

CONSEQUENTIAL MODELLING

- IN LIFE CYCLE INVENTORY ANALYSIS

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Overview of videos

- 1) Attributional and consequential responsibility
- 2) ISO 14040/44: A standard for consequential LCA
- 3) How to fully reflect both physical and monetary causalities in LCA
- 4) Temporal issues in LCA
- 5) Learning from non-intuitive results
- 6) *The comparability algorithm*: Defining the functional unit
- 7) *The linking algorithm*: Composing a consumption mix
- 8) Identifying determining products
- 9) *The co-product algorithm*
- 10) Errors in background databases



The co-product algorithm

- Stepwise procedure for substitution

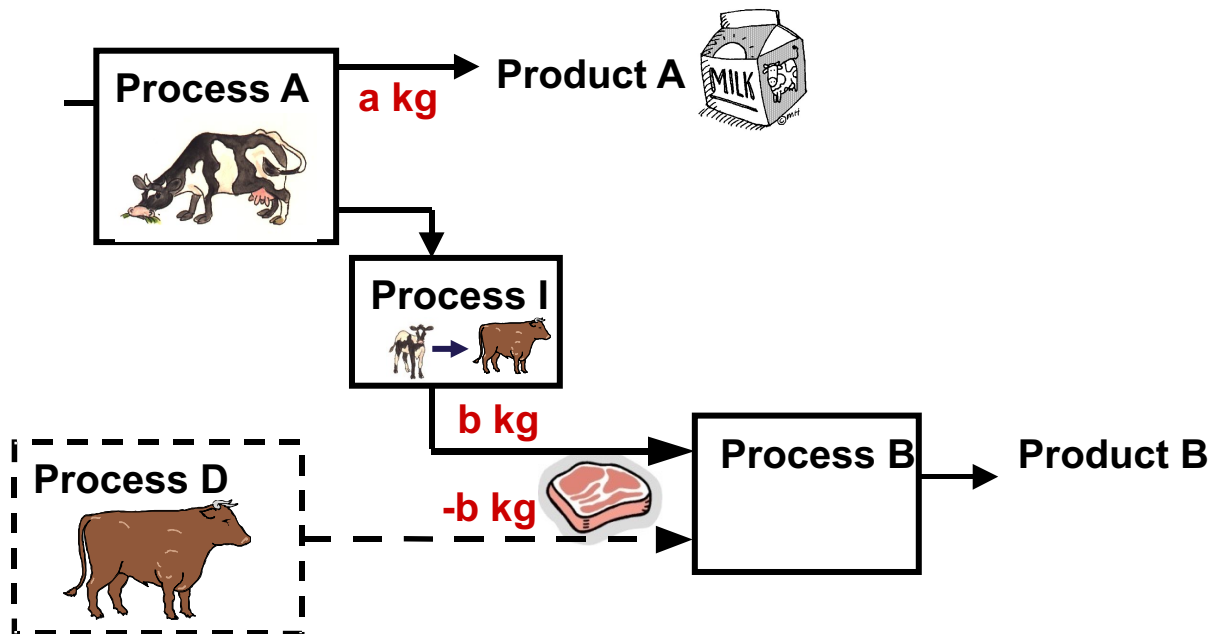
1. Combined or joint production?
 - Can the co-products be independently varied? Combined production →
The unit process can be subdivided according to physical causalities

For joint production:

2. What is the determining product?
3. Is the dependent product fully utilised?

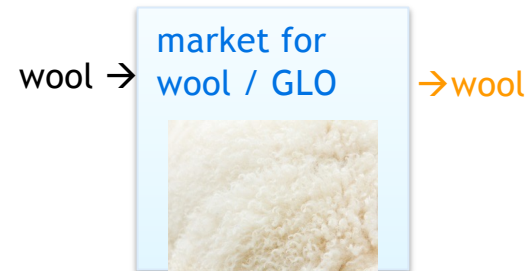
Substitution

when the dependent co-product is fully utilised



Demand for Product A causes activities:	A+I-D	+ ΔB downstream
Demand for Product B causes activities:	D+B	- ΔB downstream

