SUSTAINABILITY WORKSHOP
24.-26. SEPTEMBER, SYKE, HELSINKI
Carbon Cycling Model and Sustainability Analysis
SAMSØ

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SAMSØ
Renewable Energy Island

- **Area 114 km^2**
- **4000 Inhabitants – during summer + 4000 tourists. Impact corresponding to 5000 inhabitants on an average annual basis**
- **Density 46 inh included impacts of tourism / km^2**
- **Samsø won in 1997 a competition: the best plan for a renewable energy island in Denmark**


Kattegat
Nordjylland
Denmark
Vesterhavet
Copenhagen
Sylt
Schleswig-Holstein
Image © 2013 TerraMetrics
© 2013 Google
© 2009 GeoBasis-DE/BKG
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
55°56'09.75" N 11°45'48.69" E elev -1 m
Google earth
Eye alt 604.53 km


Samsø
Samsø
Samsø Bælt
Endelave
Image © 2013 TerraMetrics
© 2013 Google
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
55°52'05.00" N 10°40'38.94" E elev 0 m
Google earth
Eye alt 45.86 km


BONUS

Samsø Energy Academy

Carbon is participating in many processes on the island included the photosynthesis of decomposition of organic matter in soil

- **THEREFORE WE NEED A CARBON MODEL OF THE ISLAND AND WE NEED**
- **TO DETERMINE THE SUSTAINABILITY**

Two types of energy

- **Work energy – useful energy that can do work**
- **Heat energy at the temperature of the environment – cannot do work (no gradient in temperature)**
- **Energy is conserved – therefore energy efficiency is always 100%**
- **But by all activities work energy is lost as heat energy – efficiency= work energy obtained / work energy used for instance in a power plant**
- **Efficiency = Work energy of the electricity / chemical energy of fossil fuel**

Samsø: energy in TJ (2007)

Item	Consumption	Production
Electricity	285.7	386.0
Heat	140.4	66.3
Gasoline + diesel	86.3	
Total	512.4	452.3

- Plan 2020: Complete fossil fuel free

The sustainability examination of Samsø encompasses two analyses:

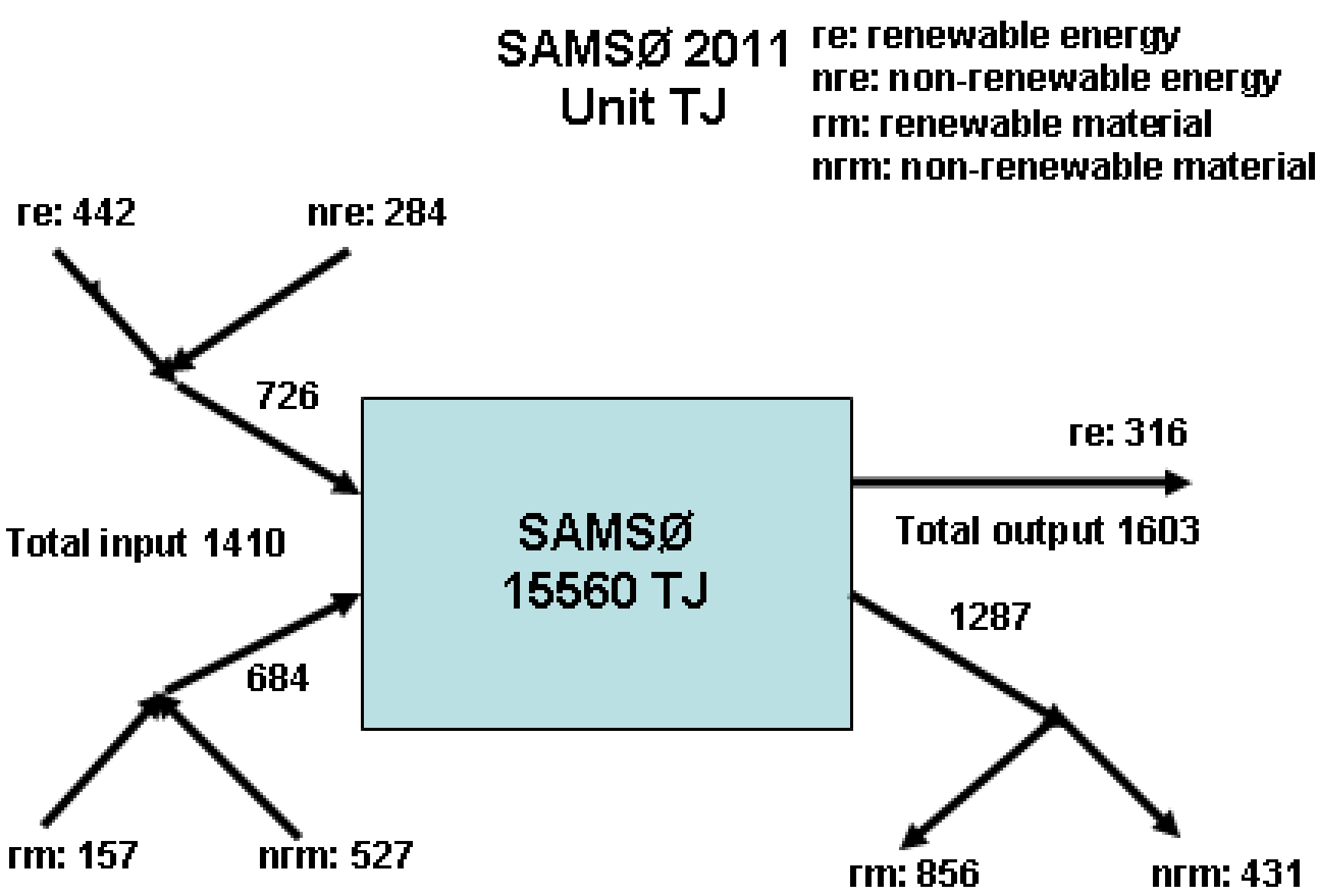
- 1) Determination of the annual change in work energy capacity of the island, included the nature. It is used as an expression for the sustainability
- 2) A total carbon balance to determine the annual emission of carbon dioxide and methane
- NOTICE THAT THE WORK CAPACITY OF AN ECOSYSTEM HAS BEEN USED TO EXPRESS THE SUM OF ALL ECOSYSTEM SERVICES OFFERED BY THE ECOSYSTEM

Sustainability can be expressed by work energy:

- Work energy = the part of the total energy that can do work in contrast to the heat released at the temperature of the environment that cannot be utilized to do work, because there is no gradient (temperature difference). All activities require work-energy – therefore it seems reasonable to apply work-energy to express sustainability
- Both consumption of mass and energy can be expressed as work energy. We can furthermore distinguish between renewable work energy and material and non-renewable work energy and material

Annual work energy changes on Samsø TJ (year)

Item	Comsumption	Production
Electricity	285.7	386.0
Heat	140.4	66.3
Gasoline + diesel	86.3	
Food	27.0	
Milk		1.8
Potatoes		149.6
Vegetables		112.2
Grain		271.2
Pigs		106.3
Pesticides	1.0	
Other items	340.0	
Timber / forest growth	47.0	804.0
Total	927,4	1897,4

