Energy efficiency of fossil and renewable fuels

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Crafoord price* award laureat H. T. Odum

"Because global consumption of fuels is occurring faster than their production by the environment, carbon dioxide has been increasing, affecting the climate....

Although biomass is more renewable, its EMERGY yield ratio is less than that of fossil fuels, and substitution would not reduce carbon dioxide release"

'**Ecosystem ecology 1987**. Administered by the Royal Swedish Academy of Sciences, the prize is intended to promote international basic research in the disciplines: Astronomy and Mathematics, Geosciences, and Biosciences. According to the Academy, "these disciplines are chosen so as to complement those for which the Nobel Prizes are awarded". http://en.wikipedia.org/wiki/Crafoord_Prize

Odum, H.T., 1996. Environmental Accounting: EMERGY and Environmental Decision Making. Wiley. Odum, 1996 p.163

From fossil to renewable energ
farm level?

Scenarios

- Shall we reduce animal production?
  Because animal production is the greatest energy consumer
- Shall we replace chemical fertilisers by organic ones?
  Because recycling of manure – by the way a primary target of organic farming since ever - is presently in vogue
- Shall we promote mixed farming?
  Because mixed farms lower the logistic problems caused by separating crop and animal production far from each other
- Shall we charge farmers with external cost?
  Because allocating cost of environmental pollution to producers may decrease use of fossil energy, see CO_2 certificates
- Shall we outsource agricultural production?
  Because outsourcing will be the cheapest way to fulfil the EU targets to reduce CO_2 emissions

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Methodology

A. Calculation of the energy return on investment (EROI) of a fuel, to compare the energy efficiency of different alternatives.

B. Calculating the energy balance of farms using a holistic farm model where the farm boundary = system boundary. This approach may also consider the agricultural production of a country as one big farm.

C. Fossil energy input calculation. Because reliable figures for the consumption of indirect fossil fuels is hardly available, I use two methods to assess indirect energy input:
   1. multiplying mass with a mass to energy conversion factor (LCA-approach)
   2. multiplying the energy costs with the energy intensity (kWh/€).

A. Energy return on investment (EROI)

The energy return on investment is the ratio between energy output and input and describes how much energy is necessary to supply a fuel:

$$\mathbf{EROI} = \frac{\textbf{energy content of a fuel}}{\textbf{energy input to supply a fuel}} - 1$$

An EROI > 0 means,
that the supplied fuel contains more energy than the energy supply chain consumed.

An EROI < 0 means,
that the supplied fuel contains less energy than the energy supply chain consumed.

An EROI = 1 means,
that the supplied fuel contains two times more energy than the energy supply chain consumed in other words, the energy yield is 100%.

The advantage of this measure is that energy input and output as well as resulting CO_2 emissions are comparable.

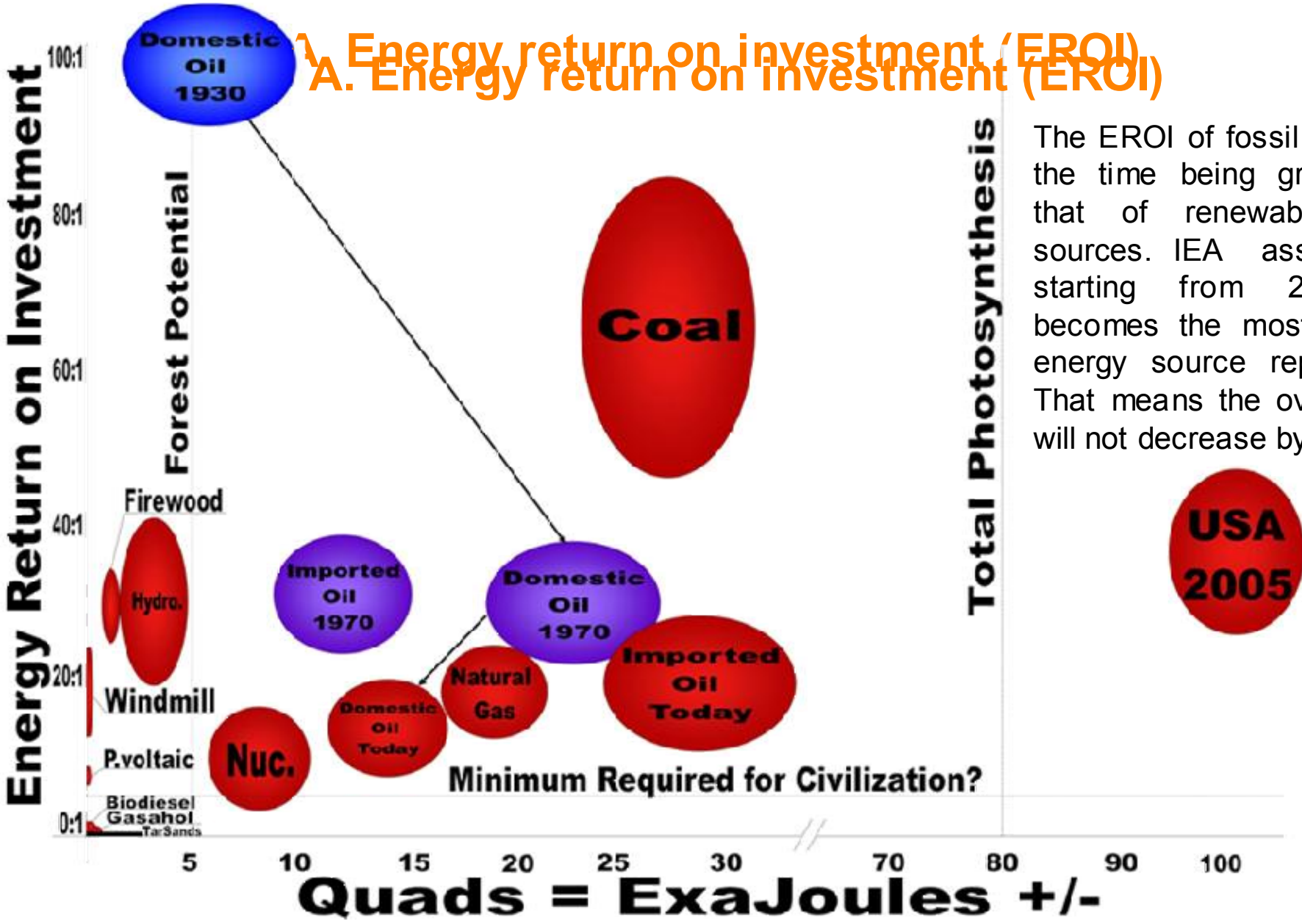
A. Energy return on investment (EROI)

Examples

1. A farm consumes 100 energy units of fossil fuels, exploited with an EROI of 20. Than the overall fossil energy consumption is 100+100/20=**105** fossil energy units. Given, the farm replaces the fossil fuel with renewable fuel, produced with an EROI of 2, the overall energy consumption of renewable energy is 100+100/2=**150** renewable energy units. In turn, if the energy input is limited to 105 energy units to maintain the same CO2 emission level, than only **70** (105=70+70/2) renewable energy units remain at the farms disposal.

2. A car consumes 100 gasoline units produced with an EROI of 4.25. Than the overall fossil energy consumption is 100+100/4.25=**124** fossil energy units. If we replace gasoline by ethanol produced from sugar cane with an EROI of 0.2 like we do in E95 gasoline, than the overall energy consumption of renewable energy is 100+100/0.2=**600** renewable energy units. If the energy input is limited to **124** to maintain the same CO_2 emission level**,** only **21** (124=20.7+20.7/0.2) renewable energy units - that is about 1/5th - remain at the car owners disposal.

A. Energy return on investment (EROI)



The EROI of fossil fuels is for the time being greater than that of renewable energy sources. IEA assumes that starting from 2020 coal becomes the most important energy source replacing oil. That means the overall EROI will not decrease by 2030.

