

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 km² of agricultural surface (25.5% of the total country surface) 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 (m³/h)?
(Assume 66% CH₄ in the biogas and 11 kWh per m³ CH₄)

⇒ 16 PJ/yr for 57'617 farms ⇒ 277.7 GJ/yr per farm ⇒ 8.8 kW per farm

⇒ 8.8 kW / 11 kWh/m³ = 0.8 m³ / h CH₄ = 1.2 m³ / h biogas

The reality of Swiss agricultural biogas exploitation in 2018 is a production of 150 GWh_{el} in 110 installations in ICE CHP with 36% electric efficiency.

How does this compare to the theoretical energy potential ?

Primary agro-biogas = 150 GWh_{el} / 0.36 = 417 GWh = 1.5 PJ, which is only 9.4% of the potential of 16 PJ

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

417 GWh for 110 sites = 3.79 GWh per site on average

For 7000h per year operation, the biogas energy input is : 3790 MWh / 7000h = 541 kW

With 36% electrical efficiency, the engine power size ≈ 541 * 36% = 195 kW_e.

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 a certain '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 scales of 10 kW_e. The bottleneck is the cost of small-scale digesters.)

Gasoline / Diesel replacement by inland bioethanol / biodiesel production ?

Inland mobility fuel in Switzerland is ~5.1 Mtoe gasoline and ~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 km² of the Swiss territory (total: 41'000 km²) to sugar beet plantation and 1000 km² to rapeseed plantation.

Bioethanol (21.3 MJ / L) from sugar beet : yield 2500 L / ha (1 ha = 10'000 m² = 0.01 km²)

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

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

Ethanol : $2500 \text{ L/ha} * 100 \text{ ha/km}^2 * 1000 \text{ km}^2 * 21.3 \text{ MJ/L} = 5.325 \text{ PJ}$

Fossil gasoline = 5.1 Mtoe = $5.1 * 42 \text{ PJ} = 214 \text{ PJ}$

→ **2.5%** of gasoline could be replaced with bioethanol

Biodiesel : $700 \text{ L/ha} * 100 \text{ ha/km}^2 * 1000 \text{ km}^2 * 33 \text{ MJ/L} = 2.31 \text{ PJ}$

Fossil diesel = 2 Mtoe = 84 PJ

→ **2.75%** of diesel could be replaced with biodiesel

If we were to dedicate instead 1000 km² of forest land (there is ~11'000 km² 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)

$0.333 \text{ (weight yield } 3 \text{ kg wood} \Rightarrow 1 \text{ kg ethanol)} * 20'000 \text{ kg/ha} * 100 \text{ ha/km}^2 * 1000 \text{ km}^2 * 21.3 \text{ MJ/L} / 0.8 \text{ kg/L} = 17.75 \text{ PJ}$

→ **8.3%** 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)

$0.7 \text{ (energy yield wood} \Rightarrow \text{CH}_4) * 20'000 \text{ kg/ha} * 100 \text{ ha/km}^2 * 1000 \text{ km}^2 * 16.73 \text{ MJ/kg} = 23.42 \text{ PJ}$

Comment the results.

Wood energy is considerably 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.

With the efficiency of engines for transport of around ~20% (fuel-to-wheel), it is in fact smarter to convert the fuel to electricity (e.g. with fuel cells, to 50%) and then charge an electric vehicle with it.