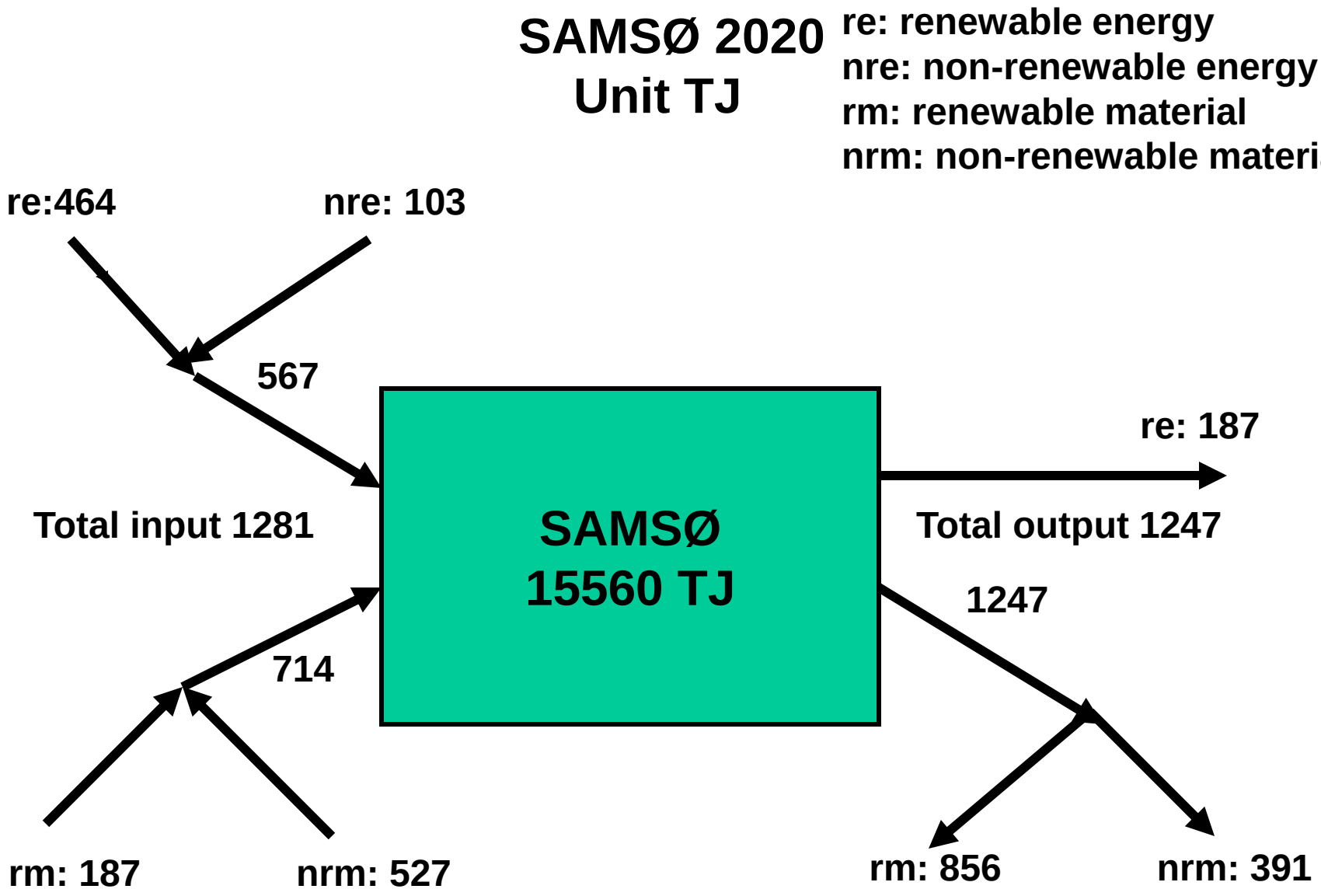

SAMSØ 2011
Unit TJ
re: renewable energy
nre: non-renewable energy
rm: renewable material
nrm: non-renewable material
re: 442
nre: 284
726
Total input 1410
SAMSØ
15560 TJ
re: 316
Total output 1603
1287
684
rm: 157
nrm: 527
rm: 856
nrm: 431

Plan year 2020 (scenario)

5% higher production of renewable energy

Fossil fuel still used to day for cars, heating in a few houses and in the industries will be replaced by electricity produced on the island

3) 1/3 of the fossil fuel to day applied on the ferries is replaced by electricity or biogas


SAMSØ 2020
Unit TJ
re: renewable energy
nre: non-renewable energy
rm: renewable material
nrm: non-renewable material
re:464
nre: 103
567
Total input 1281
SAMSØ
15560 TJ
re: 187
Total output 1247
1247
714
rm: 187
nrm: 527
rm: 856
nrm: 391

3 Sustainability Indicators are applied:

1) Structure indicator: % work energy needed to maintain the work energy storage, SI
2) Renewable work energy input / total work energy input, R-ratio
3) Export or loss of work energy/ import or input of work energy, E/I ratio

Results, comparison 2011/2020

	2011	2020	Ideal
SI	0.090	0.082	low
R-ratio	0.43	0.51	1.00
E/I ratio	1.14	1.12*)	1.00**)

All three indicators show improvements

from 2011 to 2013

***) can be reduced to 1.00 by supplementary crops**

****) but export as work energy is used (electricity and food) beneficially outside Samsø**

5 sectors, 2011

Sector	WE*)	SI	R-ratio
Public	9191	0.051	0.047
Private	2187	0.094	0.62
Agriculture	4996	0.103	0.828
Industry	754	0.086	0.393
Nature	6562**)	sun	1.00

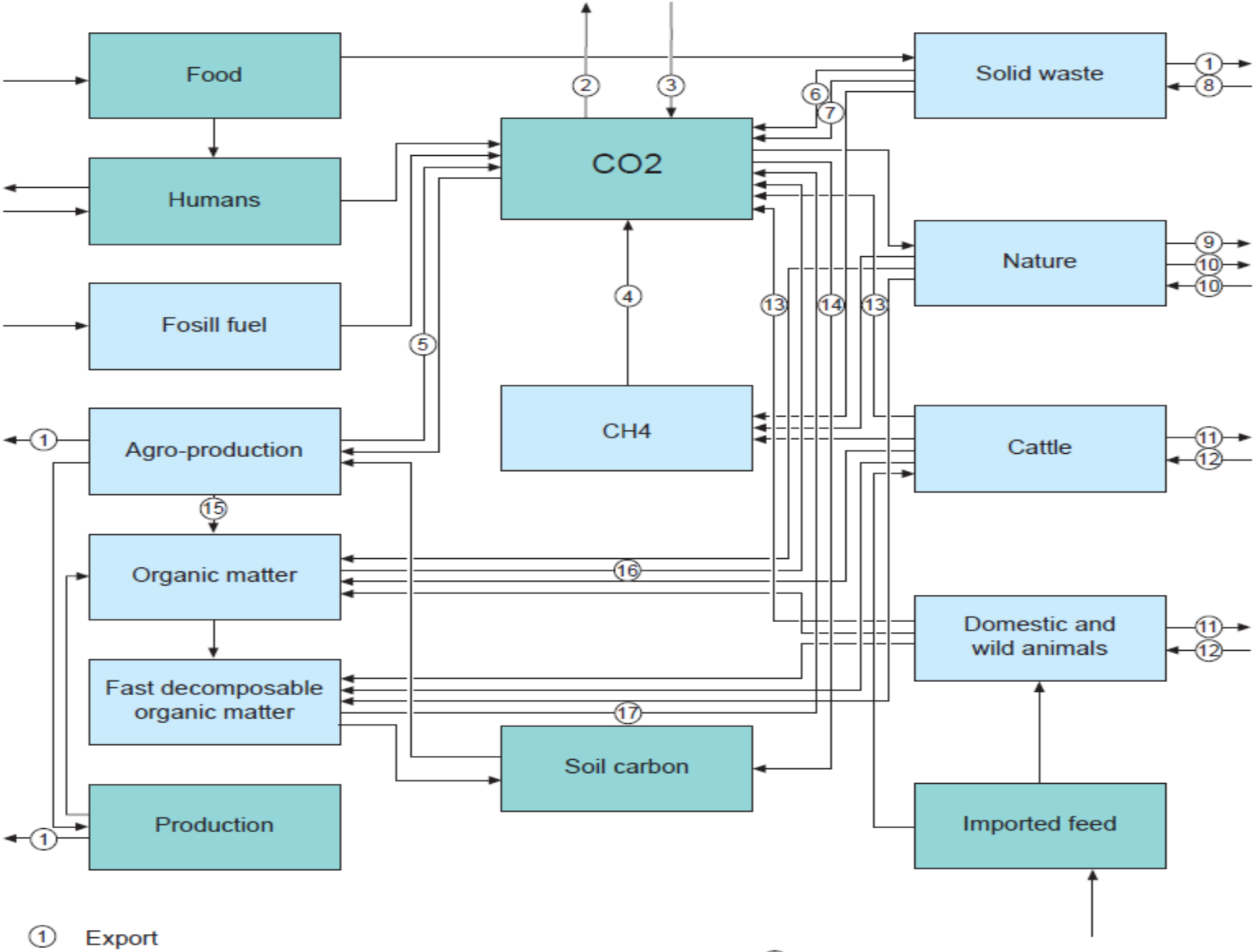
*)WE= work energy stored in the sector

**) without incl. of information – eco-exergy not applied

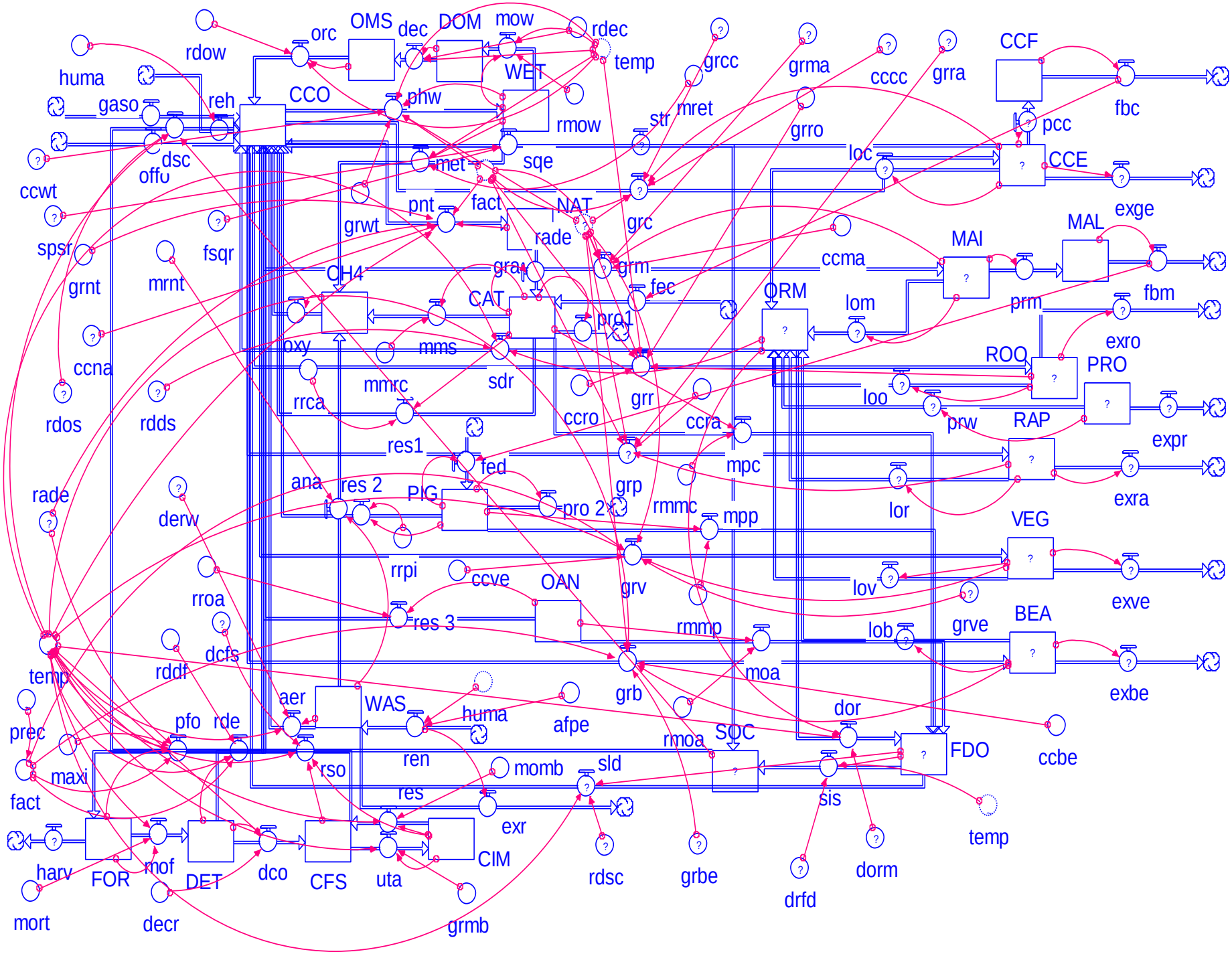
SI is reasonable for all 5 sectors, but R-ratio is much too low for the public sector and too low for the industrial sector