Source: *US EIA, Cutler Cleveland and C. Hall's own EROI,* http://www.theoildrum.com/files/ch_balloon_tod.png

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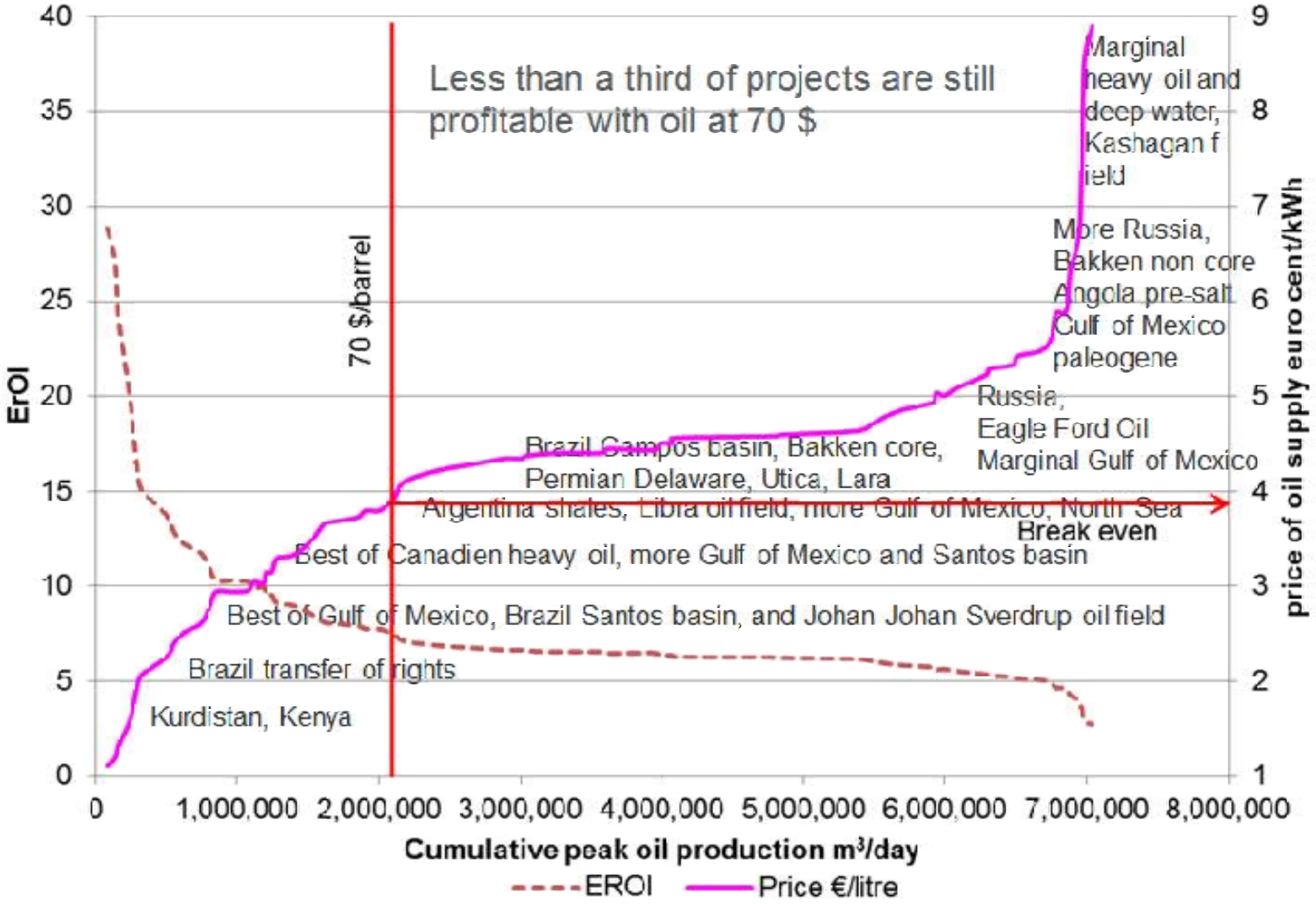
The top 400 new fields, how much future oil production they represent, and resulting EROI



Assumptions:

- 159 litre/barrel
- heat value 1634 kWh/bbl
- oil price100 $/bbl,
- exchange rate 1,10 $/€
- world energy intensity of fossil fuels 3,01 kWh/€

Source:
Tom Randall, 7:52 AM EET December 18, 2014. There are zombies in the oil fields. Bloomberg Business. http://www.bloomberg.com/news/articles/2014-12-18/bankers-see-1-trillion-of-investments-stranded-in-the-oil-fields

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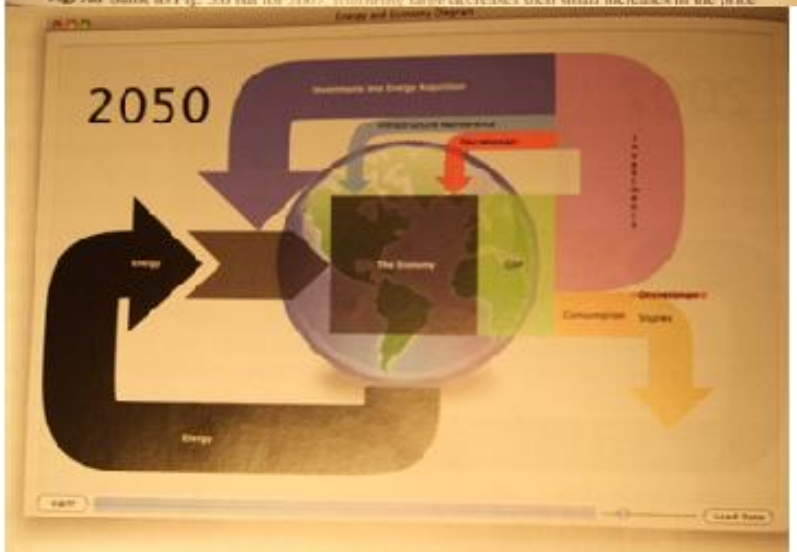
Simulation of the USA economy changing EROI of fossil energy

Fig. 5.8 Same as Fig. 5.6 but for 2007, following large decreases then small increases in the price



"The results suggest that discretionary income including both discretionary investments and discretionary consumption will move from the present 50 or so per cent in 2005 to about 10 per cent by 2050 whenever (or if) the composite EROI of all of our fuels reaches about 5, in other words, we will in future mainly work to supply energy.

2007 EROI = 20:1
2030 EROI = 10:1
2050 EROI = 5:1

Source: Hall, C., Powers, R., Schoenberg, W. 2008. Peak Oil, EROI, Investments and the Economy in an Uncertain Future. In: Pimentel, D. (ed.). Biofuels, Solar and Wind as Renewable Energy Systems , Springer Netherlands. s 109-132.