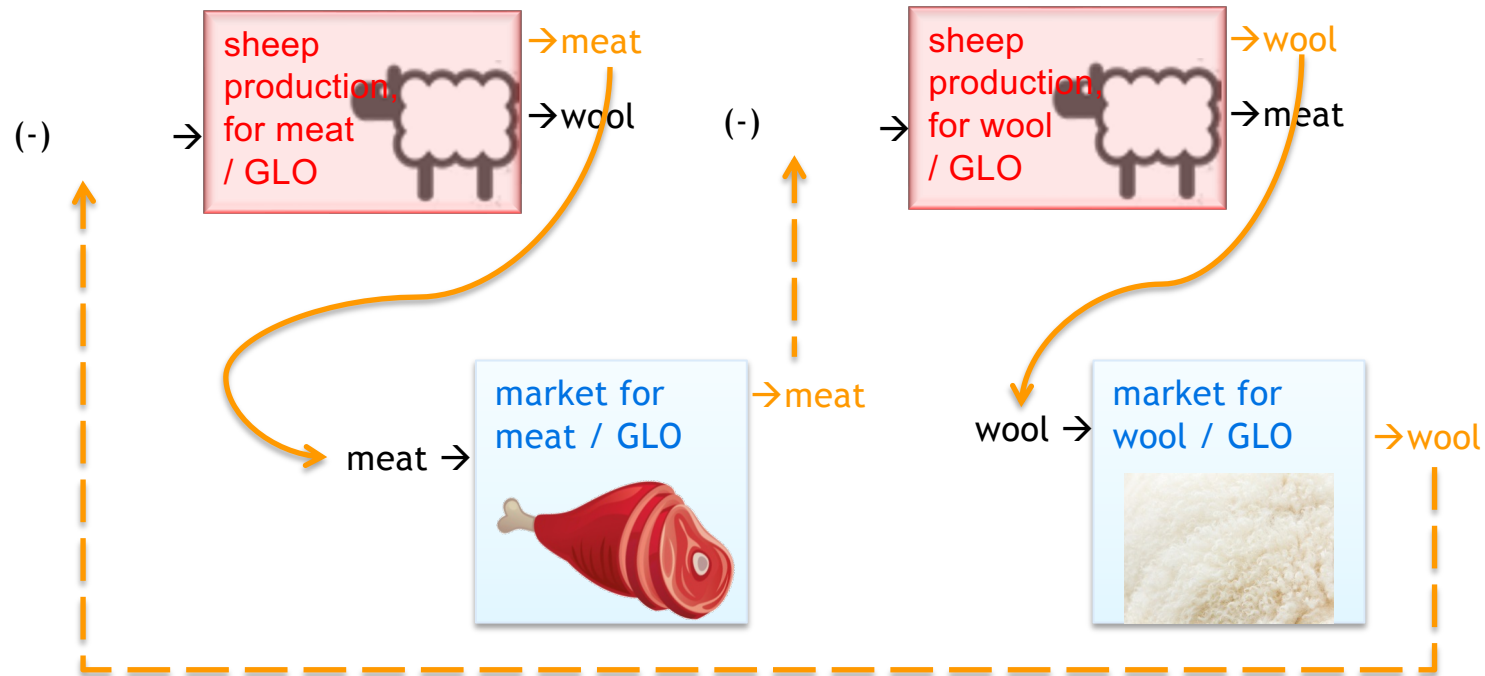
Example from ecoinvent: Sheep production – unallocated:



*Ecoinvent name: sheep fleece in the grease

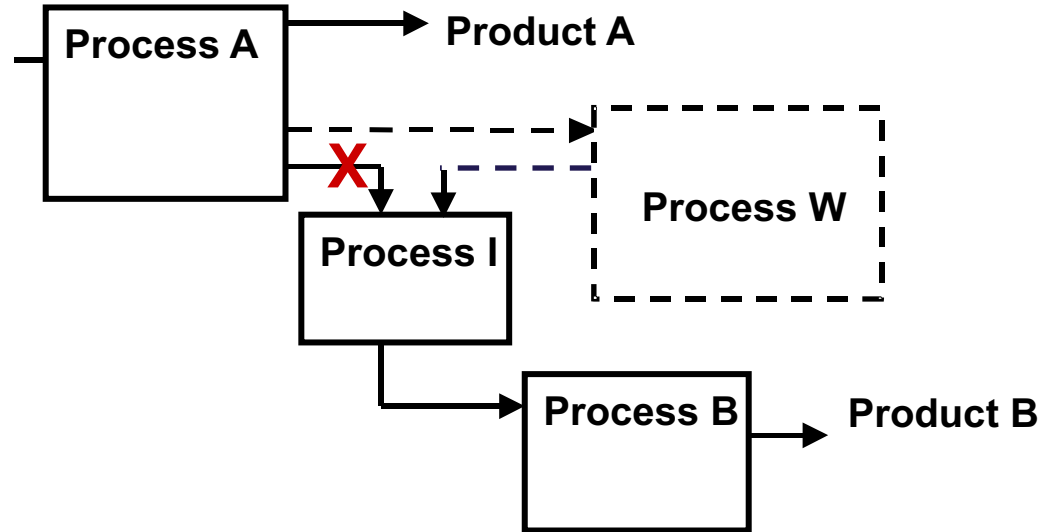
**Ecoinvent name: sheep for slaughtering, live weight