Samsø, a renewable energy island in Denmark

- Notice that preservation of ecosystems implies that the work capacity of nature has been maintained or increased.
- A carbon model with 26 state variables is developed to find the total production and consumption of green house gases



① Export
② Electricity export
③ Electricity import
④ Oxidation
⑤ Straw used for heating
⑥ Incineration
⑦ Decomposition
⑧ Renovation
⑨ Environmental planning and management
⑩ Harvest
⑪ Production
⑫ New animals
⑬ Respiration
⑭ Adsorption
⑮ Loss
⑯ Slow decomposition
⑰ Fast decomposition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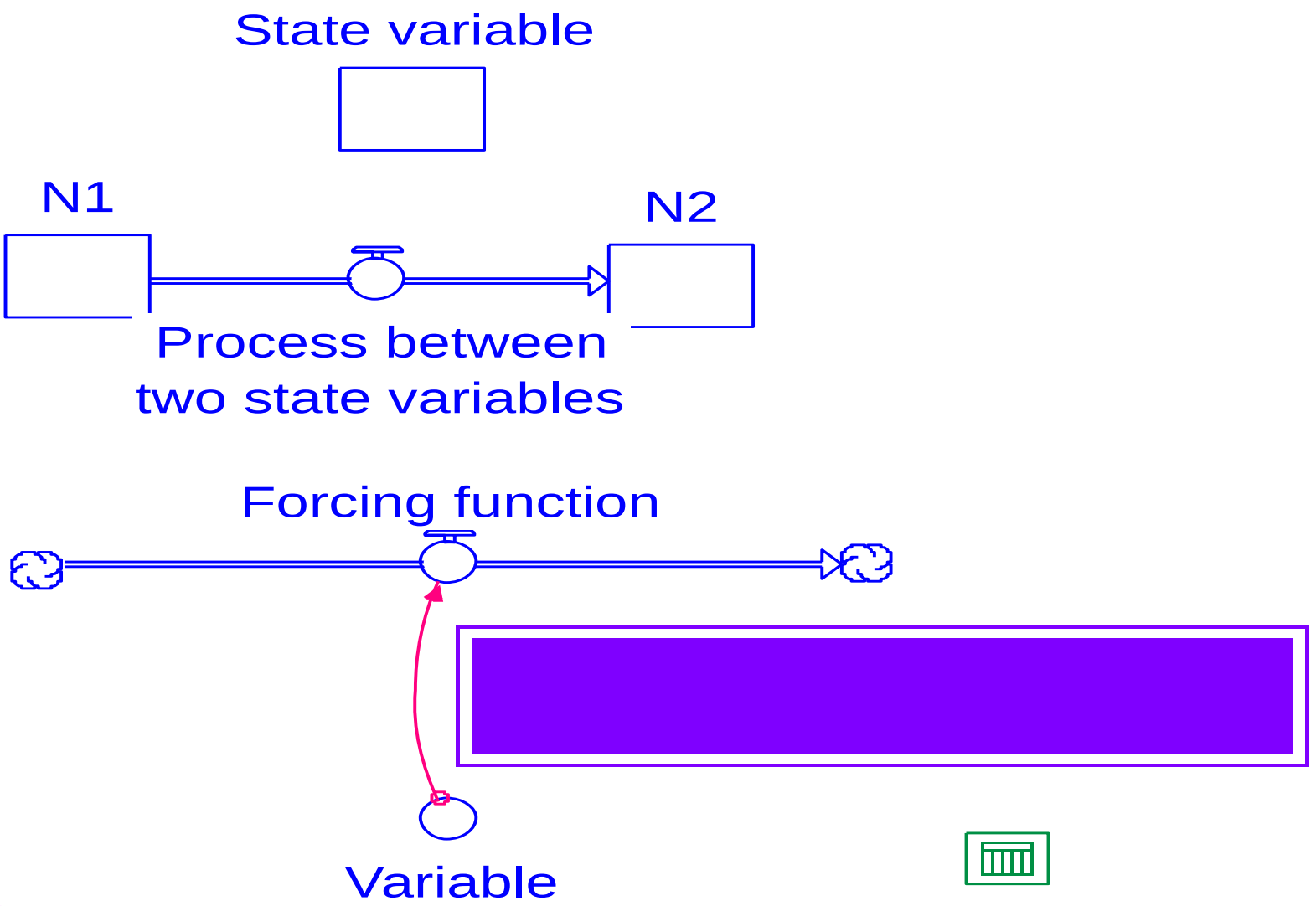
The model is developed by the software STELLA:



Modellen has 26 state variable (as t C): Abbreviation by three capital letters and the definition. Alphabetic

BEA(t) = Berries as f(time)

CAT(t) = Cattle as f(time)

CCE(t) = Wheat and Barley on Fields as f(time)

CCF(t) = Wheat and Barley stored on the island, to be used as cattle feed as f(time)

CCO(t) = Total Carbon Dioxide Production – Uptake as f(time)

CFS(t) = Carbon stored in the Forest Soil as f(time)

CH4(t) = Carbon in form of Methane produced as f(time)

II State variables Abbreviation by three capital letters and the definition. Alphabetic

CIM(t) = Carbon of Microorganisms in Forest Soil.

DET(t) = Detritus / Dead Organic Matter in the Forest Soil as f(time)

DOM(t) = Detritus / Dead Organic Matter in Wetland Soil as f(time)

FDO(t) = Carbon in fast decomposable Organic Matter as f(time)

FOR(t) = Carbon in Trees and Plants in the Forest as f(time)

MAI(t) = Maize on fields as f(time)

MAL(t) = Maize stored on the island to be used as pig feed as f(time)

NAT(t) = Carbon in Nature as f(time)

III state variables (continued)

OAN(t) = Carbon in other Animals than Cattle and Pigs (both domestic and natural animals) as f(time)

OMS(t) = Organic Matter (fresh) in agricultural Soil as f(time>)

ORM(t) = Organic Matter in Wetland Soil as f(time)

PRO(t) = Products (food, mainly vegetables) processed (as f(time)

RAP(t) = Rape Plants as f(time)