Output		**Input**	
Green:	GDP	*Black:*	Energy supply
Ocra:	Consumption	*Dark blue:*	*Investments into energy acquisition*
Yellow:	Staples		
Orange:	Discretionary consumption	*Blue*:	Infrastructure, maintenance
		Mangenta:	Investments
		Orange:	Discretionary investments

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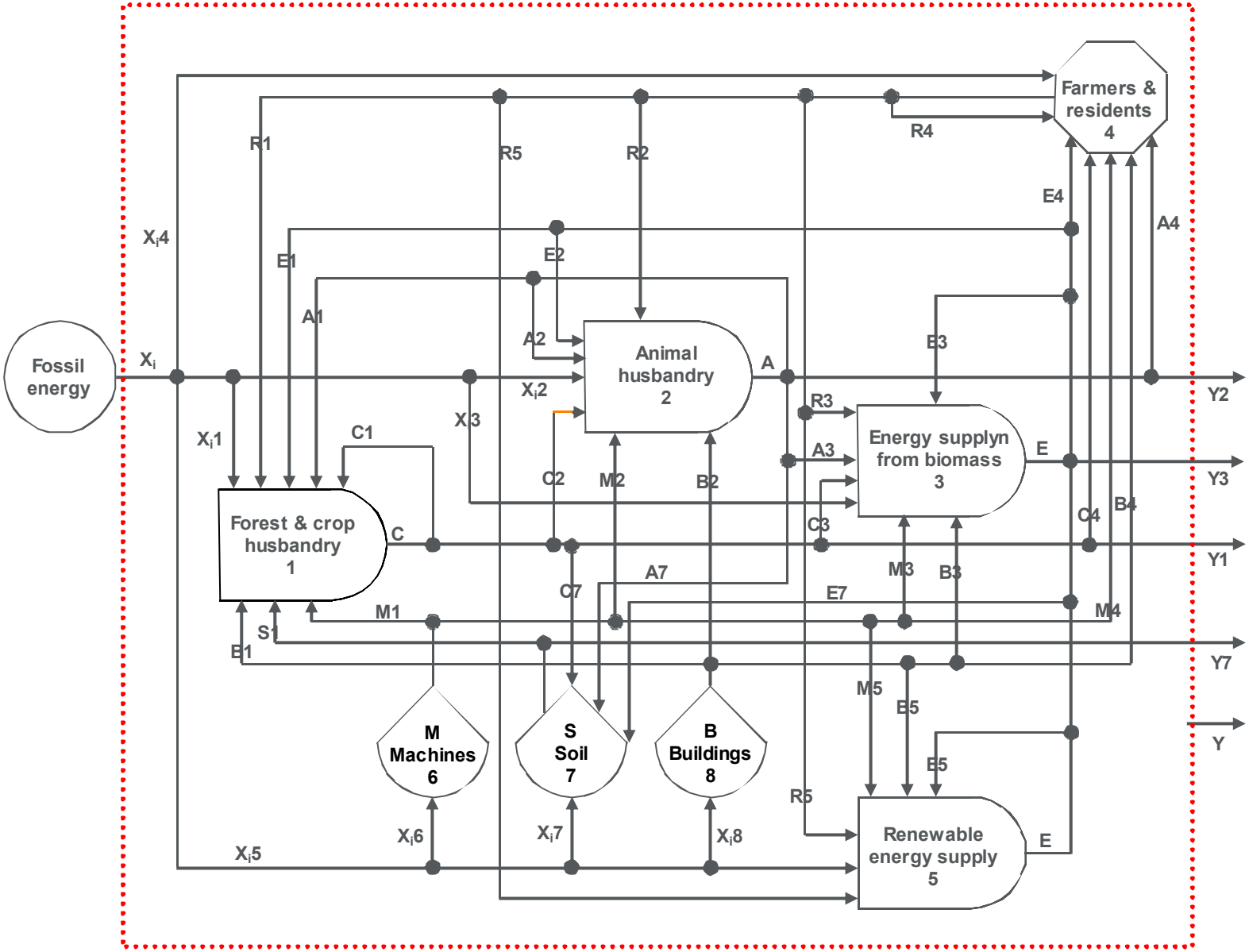
B. The holistic farm model



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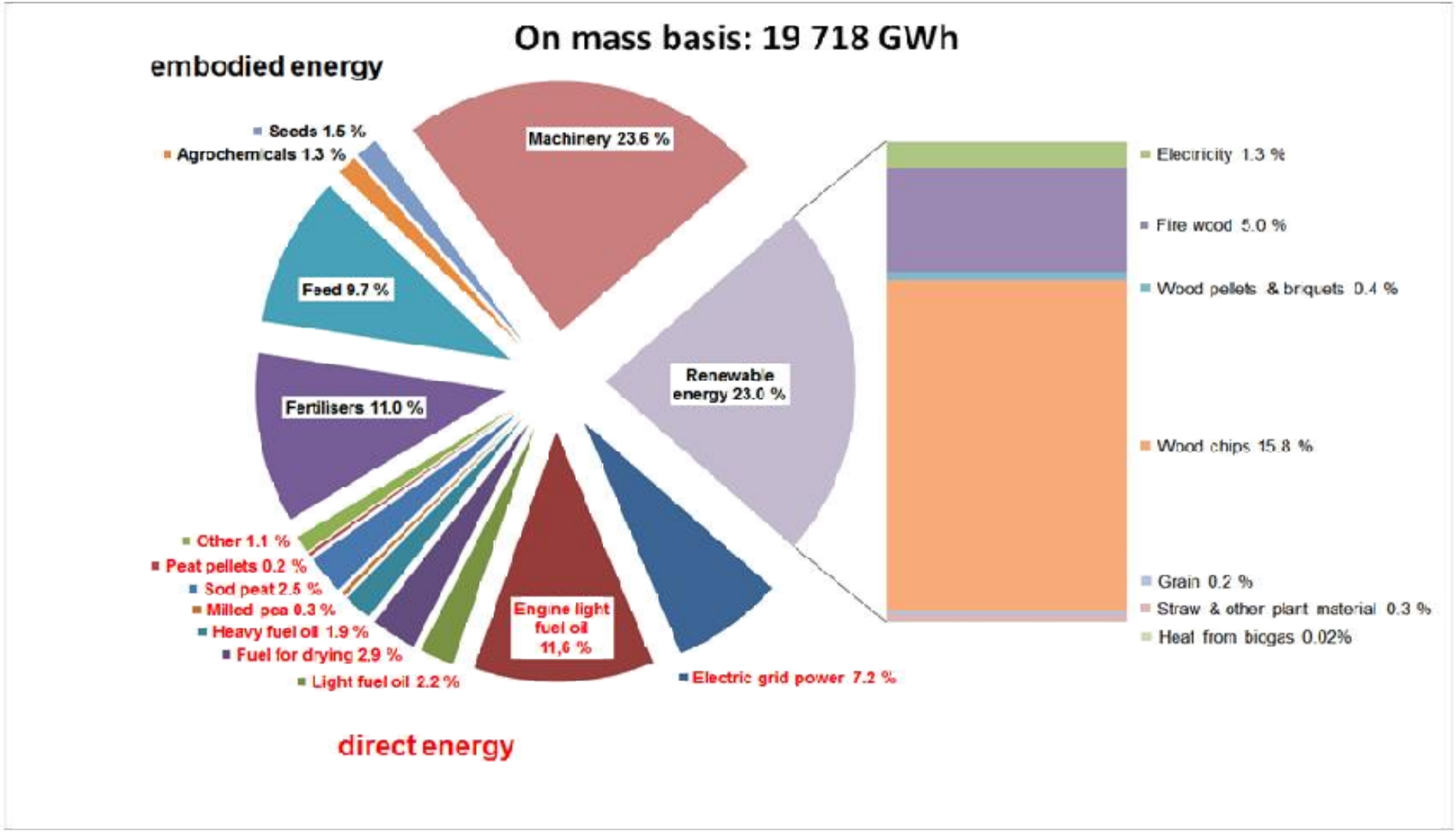
B. The holistic farm model: energy consumption of Finnish agriculture 2010 on mass basis



