Solar: 20% efficiency of an average daily irradiance of 110 W/m^2 (solar irradiance: 1 kW/m^2, for 1000 sunshine hours and 8760 hours per year): 200 kWh/ m^2·yr.
   + Wind: $2W/m^2$ average annual power are typical, that is about 17 kWh/ m2·yr.
   + Biomass: Best plants are 2% efficient in converting sunlight to energy stored in biomass, but 0.5% is more common.

2) How many people can be supplied with electricity, given that the typical energy need of a citizen in an industrial society is around 300 GJ/cap/yr (Haberl et al., 2011) and we assume that all energy is consumed in form of electricity (1 kWh is 3.6 MJ)?

3) Are these values realistic or do they represent under- or overestimates and why?

References:

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Sieferle, R.P., Krausmann, F., Schandl, H., Winiwarter, V., 2006. Das Ende der Fläche. Böhlau & Cie., Cologne, Germany.