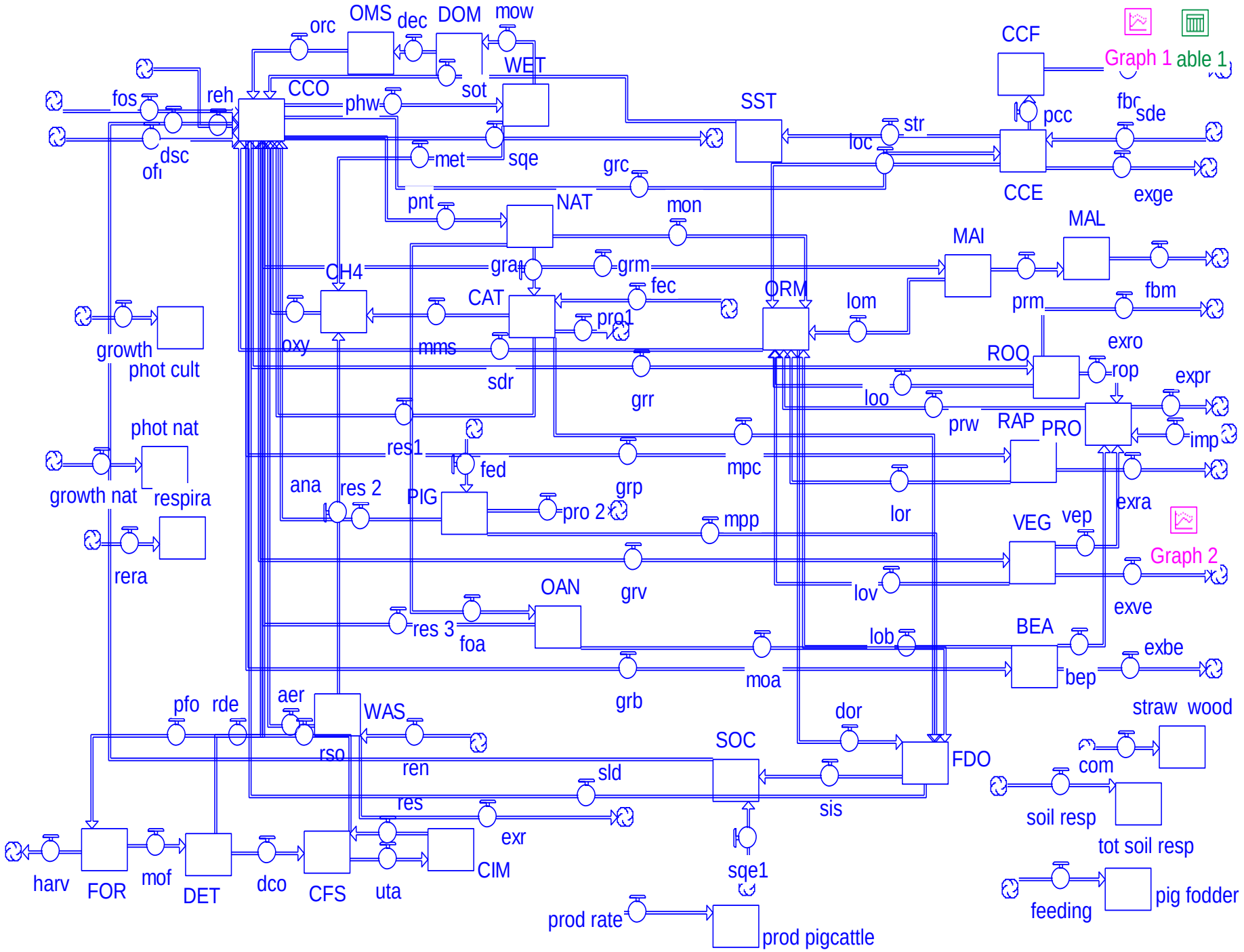
ROO(t) = Root Fruits included potatoes,

SOC(t) = Soil Organic Carbon, relatively stable fraction

SST = Storage of straw for provision of heating

VEG(t) = Vegetables as f(time)

WAS(t) = Waste as f(time)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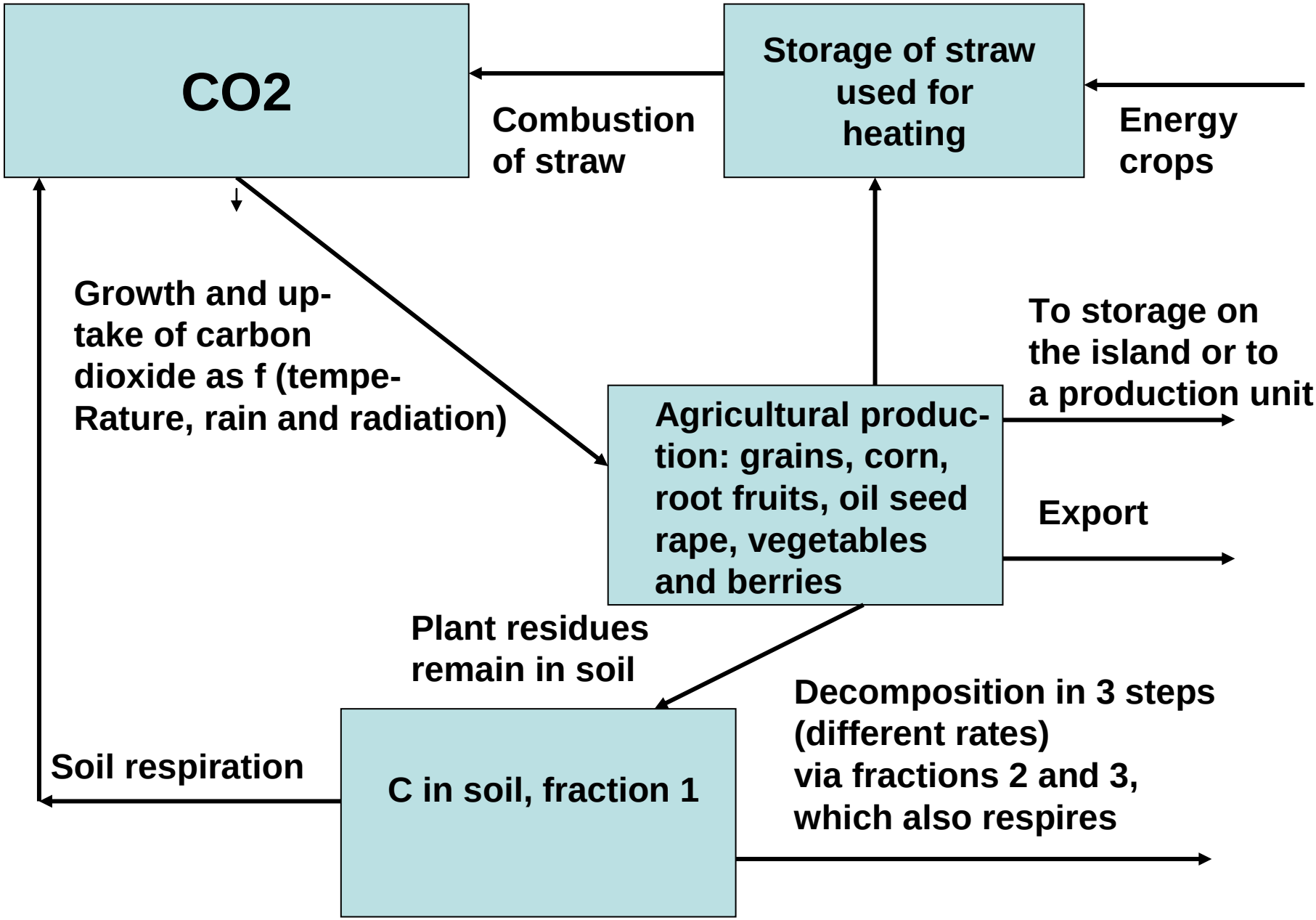
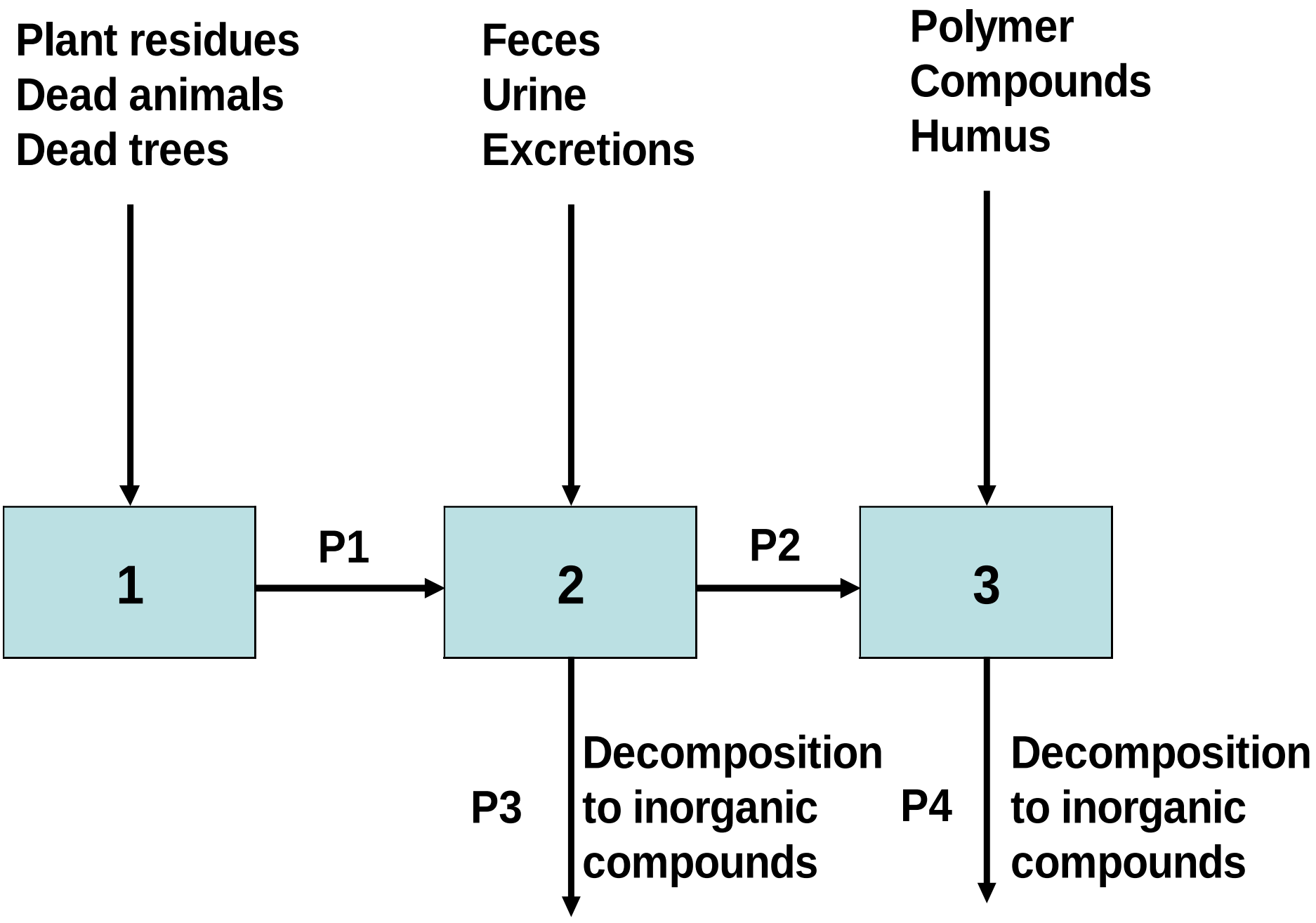