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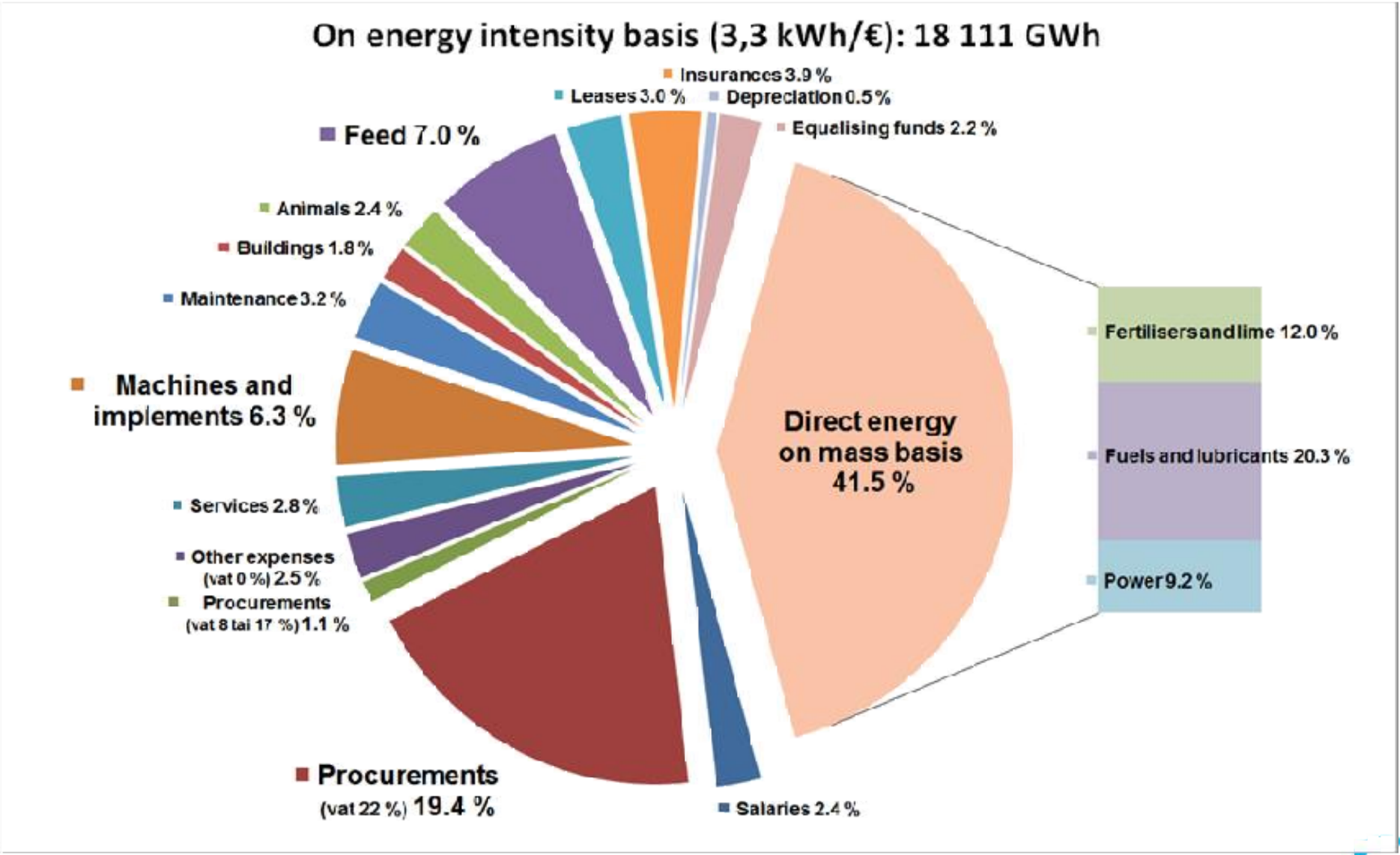
C. Fossil energy input calculation on basis of energy intensity (kWh/€)

World energy intensity		GDP	Fossil energy	Source
kWh/€	MJ/€	€	kWh	
Fossil Energy				
3,38	12,16	3,77E+13	1,27E+14	EIA
3,18	11,44	3,77E+13	1,20E+14	IEA
2,48	8,92	4,76E+13	1,18E+14	World Bank
3,01	10,84			Average
Primary Energy				
3,95	14,23	3,77E+13	1,49E+14	EIA
2,90	10,45	5,09E+13	1,48E+14	IEA
3,06	11,00	4,76E+13	1,46E+14	World Bank
3,30	11,89			Average

C. The holistic farm model: energy consumption of Finnish agriculture 2010 on basis of energy intensity



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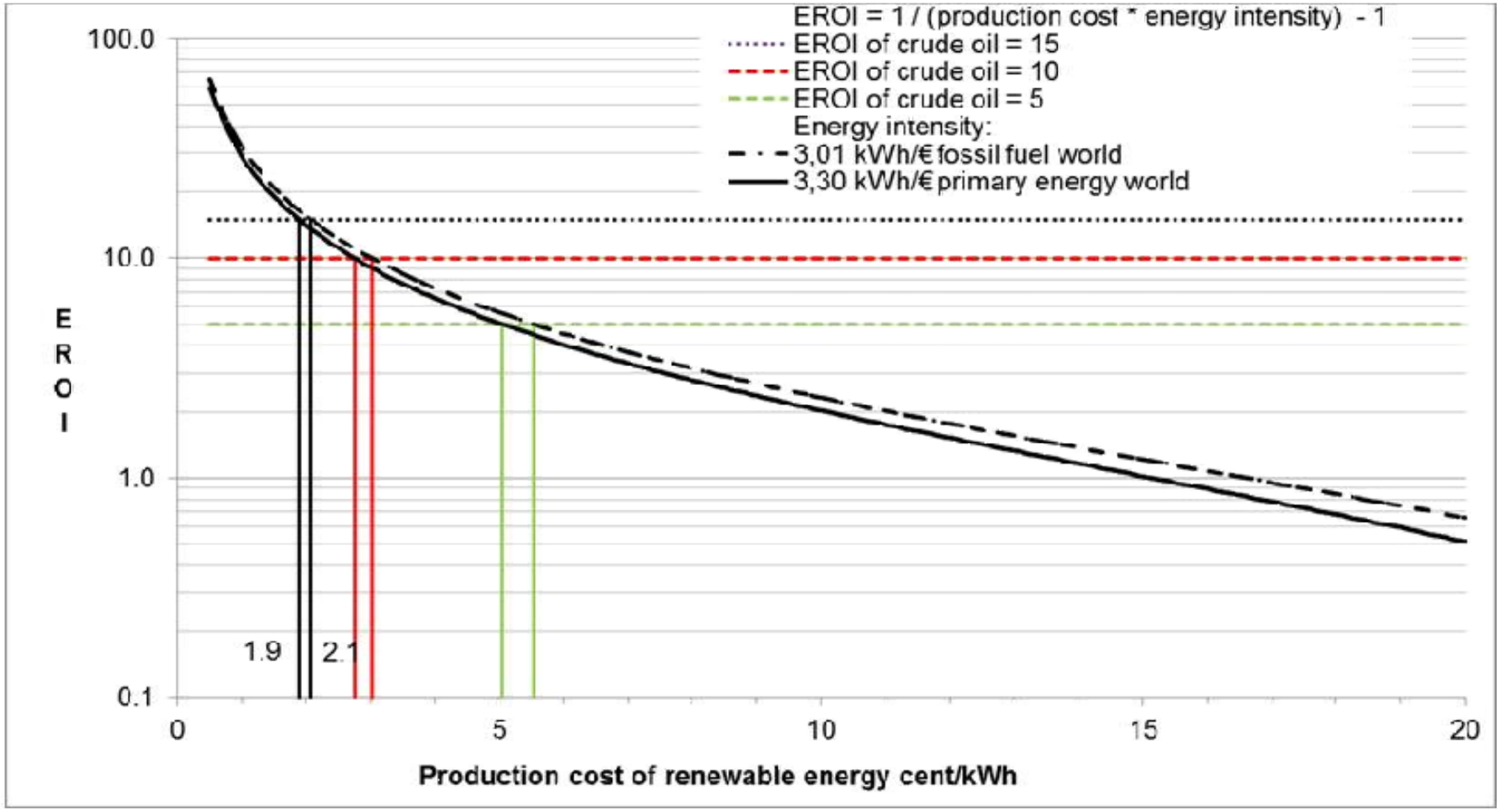
The impact of EROI on the competitiveness of renewable fuels



The EROI depending on cost of renewable energy supply and energy intensity. Given, the EROI of oil is 15, than the resulting supply cost is about 1.9 to 2.1 euro cent/kWh based on the world energy intensity of 3 to 3.3 kWh/€. Raakaöljyn maailman markkinahinta on noin 4.5 sentti/kWh. The difference augments the common wealth of the world economy. 159 litre/barrel (bbl), heating value 1 634,38 kWh/bbl, oil price 100 $/bbl, exchange rate 1,35 $/€