Sheep production – linked in consequential system model



Substitution

when the dependent co-product is **not** fully utilised



Demand for Product A causes activities:	$A+W$
Demand for Product B causes activities:	$I+B-W$

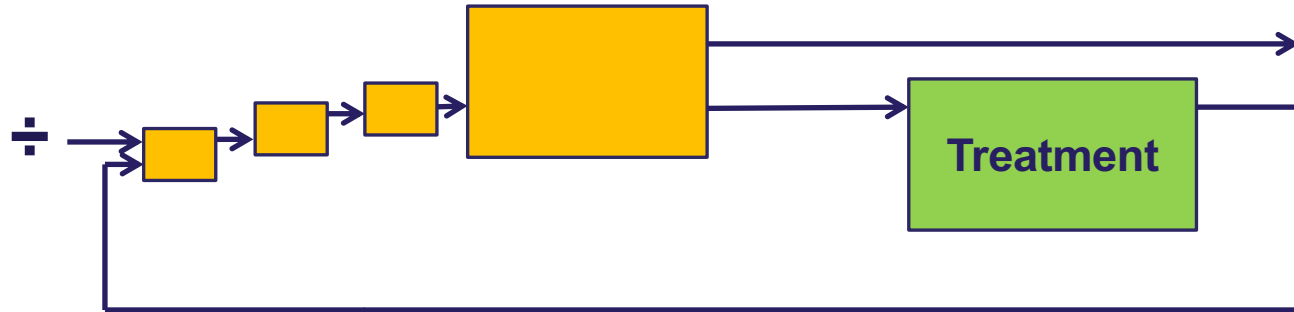
The co-product algorithm

- Substitution shown to be the only algorithm that consistently maintains mass, elementary, energy and monetary balances of the resulting single-product systems (Weidema & Schmidt 2010)
- Suh et al. (2010) clarifies the simplicity of the algorithm: By-product outputs are modelled as negative inputs



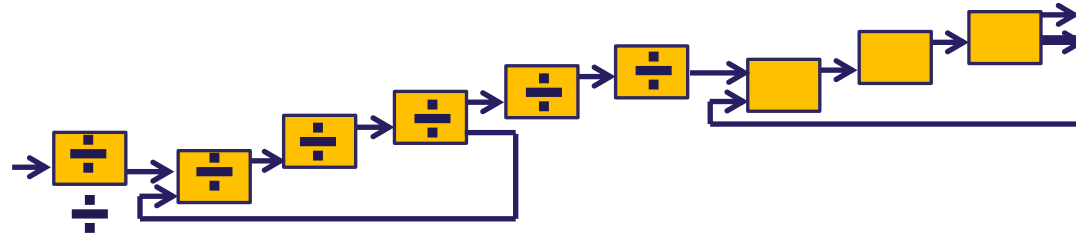
- What is substituted is the inputs to the market that the negative input is linking to → Justification of what is substituted is already given by the comparability and linking algorithms

Substitution or system expansion?



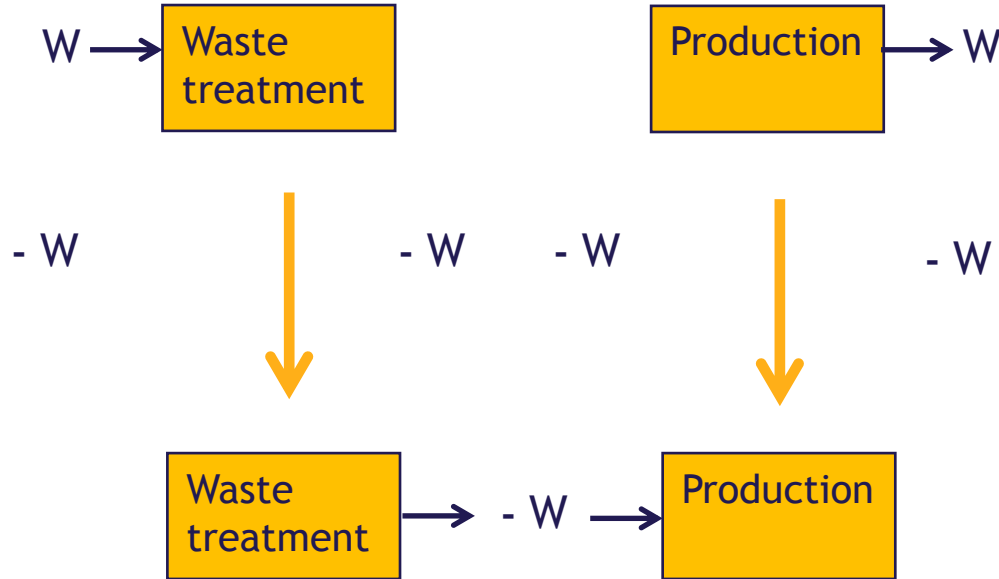
- The term "system expansion" implies that your original system was incomplete
- "Substitution" is a more general term and the most appropriate when your initial system is already complete
- In practice, the terms are used as synonyms (see ISO 14044:2006 Amendment 2:2020 Annex D.2)