CO2
Combustion of straw
Storage of straw used for heating
Energy crops
Growth and up-take of carbon dioxide as f (tempe-Rature, rain and radiation)
To storage on the island or to a production unit
Agricultural produc-tion: grains, corn, root fruits, oil seed rape, vegetables and berries
Export
Plant residues remain in soil
Decomposition in 3 steps (different rates) via fractions 2 and 3, which also respires
Soil respiration
C in soil, fraction 1


Plant residues
Dead animals
Dead trees
Feces
Urine
Excretions
Polymer
Compounds
Humus
1
P1
2
P2
3
P3
Decomposition
to inorganic
compounds
P4
Decomposition
to inorganic
compounds

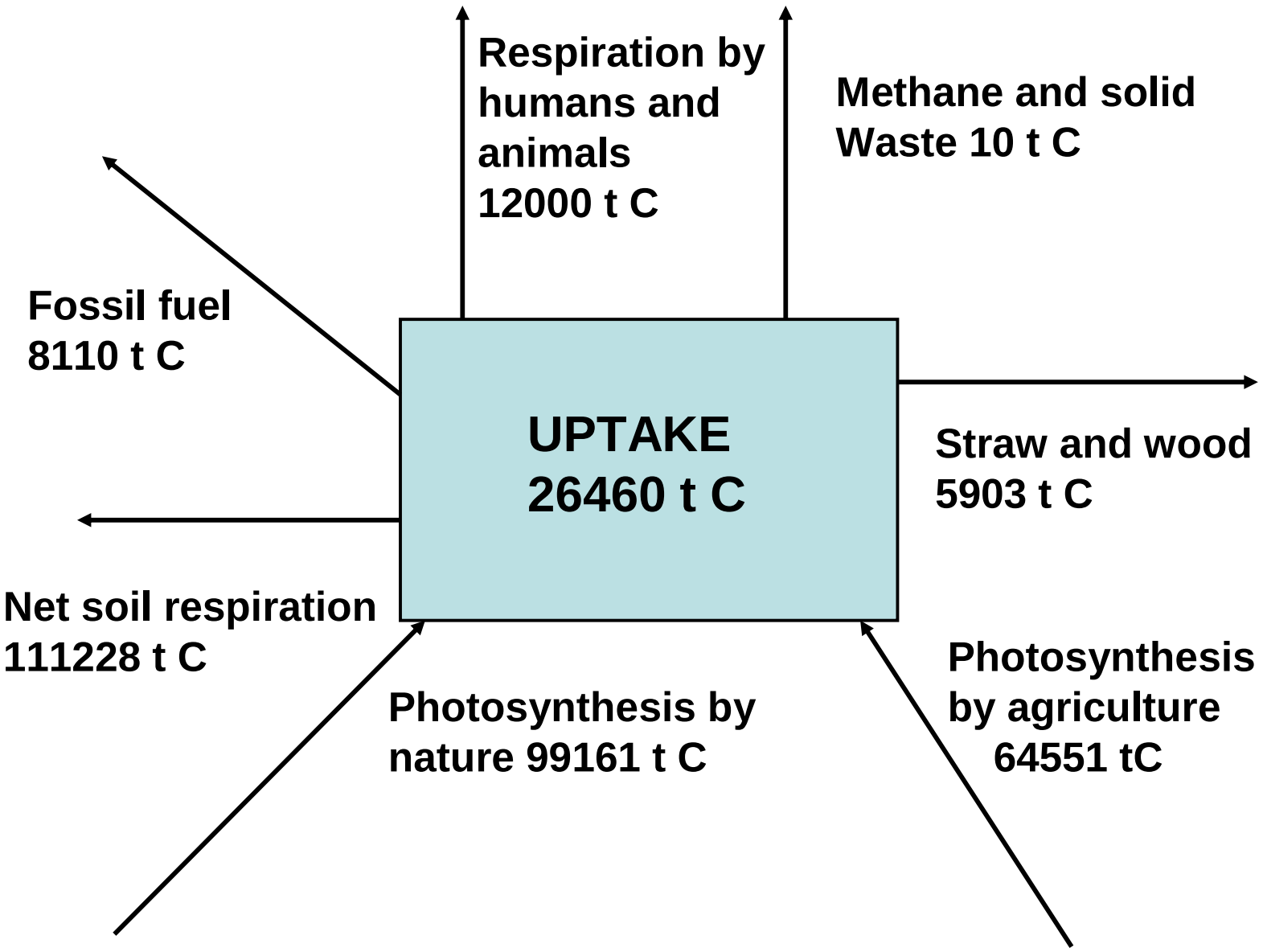
The work energy balance and the carbon model are applied as management tools

For all suggestions about environmental changes and changes of the energy supply or energy consumption, it is possible before the decision is taken to express the consequences for the emission of green house gases and for the development of the sustainability

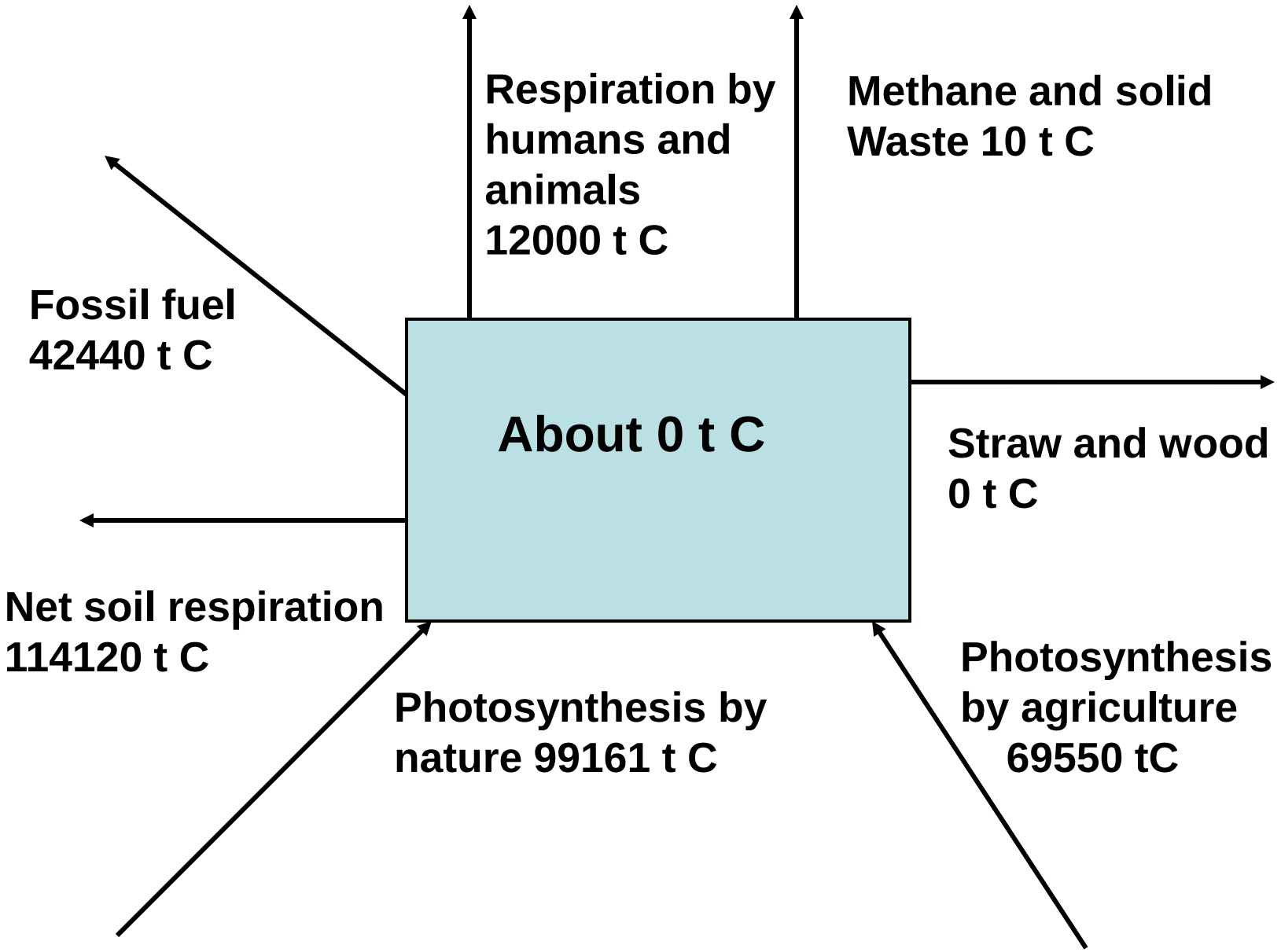
Questions to the Model.

1) El or biogas for the vehicles and ferries?
2) El heating for the “last” individual houses?
3) If biogas, which “raw material” should be applied?
4) No tillage or reduced tillage – what can it give in reduced carbon dioxide emission?
5) How much can we reduce the carbon dioxide emission by supplementary crops?