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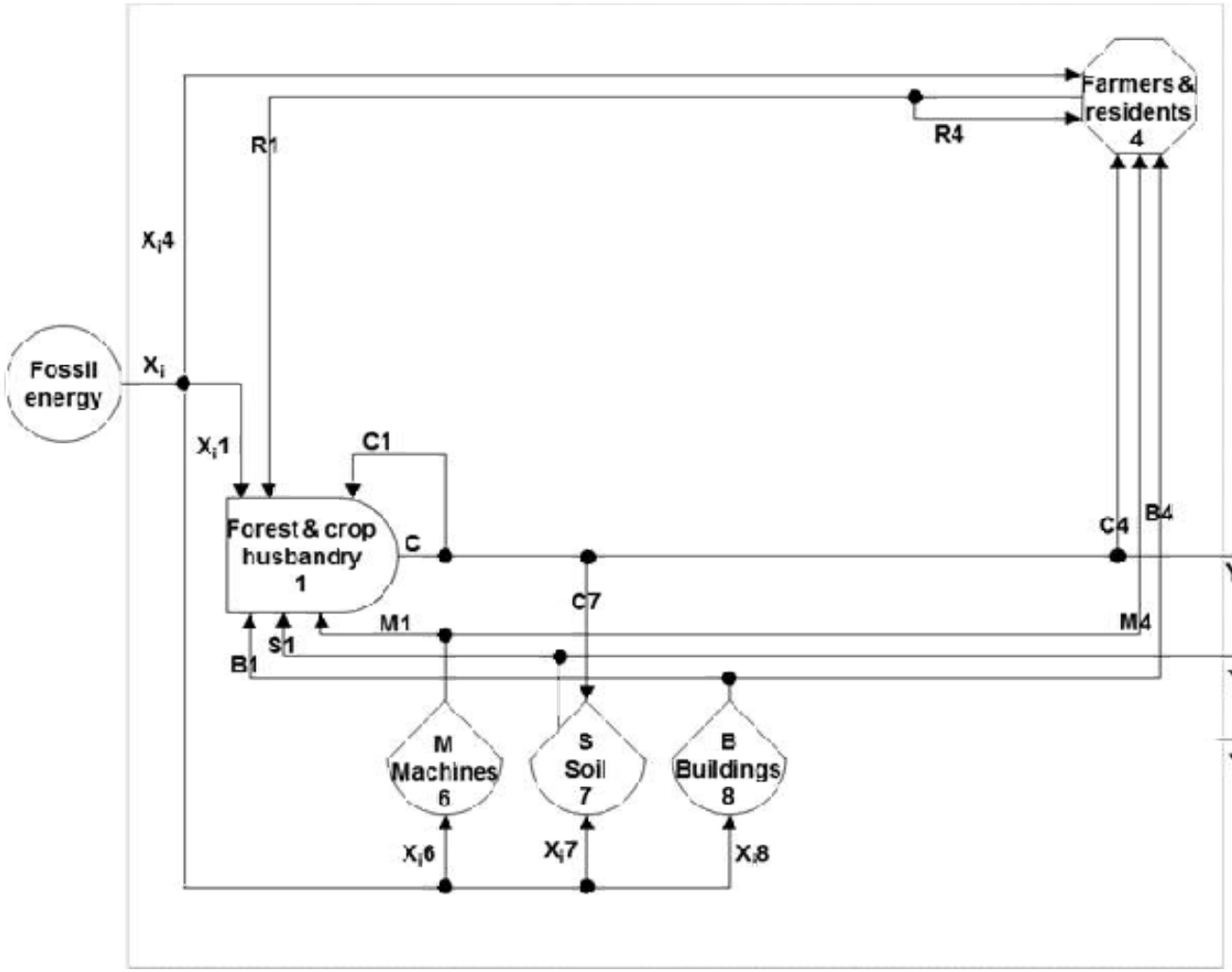
Lessons learned from these facts

- Substitution of fossil fuels by renewable ones increases energy consumption and production costs
- More important is the mitigation potential of embodied energy in goods and services. Organic crop production saves the embodied fossil energy of nitrogen fertilisers and the improved soil fertility may absorb up to 50 % of the CO_2 emissions of agriculture (FAO 2003, Mäder et al. 2002, Gattinger et al. 2012, Skinner et al. 2014.)
- Renewable engine fuel, produced from biomass, is not competitive with fossil fuels in terms of EROI. The same is valid for renewable energy techniques.
- In agriculture the most efficient way to mitigate CO_2 emissions is, to include the entropy of agricultural products in energy policy decision making. Thus, fossil energy outside the farm may be saved, e.g. fibre crops may replace raw material produced by fossil fuels, e.g. insulation material like pulp.

Alternatives to reduce CO_2 emissions: the crop production farm



X_i = direct and indirect fossil energy input (fuels, goods and services, investments):
X_i1 = for crop husbandry; X_i4 = for residents; X_i6 = for machines; X_i7 = for land clearing, drainage; X_i8 = for buildings

C = crop husbandry (process 1):
C1 = seeds, seedlings, C4 = food, fibre, fuel, timber for residents; C7 = crop residues, roots

R = Farmer, residents (work force and consumers 4):
R1 = work for crop husbandry; R4 = work for farm yard and residents

M = machines (storage 6):
M1 = for crop husbandry; M4 = for transport, farm yard

S = soil (nutrients and carbon storage 7):
S1 nutrients for crop husbandry

B = buildings (storage 8):
B1 for crop husbandry; B4 = other farm yard buildings and accommodation

Y = farm output:
Y1 = crop products (food, feed, fibre, fuel, wood); Y7 = soil erosion, nutrient leaching; Y = emissions, waste, used up energy, losses

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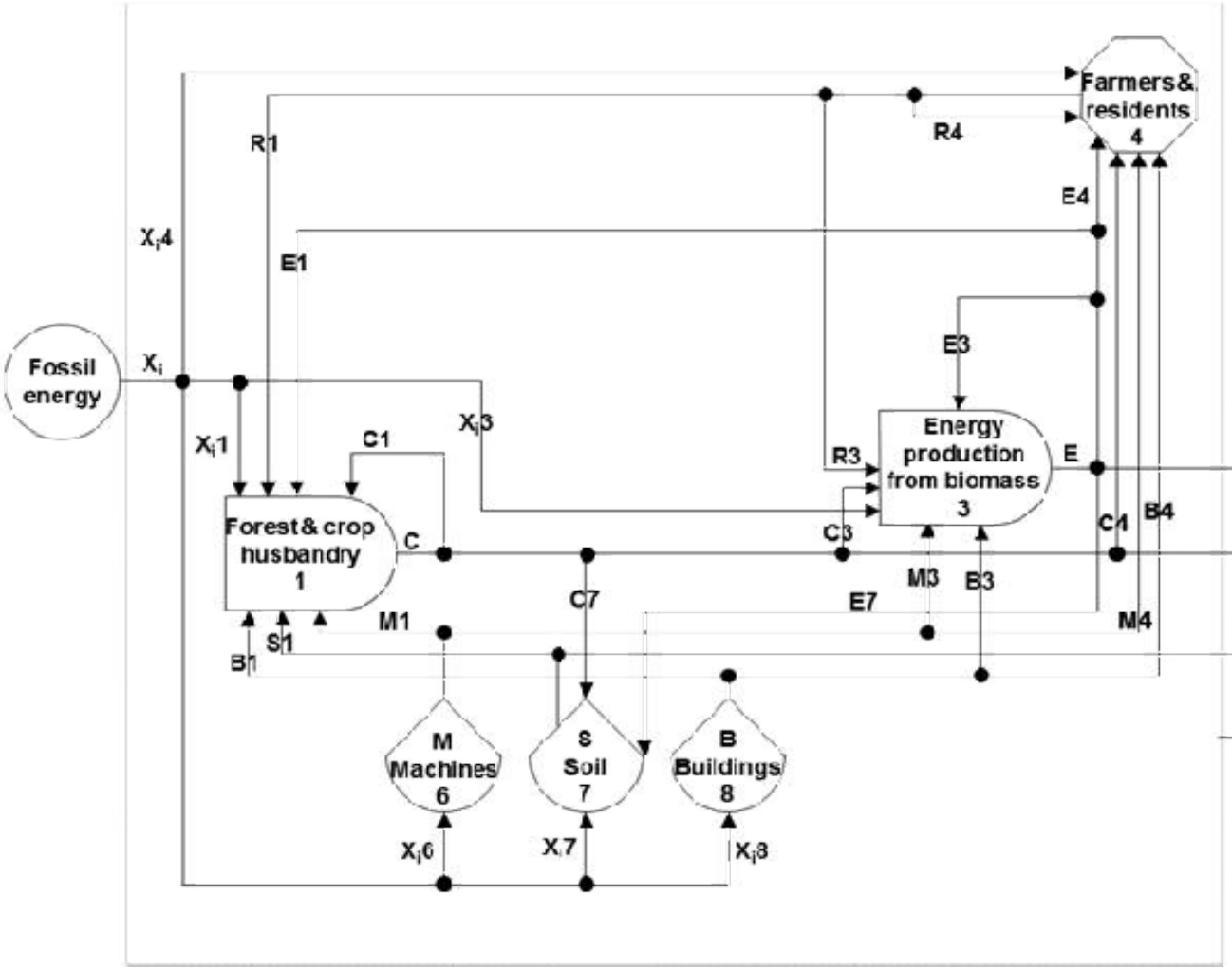
Alternatives to reduce CO_2 emissions: the crop and bio energy production farm



