Competition biomass energy vs food

An adult human being is a 120 W machine. Suppose we get our energy 80% from vegetables (= 'direct' biomass) and 20% from meat (= 'indirect' biomass), assuming an 'efficiency' from primary biomass-to-meat of 10%:

- how much MJ/day, and kWh/yr, does 1 adult need in food from primary biomass?
- how much primary biomass does the world population consume? (8.2 billion people). Assume that average consumption is about half of the 'standard adult' (to account for children, elderly, …).
- assess the results in view of the biomass energy potential and agricultural production.

Solution:
→ 120 J/s * 3600 s/h * 24 h/day = 10.4 MJ/day (2500 kcal/day)* 365 d/yr = 3.8 GJ/yr = 1052 kWh/yr
80% as vegetables = 842 kWh/yr primary biomass
20% as meat = 210 kWh/yr secondary biomass ≈ 2100 kWh/yr primary biomass (assuming 10% efficiency)
Total primary biomass per person = 842 + 2100 = 2942 kWh/yr = 10.6 GJ/yr
→ World population (8.2 billion) → 10.6 GJ * 8.2 E+9 = **87 EJ**
Assume that average consumption is about half of the 'standard adult' (to account for children, elderly, …):
→ 87 EJ / 2 = 43 EJ
→ Comparison with:
– yearly biomass production: 3000 EJ
– yearly sustainable production (9%): 270 EJ
– yearly agricultural production (5%): **152 EJ**
Hence the agricultural production is roughly in 3.5-fold excess to feed all people.
Rem: from the agricultural production, we feed domestic animals too, and not all the produce is edible. But we obtain sort of the order of magnitude.

Estimate of residual biomass as resource, primary and final energy

Assumptions:

a) Agriculture: from the total yearly human production (152 EJ), discount food requirement (43 EJ, previous exercise). Assume that from the remainder, most is used to feed animals, some is composted, and 10% can counts as 'residual' energy from agro-waste.

b) Forestry: take 2 kg/m^2 new wood growth per year (LHV: 17 MJ/kg); assume 1% of the world's forests area is trimmed (from where this waste wood can be recovered as 'residual' energy)

c) Animal manure: assume a production of 1 m^3 of biogas per day (50% CH_4 content) per large farm animal and there are half as many large farm animal-equivalents as people. (LHV of CH_4 = 36 MJ/m^3 = 10 kWh/m^3)

d) Solid organic wastes from human activities (food waste, park and garden waste, food industry): assume a waste of 1 kg dry organic matter per week per person, converted to 500 L biogas per kg, with a CH_4 content of 60%

e) Human liquid organic waste (sewage → waste water treatment plants): assume a production of 30 L biogas per person per day, with a CH_4 content of 65%

From all this data, compute the total residual biomass primary energy potential and how this relates to the total human primary energy consumption/yr.
For the conversion to final energy, make realistic choices for the conversion technology (for power) and the conversion efficiencies.

Solution:

Agroresidues: 152 EJ total production
residue: 10% = **15 EJ**

Forestry: 2 kg/m^2 (17 MJ/kg). Forests cover 11% of the Earth surface (Earth surface = 5.1 E+14 m^2) = 5.6 10^{13} m^2. Assume 2% of the forest area is trimmed for energy use → 1.12 10^{12} m^2 → multiplied with 2 kg/m^2 sustainable wood production (→ 2.24 10^{12} kg) with energy content of 17 MJ/kg → **38 EJ**
(this figure is remarkable close to the 40 EJ of 'traditional biomass' energy use from the previous biomass exercise series)

Manure: 1 m^3 biogas/day (50% CH_4) with LHV(CH_4) = 36 MJ/m^3
18 MJ/m^3.day per large farm animal* 365 days * 4 billion large animal-equivalents (estimate!) gives **26.3 EJ** (730 billion m^3 bioCH_4/yr)

Estimates for Europe's biogas potential from manure are 26 billion m^3 biomethane (theoretical) to 18 billion m^3 (collectible), see N Scarlat et.al, https://doi.org/10.1016/j.rser.2018.06.035 . This is only 3% of our estimated world total. Europe's population is about 6% of the world and its animal agriculture is probably quite intense compared to the world average. So our world estimate of biomethane energy from manure may be overoptimistic by a factor 2 to 3. Let's set it at **10 EJ** as order of magnitude.

Solid waste: 1 kg dry matter/week → 52 kg/yr, converted to 500 L biogas/kg (with 60% CH_4)
52 kg/yr * 0.5 m^3/kg * 0.6 * 36 MJ/m^3 = 0.56 GJ/yr.person
for 8.2 billion people: **4.6 EJ**

Sewage: 30 L/day.person (65% CH_4)
0.03 m^3/d * 365 d/yr * 0.65 * 36 MJ/m^3 = 0.26 GJ/yr.person
for 8.2 billion people: **2.1 EJ**

⇒ **Total: 15 + 38 + 10 + 4.6 +2.1 = 70 EJ**
⇒ **12% of world primary energy**, of which half as forest waste wood (38 EJ)

When valorised to electricity :
20% efficiency for solids burnt in steam plants (15 + 38 = 53 EJ) → 10.6 EJ → 2944 TWhe
35% efficiency for biogases (10 + 4.6 + 2.1 = 16.7 EJ) → 5.85 EJ → 1625 TWhe
=> total 4579 TWhe (world: 29'500 TWhe), i.e. 15.5% of world electricity.

Rem: in 2020 **all** biomass electricity generation was around 685 TWhe.