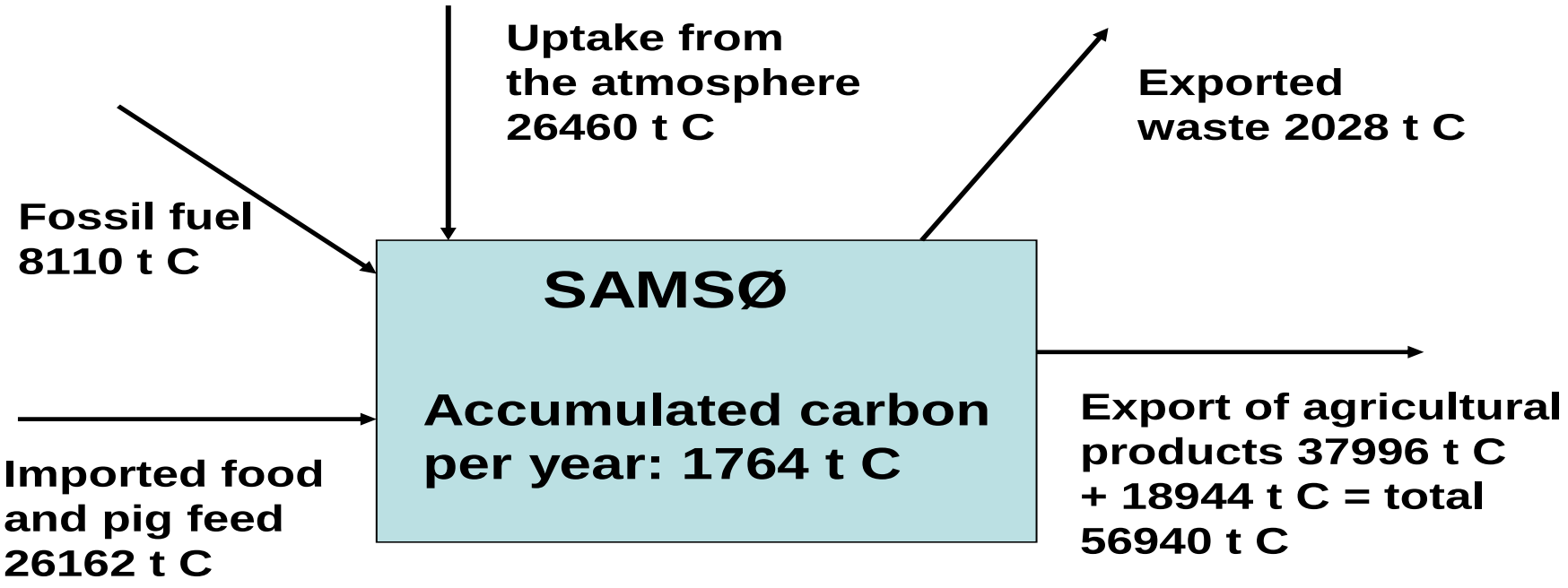
Annual Exchange of Carbon Dioxide with the Atmosphere



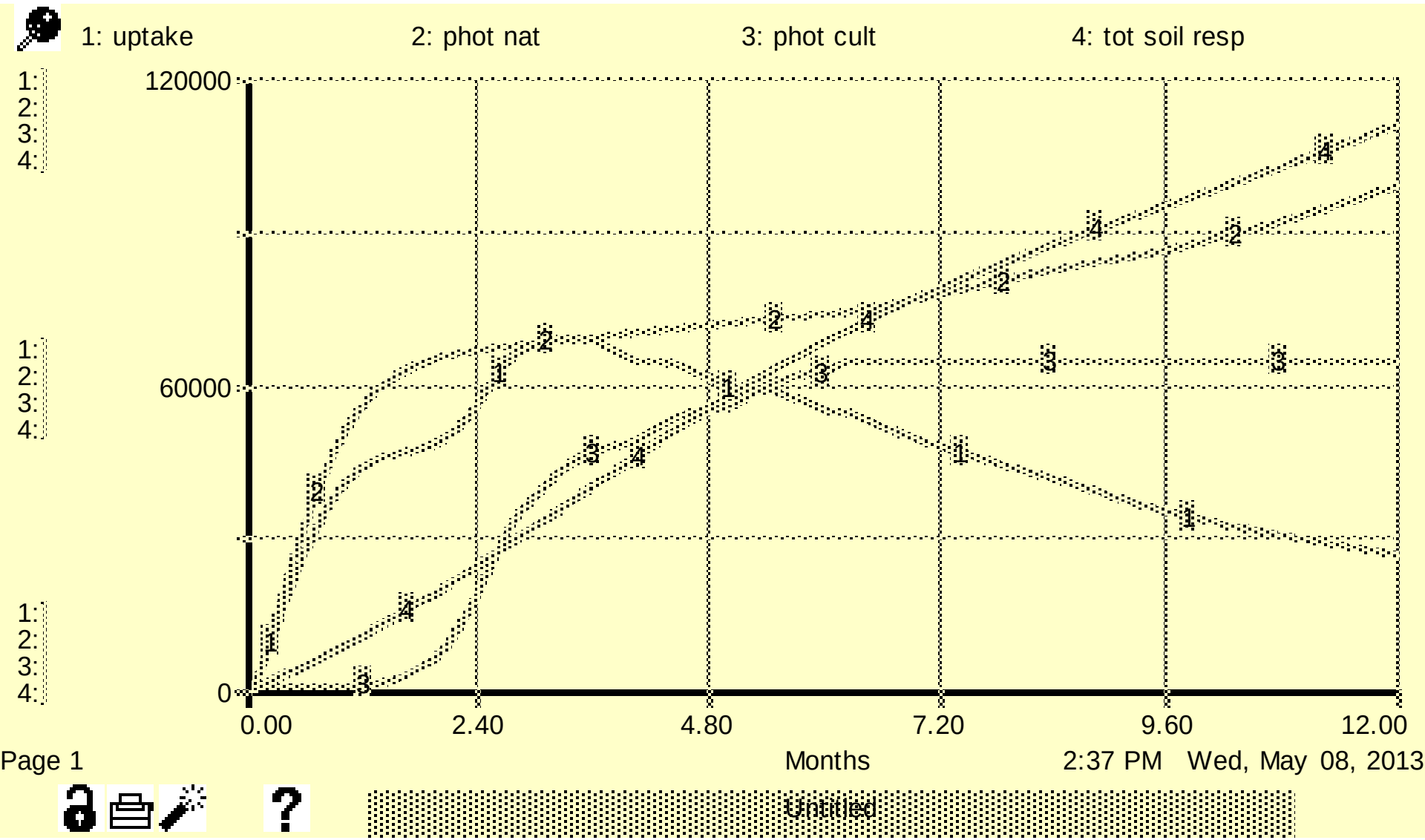
Carbon model results, 1997, before the plans were launched