X_i = direct and indirect fossil energy input (fuels, goods and services, investments):
X_i1 = for crop husbandry; X_i3 = for energy production from biomass; X_i4 = for residents; X_i6 = for machines; X_i7 = for land clearing, drainage; X_i8 = for buildings

C = crop husbandry (process 1):
C1 = seeds, seedlings; C3 = crop biomass for energy; C4 = food, fibre, fuel, timber for residents; C7 = crop residues, roots

E = renewable energy from biomass (process 3) and energy plants (process 5):
E1 = renewable energy; E3 = renewable energy feedback; E4 = renewable energy for residents; E7 = residues from renewable energy production

R = Farmer, residents (work force and consumers 4):
R1 = work for crop husbandry; R3 = work for energy from biomass; R4 = work for farm yard and residents

M = machines (storage 6):
M1 = for crop husbandry; M3 = for energy production from biomass; M4 = for transport, farm yard

S = soil (nutrients and carbon storage 7):
S1 nutrients for crop husbandry

B = buildings (storage 8):
B1 for crop husbandry; B3 = for energy production from biomass; B4 = other farm yard buildings and accommodation

Y = farm output:
Y1 = crop products (food, feed, fibre, fuel, wood); Y3 = renewable energy; Y7 = soil erosion, nutrient leaching; Y = emissions, waste, used up energy, losses

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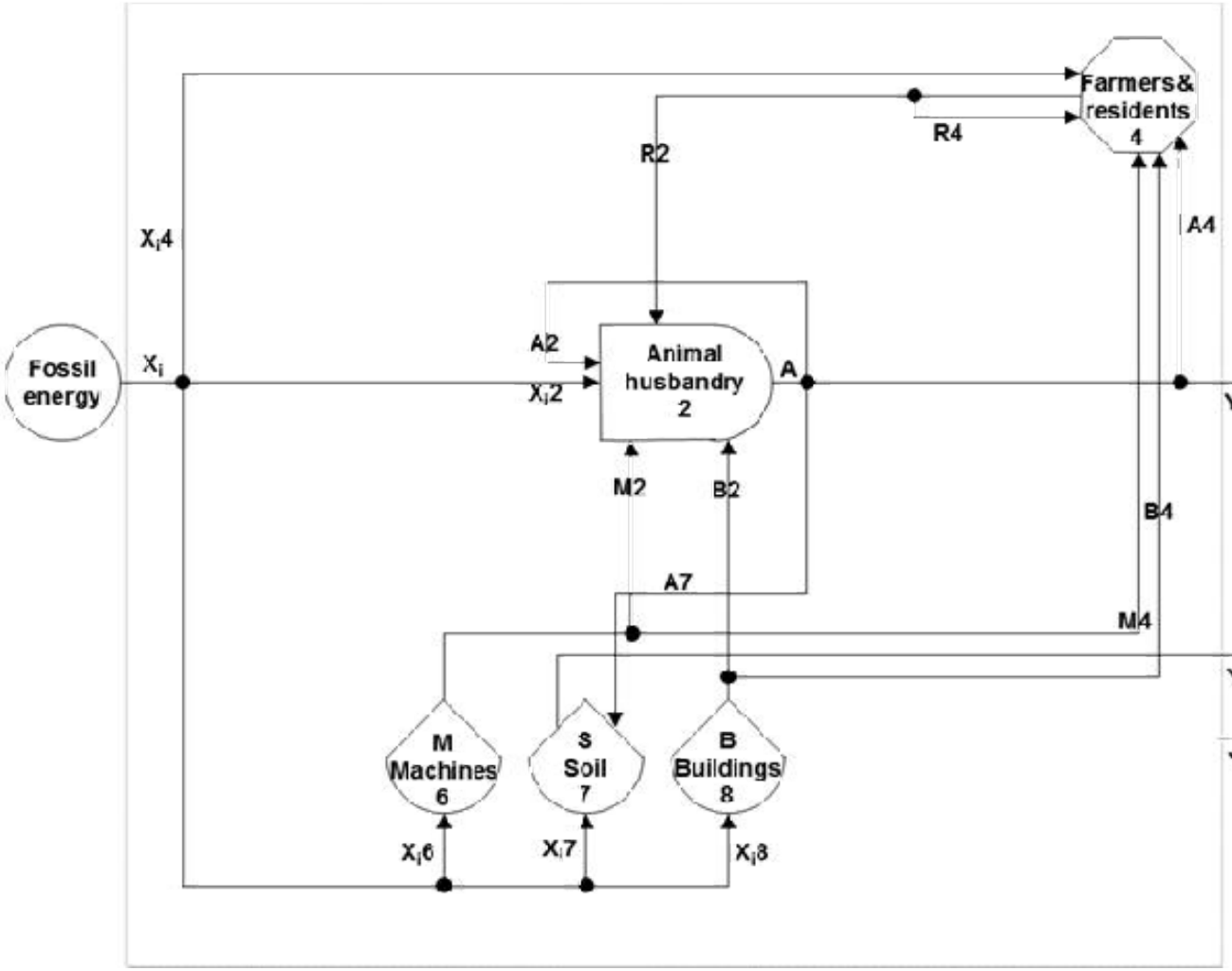
Alternatives to reduce CO_2 emissions: the animal husbandry farm



X_i = direct and indirect fossil energy input (fuels, goods and services, investments):
X_i2 = for animal husbandry; X_i4 = for residents; X_i6 = for machines; X_i7 = for land clearing, drainage; X_i8 = for buildings

A = animal husbandry (process 2):
A2 = offspring; A4 = animal products for residents; A7 = manure, slurry

R = Farmer, residents (work force and consumers 4):
R2 = work for animal husbandry; R4 = work for farm yard and residents

M = machines (storage 6):
M2 = for animal husbandry; M4 = for transport, farm yard

B = buildings (storage 8):
B2 = for animal husbandry; B4 = other farm yard buildings and accommodation

Y = farm output:
Y2 = animals dead or alive, animal products (milk, meat, eggs, honey, fur, sports, green care, etc.); Y7 = soil erosion, nutrient leaching; Y = emissions, waste, used up energy, losses

