Biogas from Swiss farms

Switzerland has 57'617 farm sites, of a mean size of 20 ha per farm, spread between 1 and 50 ha for >92% of them.
40'309 farms breed cows (1'545'600 cows, 38 cows per farm on average),
8'234 breed pigs (1'584'400 pigs, 192 pigs per farms on average)
and the country has 10'519 km^2 of agricultural surface (25.5% of the total) from which also straw and other residues are recoverable.

Recoverable power:
205 W per cow from cow manure
40 W per pig from pig manure
120.5 W from 1 ha of agro-waste

What is the recoverable yearly Swiss agro-biogas potential (in PJ)?

- ⇨ 10 PJ from cow manure
- ⇨ 2 PJ from pig manure
- ⇨ 4 PJ from agro-residues
- ⇨ Total 16 PJ

How does this relate to the total final energy of ≈800 PJ?

- ⇨ 16 PJ = 2%

What is the average potential power-size per farm: in kW? In biogas flow (m^3/h)?
(Assume 66% CH_4 in the biogas and 11 kWh per m^3 CH_4)

- ⇨ 16 PJ/yr for 57'617 farms => 277.7 GJ/yr per farm => 8.8 kW per farm
- ⇨ 8.8 kW / 11 kWh/m^3 = 0.8 m^3 / h CH_4 = 1.2 m^3 / h biogas

The reality of Swiss agricultural biogas exploitation in 2018 is a production of 140 GWh_el in 111 installations in ICE CHP with 35.7% electric efficiency.
How does this compare to the theoretical energy potential ?

Primary agro-biogas = 140 GWh_el / 0.357 = 392 GWh = 1.4 PJ, which is only 8.8% of the potential of 16 PJ

What is the average engine power size per site? (Assume 7000h load per year)

392 GWh for 111 sites = 3.53 GWh per site on average
For 7000h per year operation, the biogas energy input is : 3530 MWh / 7000h = 505 kW
With 35.7% electrical efficiency, the engine power size ≈ 505 * 35.7% = 180 kWe.

What do you conclude from this ? How could the biogas potential be better used ?

Only a limited number, i.e. the largest sites, are exploited, as a lot of waste is needed to run an engine of a size where 'economy of scale' can be used.
(We would instead be able to exploit many more sites with solid oxide fuel cells, which reach >50% electrical efficiency already on small scale.)

Gasoline / Diesel replacement by inland bioethanol / biodiesel production ?

Inland mobility fuel in Switzerland is ca. 5.1 Mtoe gasoline and ca. 2 Mtoe diesel per year.

(1 Mtoe = 42 PJ)

Assume we want to replace part of it by inland biofuel production and that we can dedicate 1000 km^2 of the Swiss territory (total: 41'000 km^2) to beet plantation and 1000 km^2 to rapeseed plantation.

Bioethanol (21.3 MJ / L) from beet : 2500 L / ha (1 ha = 10'000 m^2 = 0.01 km^2)

Biodiesel (33 MJ / L) from rapeseed : 700 L / ha

How much (%) of imported gasoline and diesel fuel consumption could we replace this way ?

Ethanol : 2500 L/ha * 100 ha/km^2 * 1000 km^2 * 21.3 MJ/L = 5.325 PJ
Fossil gasoline = 5.1 Mtoe = 5.1 * 42 PJ = 214 PJ
→ 2.5% of gasoline could be replaced with bioethanol

Biodiesel : 700 L/ha * 100 ha/km^2 * 1000 km^2 * 33 MJ/L = 2.31 PJ
Fossil diesel = 2 Mtoe = 84 PJ
→ 2.75% of diesel could be replaced with biodiesel

If we were to dedicate instead 2000 km^2 of forest land (there is ~11'000 km^2 of forest) to bioethanol production (renewable dry wood production of 20 ton / ha.yr, converting 3 kg wood to 1 kg ethanol), how much gasoline could we replace ? (ethanol density: 0.8 kg/L)

0.333 (weight yield 3kgwood=>1kg ethanol) * 20'000 kg/ha * 100 ha/km^2 * 2000 km^2 * 21.3 MJ/L / 0.8 kg/L = 35.5 PJ
→ 16.6% of gasoline could be replaced with bioethanol from wood

If we would instead convert this yearly available wood quantity into methane (wood-to-methane 70% energy efficiency yield) for mobility (gas vehicles) ? (Assume 16.7 MJ/kg dry wood)

0.7 (energy yield wood=>CH_4) * 20'000 kg/ha * 100 ha/km^2 * 2000 km^2 * 16.73 MJ/kg = **46.84 PJ**

Comment the results.
Wood energy is denser than energy crops for liquid biofuels (considering the land use). Gasification to methane is more energy efficient among the considered cases. Bioethanol and biodiesel are good for exploiting 'marginal' land areas (land not particularly used otherwise), but can only deliver a limited contribution to fossil mobility fuel replacement at the current use rate.