C-balance Samsø



Processes as f(time)
Start 1st of April



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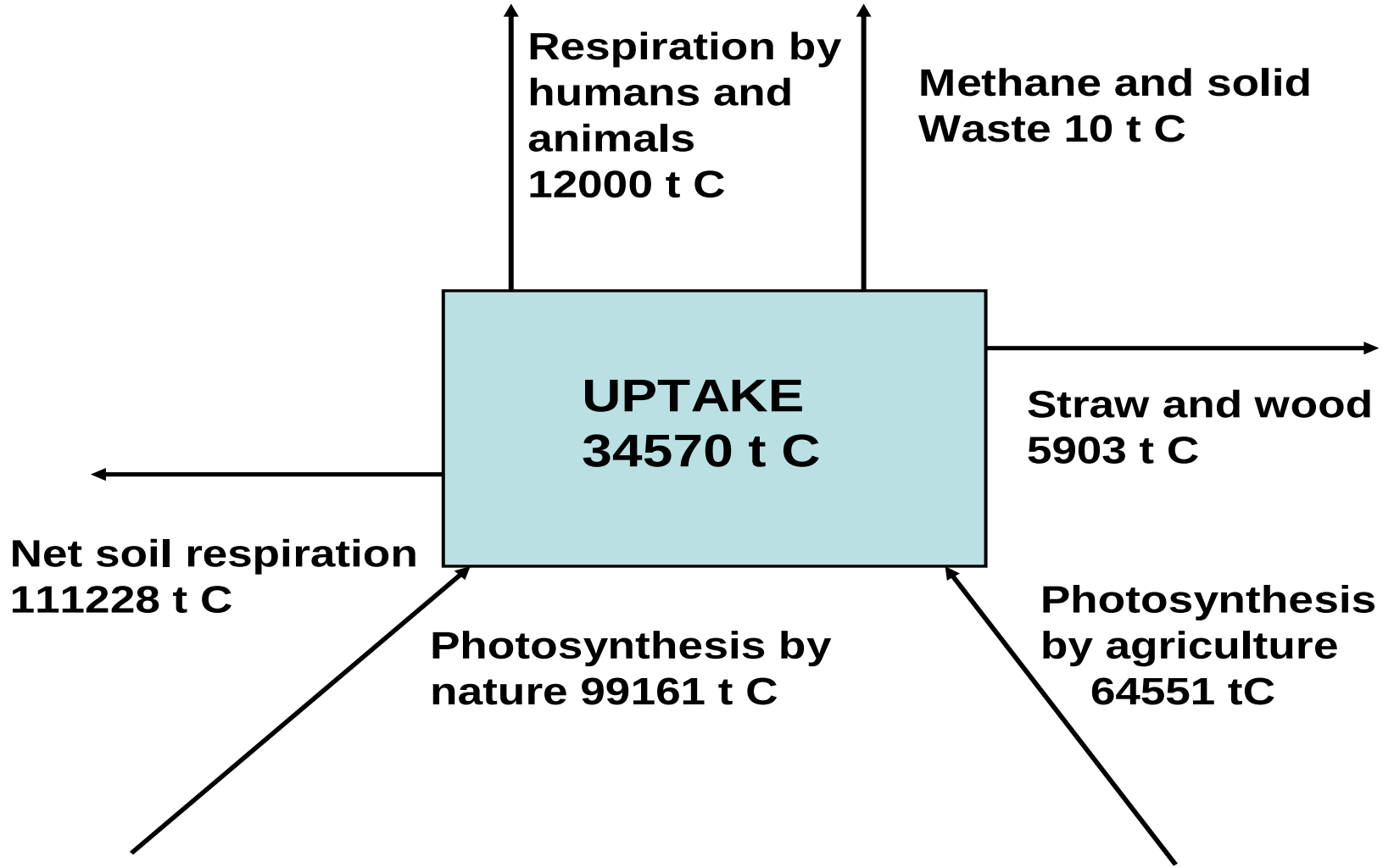
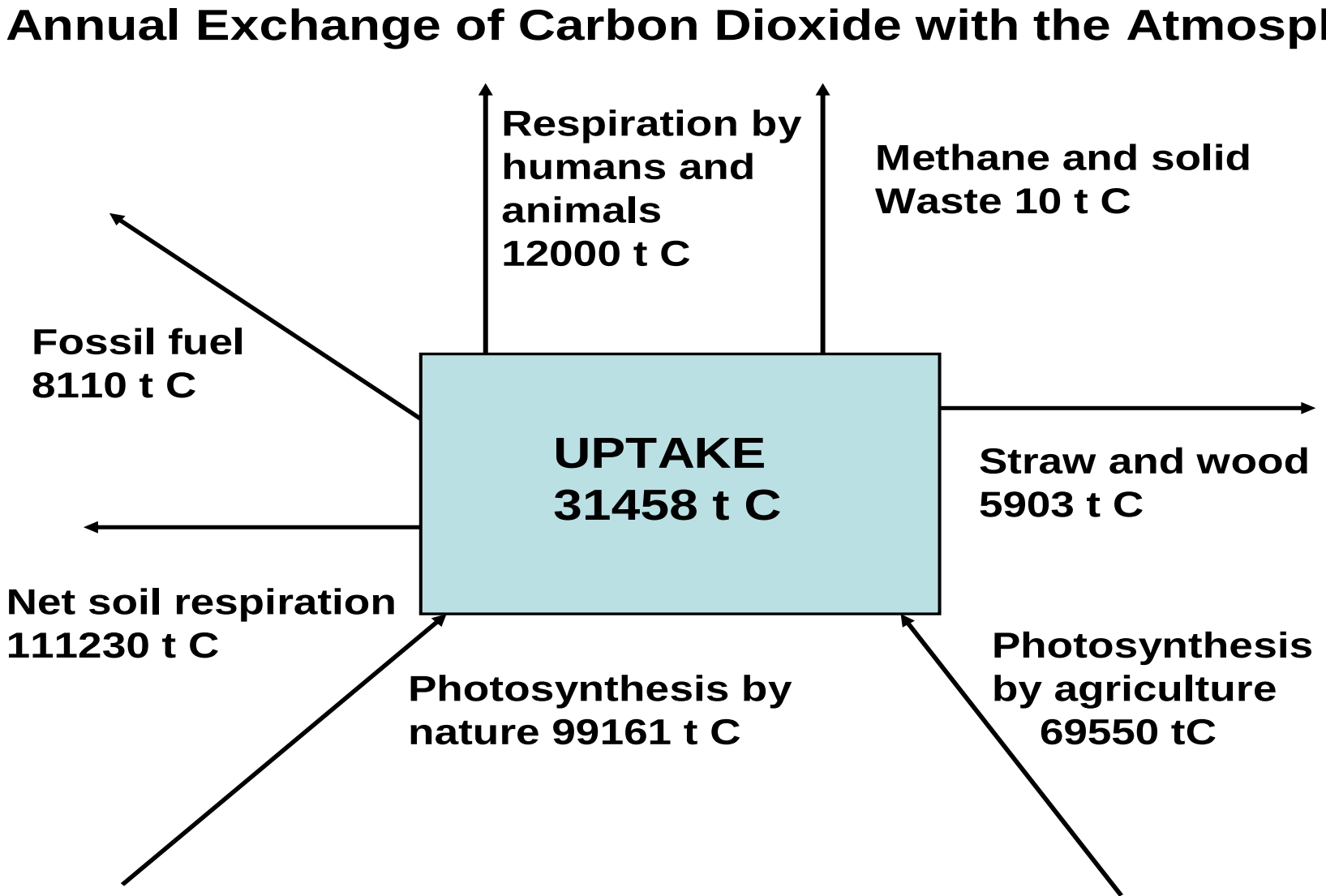
SAMSØ FOSSIL FUEL FREE 2020

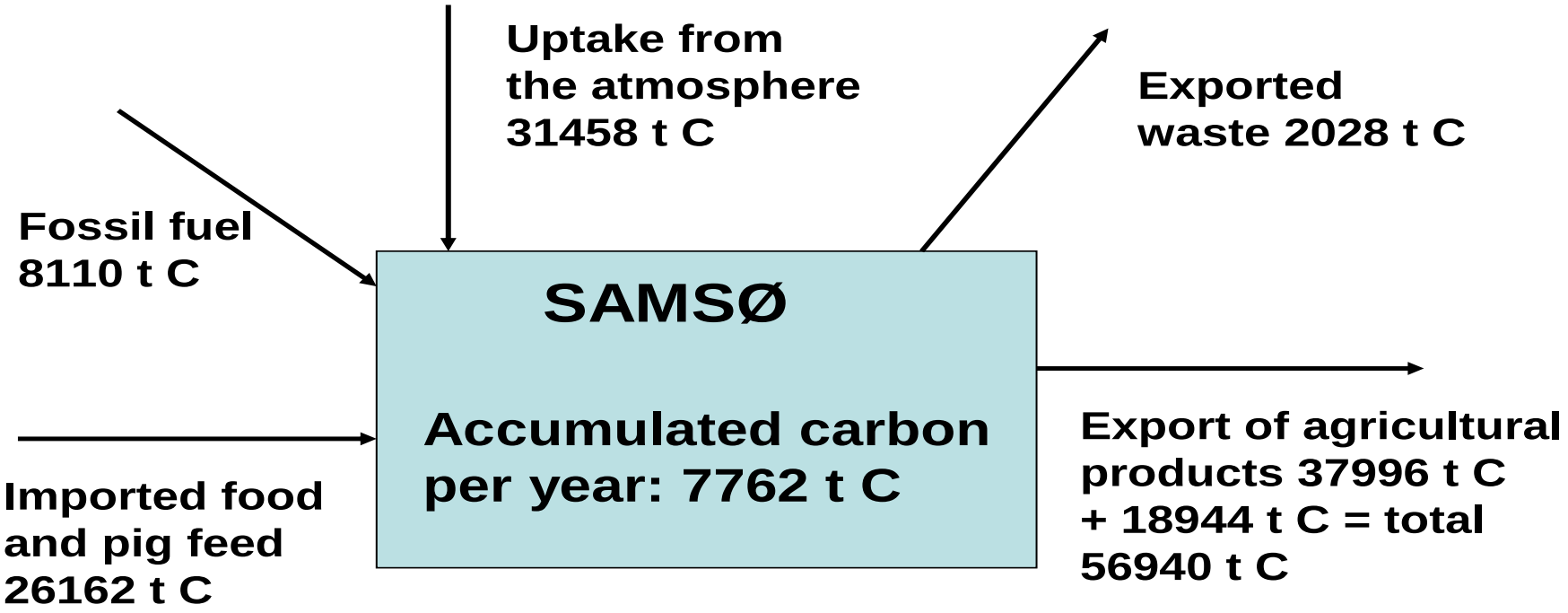
Annual Exchange of Carbon Dioxide with the Atmosphere



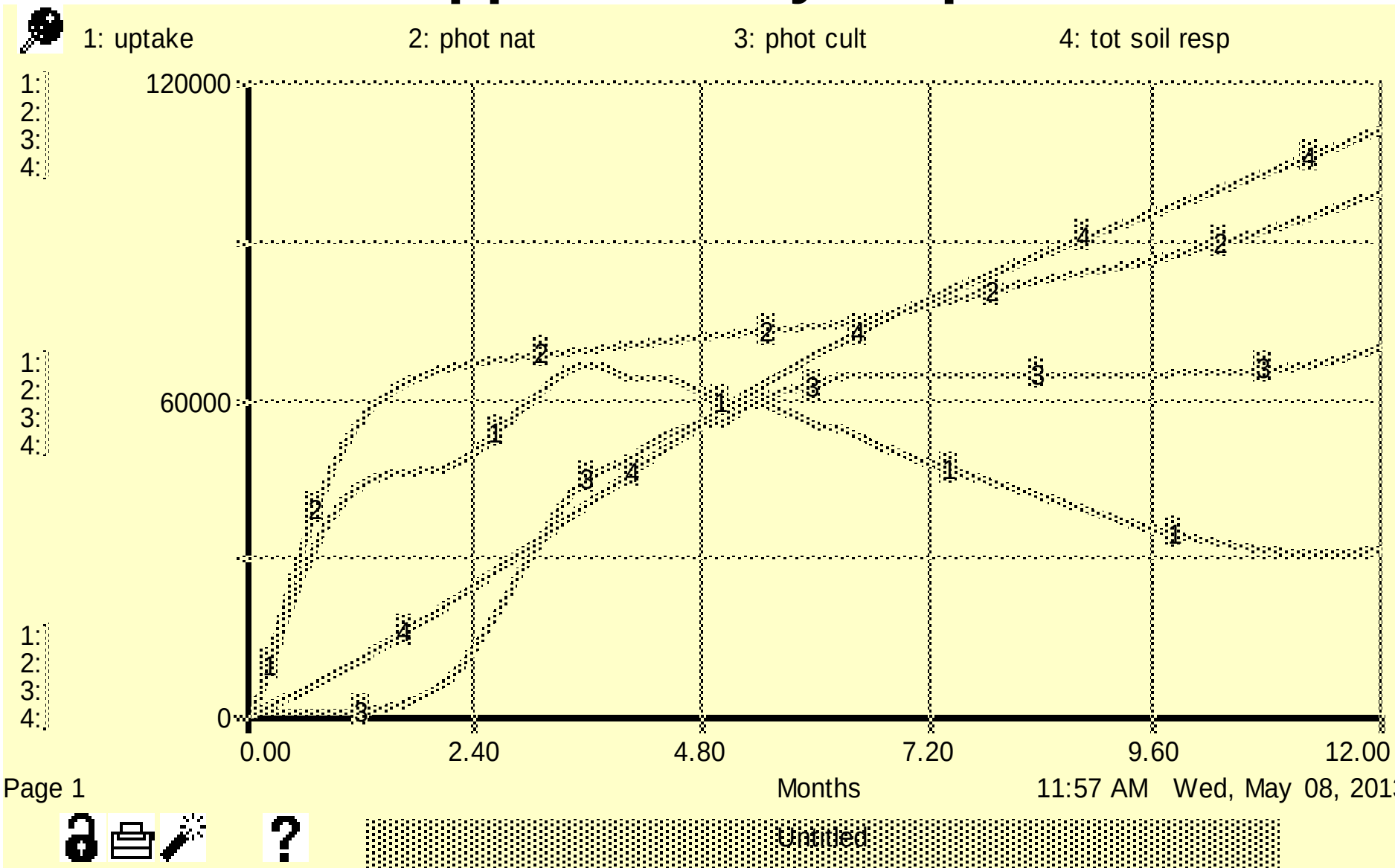
Application of 5000 tC supplementary crops per year