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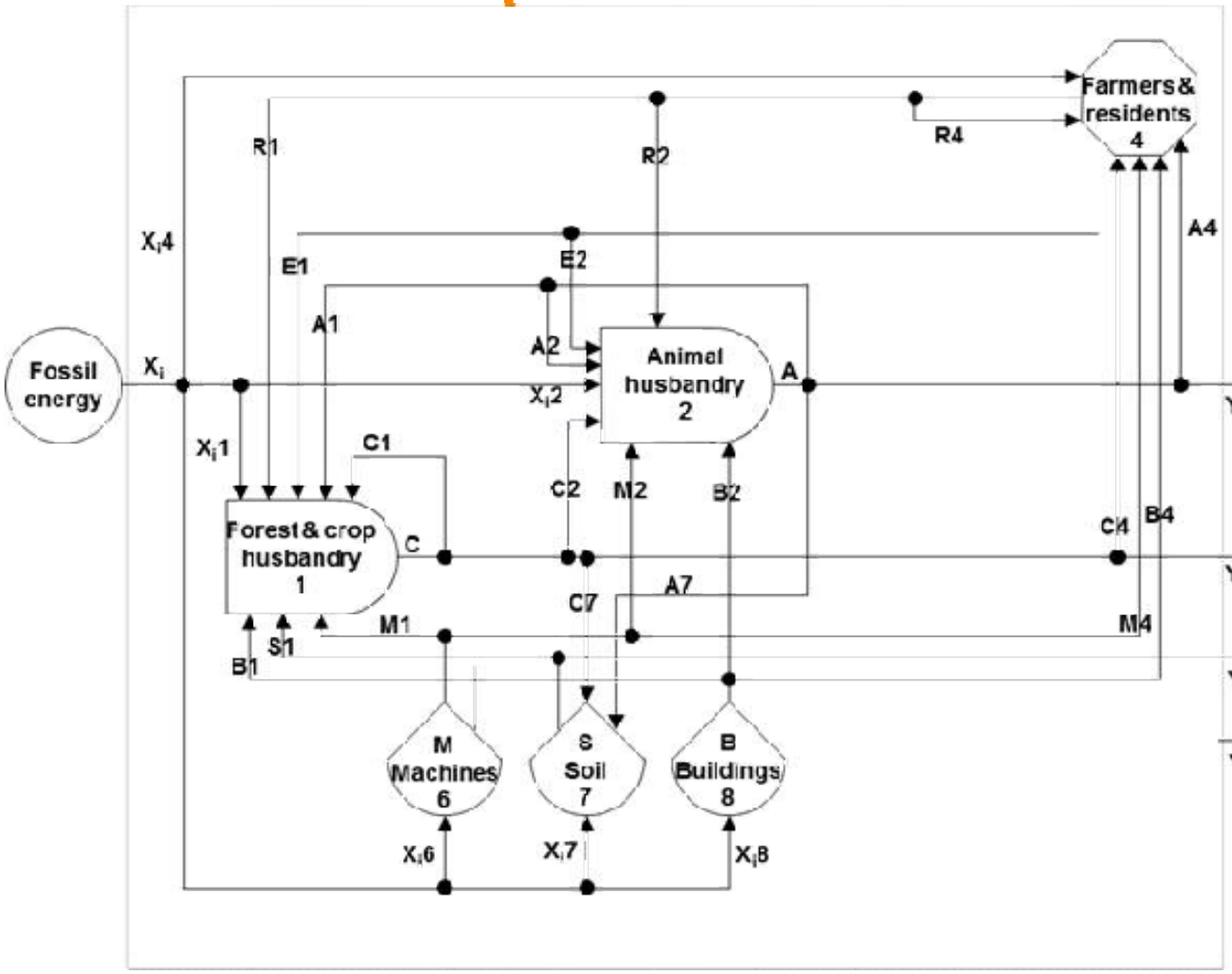
Alternatives to reduce CO_2 emissions: the mixed production farm



X_i = direct and indirect fossil energy input (fuels, goods and services, investments):
X_i1 = for crop husbandry; X_i2 = for animal husbandry; X_i4 = for residents; X_i6 = for machines; X_i7 = for land clearing, drainage; X_i8 = for buildings

C = crop husbandry (process 1):
C1 = seeds, seedlings; C2 = feed, pasture, litter; C4 = food, fibre, fuel, timber for residents; C7 = crop residues, roots

A = animal husbandry (process 2):
A1 = manure, compost, draught; A2 = offspring; A4 = animal products for residents; A7 = manure, sluryy

R = Farmer, residents (work force and consumers 4):
R1 = work for crop husbandry; R2 = work for animal husbandry; R4 = work for farm yard and residents

M = machines (storage 6):
M1 = for crop husbandry; M2 = for animal husbandry; M4 = for transport, farm yard

S = soil (nutrients and carbon storage 7):
S1 nutrients for crop husbandry

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Y = farm output:
Y1 = crop products (food, feed, fibre, fuel, wood); Y2 = animals dead or alive, animal products (milk, meat, eggs, honey, fur, sports, green care, etc.) ; Y7 = soil erosion, nutrient leaching; Y = emissions, waste, used up energy, losses

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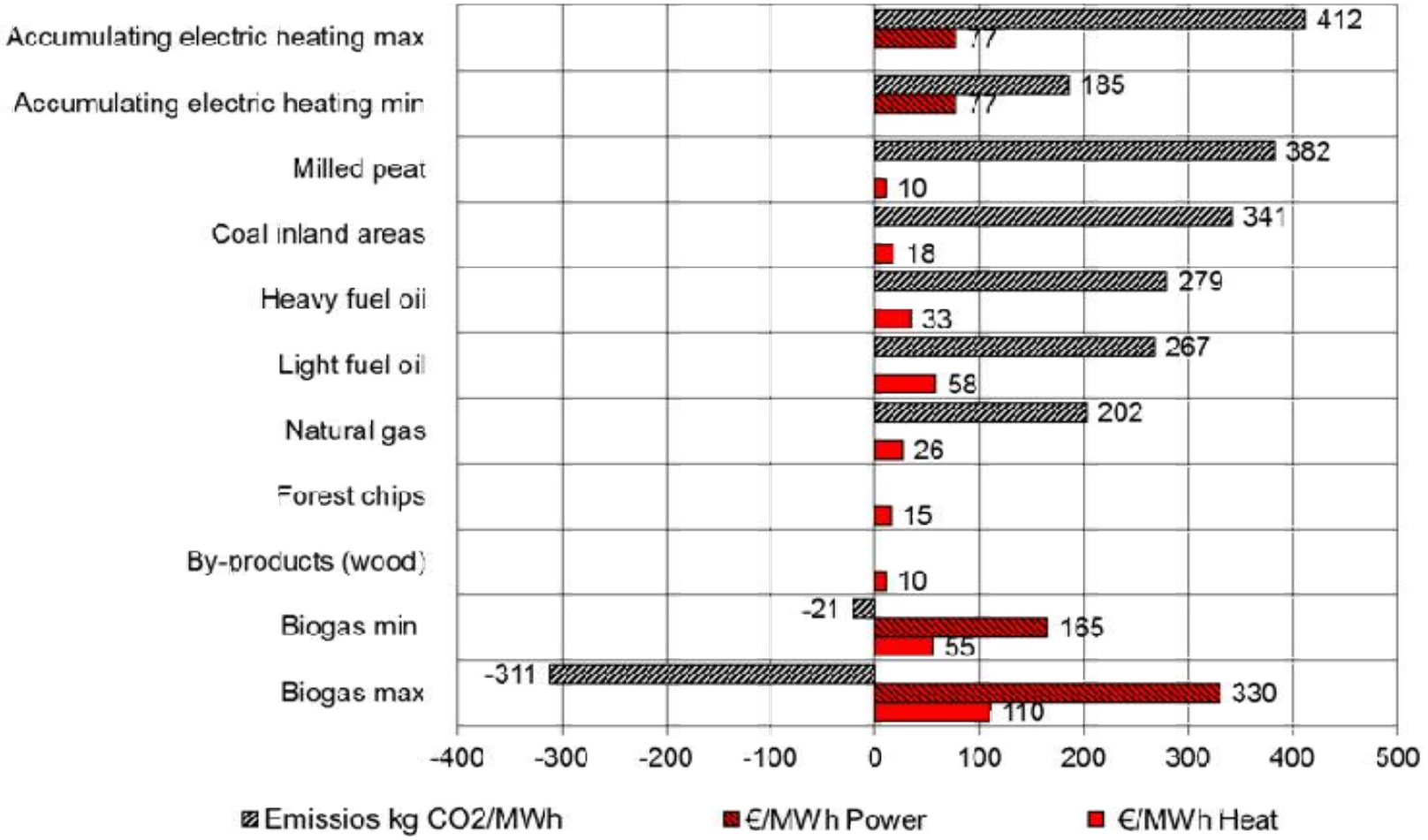
Conclusions

- The EROI of fossil fuels remains probably on high level during the next 50 to 100 years. Oil an gas will be replaced by coal, in Finland also by nuclear power, peat and wood.
- Substitution of fossil fuels by renewable ones causes always additional costs, because all known techniques to provide renewable energy need more energy than fossil fuel exploitation. In other words: Polluting the environment is - for the time being – the most competitive alternative for Finnish farms.

EXAMPLE

The more ”sustainable” environmental pollution the cheaper the energy



Source:

Soimakallio and Saikku, 2012

Ranta, T. 2007

Energiakatsaus 2/2007: Tilasto 3.2007 prices for heat production

Ranta, T. personal commuinication, 11.7.2007

Möller et al. Hrsg. 2007: Effects of biogas digestion of slurry and biomass on productivity and environmental impact in organic farming systems. Endbericht: DBU – AZ 15074, Fachbereich Agrarwissenschaften, Universität Giessen. http://orgprints.org/10970

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Conclusions

- The higher the EROI of renewable fuels, the more economic and efficient the replacement of fossil fuels may become. In other words. the more energy is consumed to supply fuels the less remains for the other sectors of the economy.
- Although biomass is more renewable than fossil fuels, its EROI is lower and substitution will not reduce CO2 emissions
- Climate change may force humankind to reduce fossil fuel consumption. The only sustainable way to achieve this is reduction of fossil fuel exploitation. However this is not possible on national level

Recommendations

- Finnish agriculture consumes more energy than it produces. Therefore substitution of fossil fuel has to start on farm level.
- **Promoting organic production may kill three birds with one stone**:
  1. Fossil energy embodied in agrochemicals is excluded and CO_2 sequestration of the topsoil may be enhanced.
  2. Food from animal production will decrease and food from crop production may increase because of increased biodiversity based on fodder production and crop rotation.
  3. In case that lower crop yields cause increased import of food to maintain the level of self-sufficiency, CO_2 –emissions are outsourced.
- A sustainable way to mitigate CO_2 emissions is, to tax consumption of fossil fuels and natural resources instead of human work.
- Another mean is to introduce the ”polluter pays” principle.

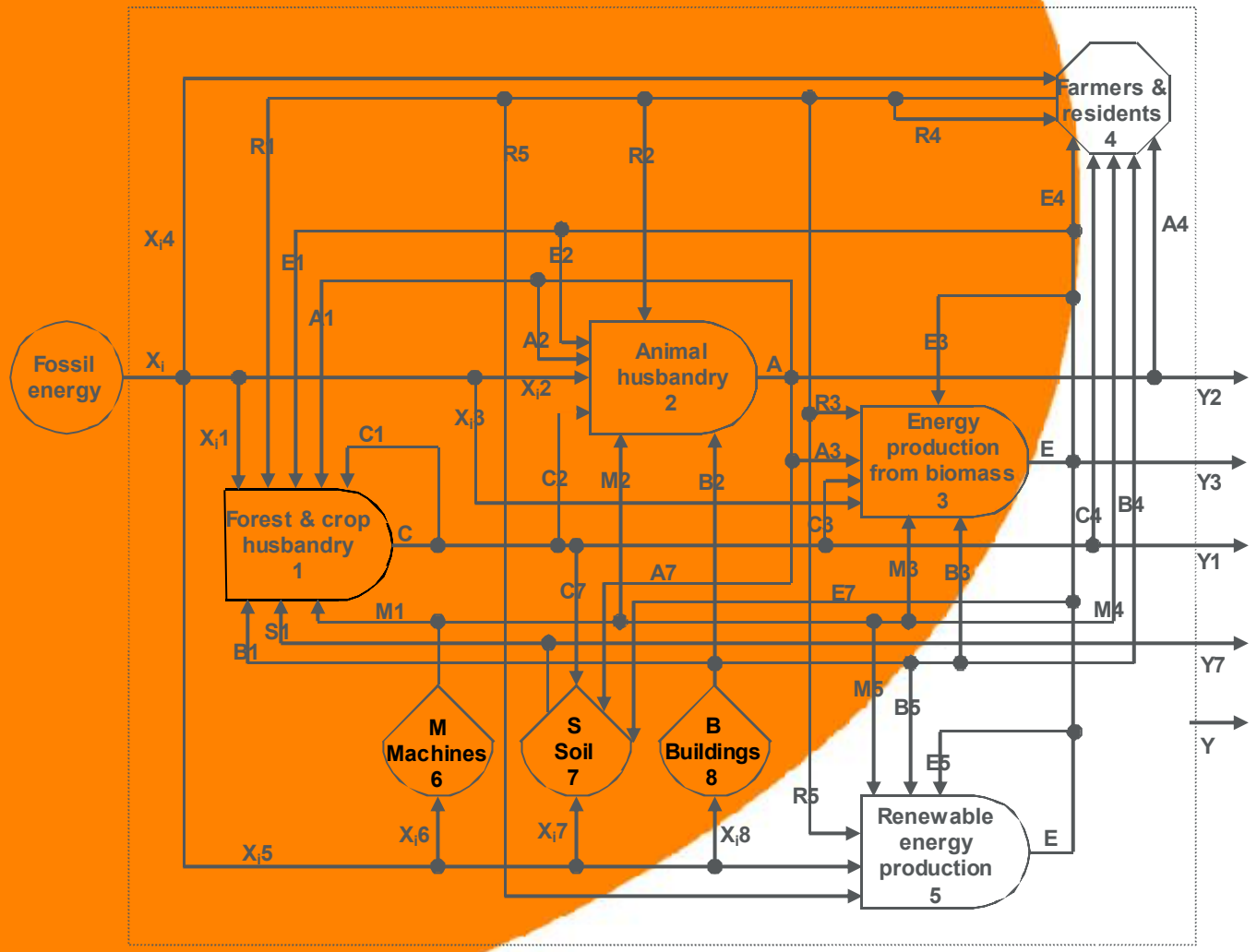
Ways out

- Fossil fuel may be increasingly used to develop techniques for the synthesis of carbon hydrates from CO2 because the conversion efficiency of sun energy into electricity and heat is up to 100 times more efficient than photosynthesis.
- In the light of these techniques and their high efficiencies, energy crops for fuel technologies have no future.
- Outsourcing of CO2 emissions to improve the national CO2 balance: for example import of palm oil, ethanol, feed, food, solar panels.
- Recognising the fact that only agricultural production - and I stress here the word culture – decreases entropy.
- This is the strongest argument to justify the existence of an agricultural ministry although the economic impact of agriculture upon the gross domestic product is quite small:.
- Thinking in systems instead of chains requires also a paradigm change as the future researcher at MIT Otto Scharmer states:

”Moving from Egosystem to Ecosystem Awareness“

Otto Scharmer, Massachusetts Institute of Technology (MIT), Presencing Institute, www.presencing.com.

Thank you!



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