C-balance for Samsø by 5000 t C supplementary crops

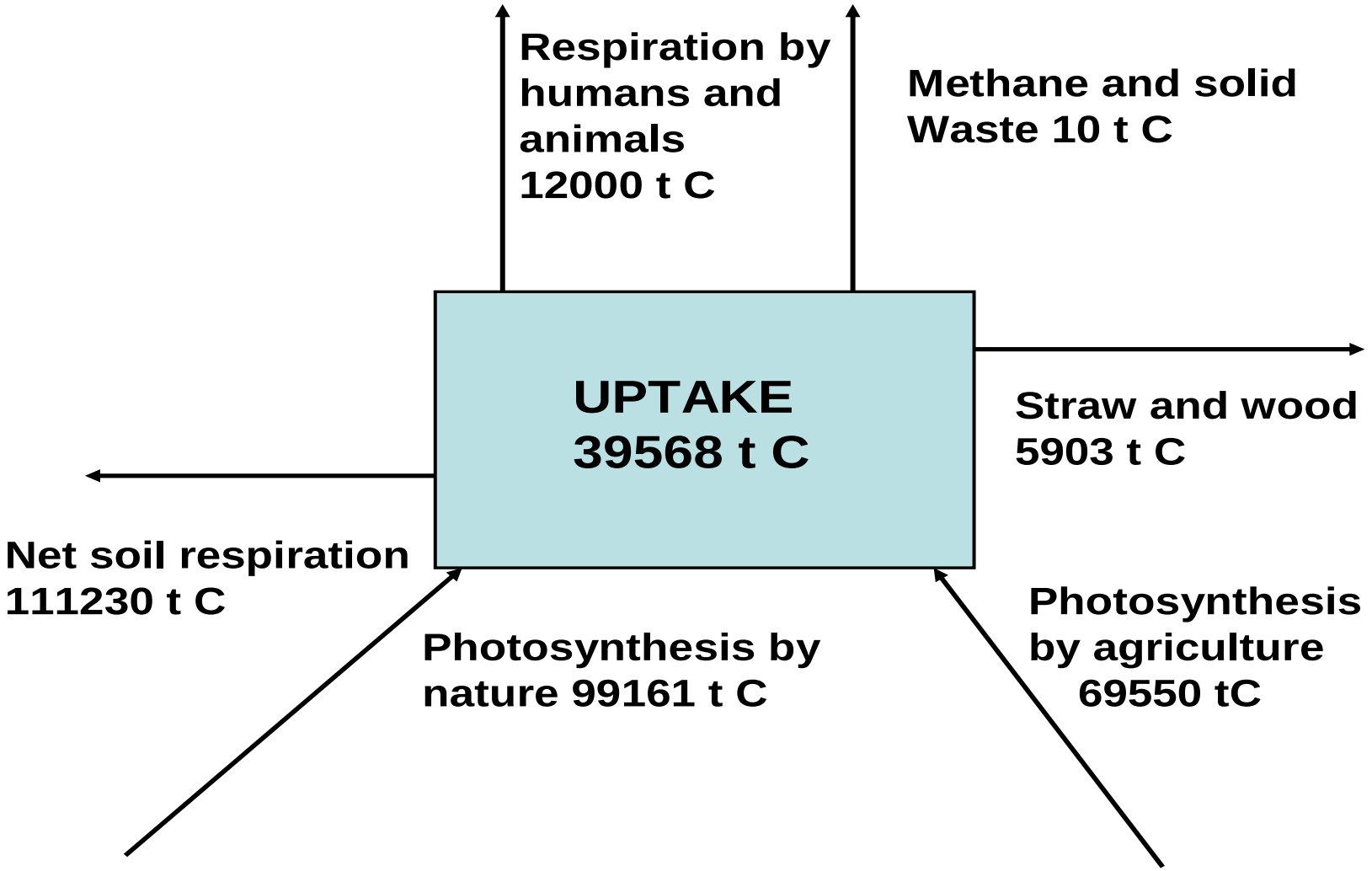


Seasonal changes by 5000 tC supplementary crops



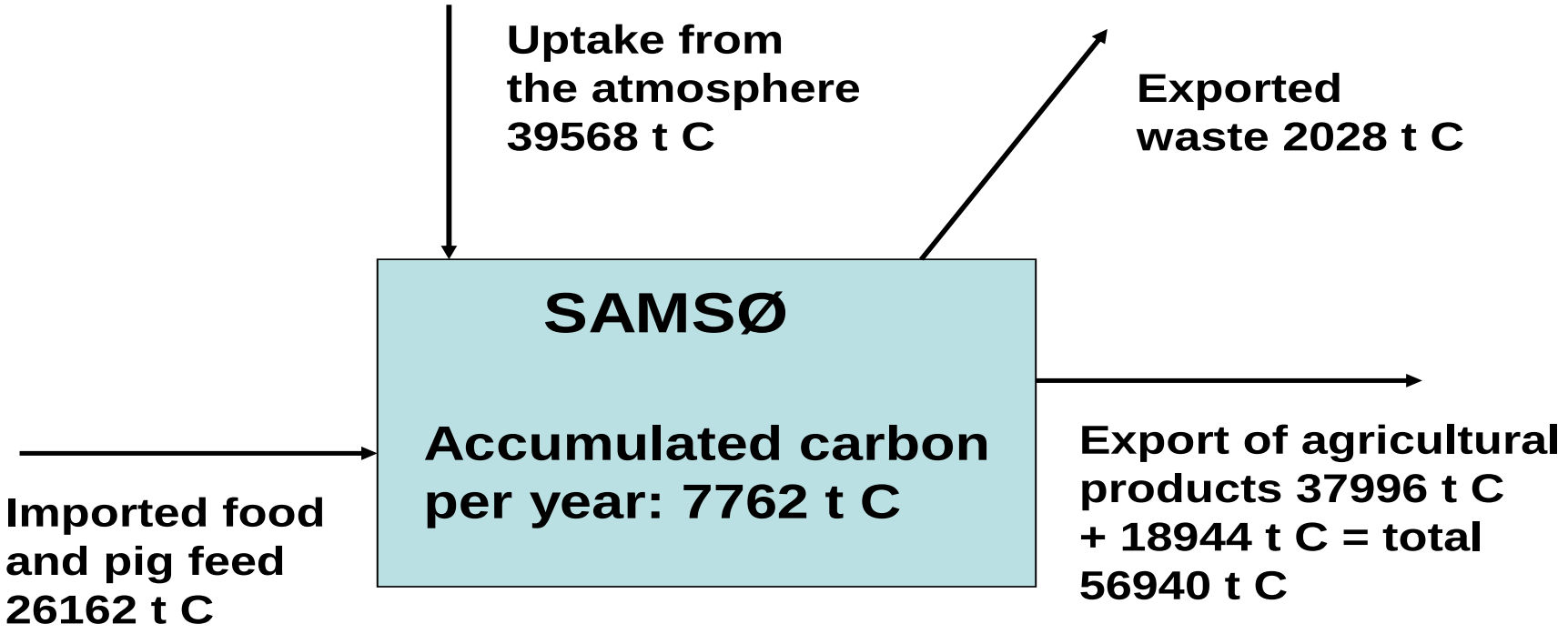
CO2 exchange: Fossil fuel free + 5000 tC

Annual Exchange of Carbon Dioxide with the Atmosphere



C-balance for Samsø,

Fossil fuel free + 5000 tC suppl. crops



Sustainability ensured by preservations of ecosystems and ecotones

- **Forest: annual increase of work energy, included in the sustainability assessment**
- **Wetlands**
- **Trees as wind shelter**
- **Ditches**
- **Ponds**
- **Wet meadows**
- **Coastal wetlands**
- **Hilly grassland**


VELDIG
VELDIG

Thank you for your attention and the discussion is open