Mass balance as a sanity check



- When substituting, no activities are partitioned
- The level of each activity is simply adjusted up or down to accommodate the output requirements
- The mass balances of each activity and of the entire system are preserved

The use of negative product flows



- An input can be modelled as a negative output
- An output can be modelled as a negative input

- Allows to **maintain mass balances** when modelling the physical and economic causality for materials for treatment

Example – Dairy milk and butter

- *Inventory problem*

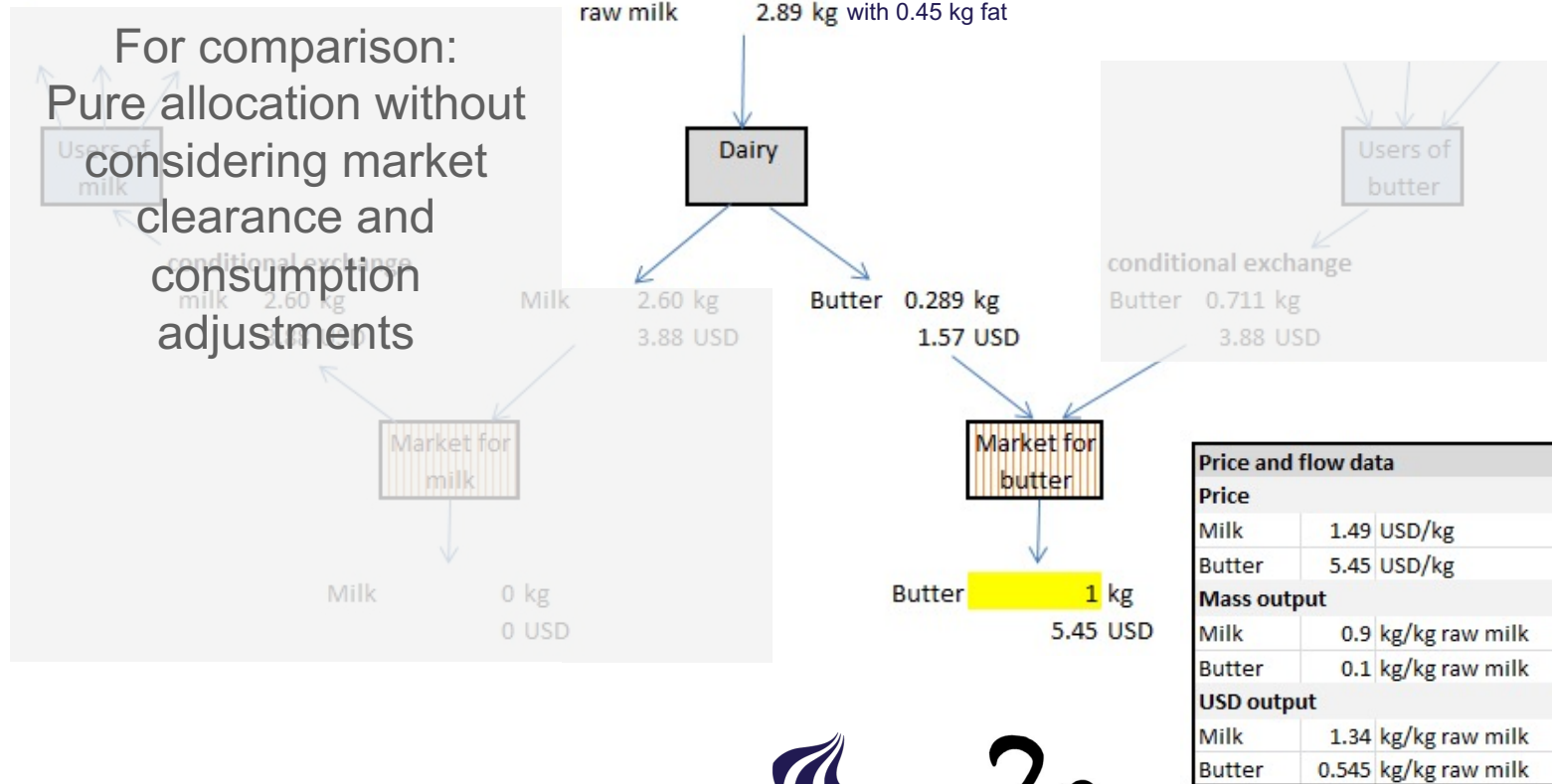
- Real life example of modelling challenges in a life cycle inventory
- Dairy milk & butter production
 - Here focus is on the modelling of **butter**



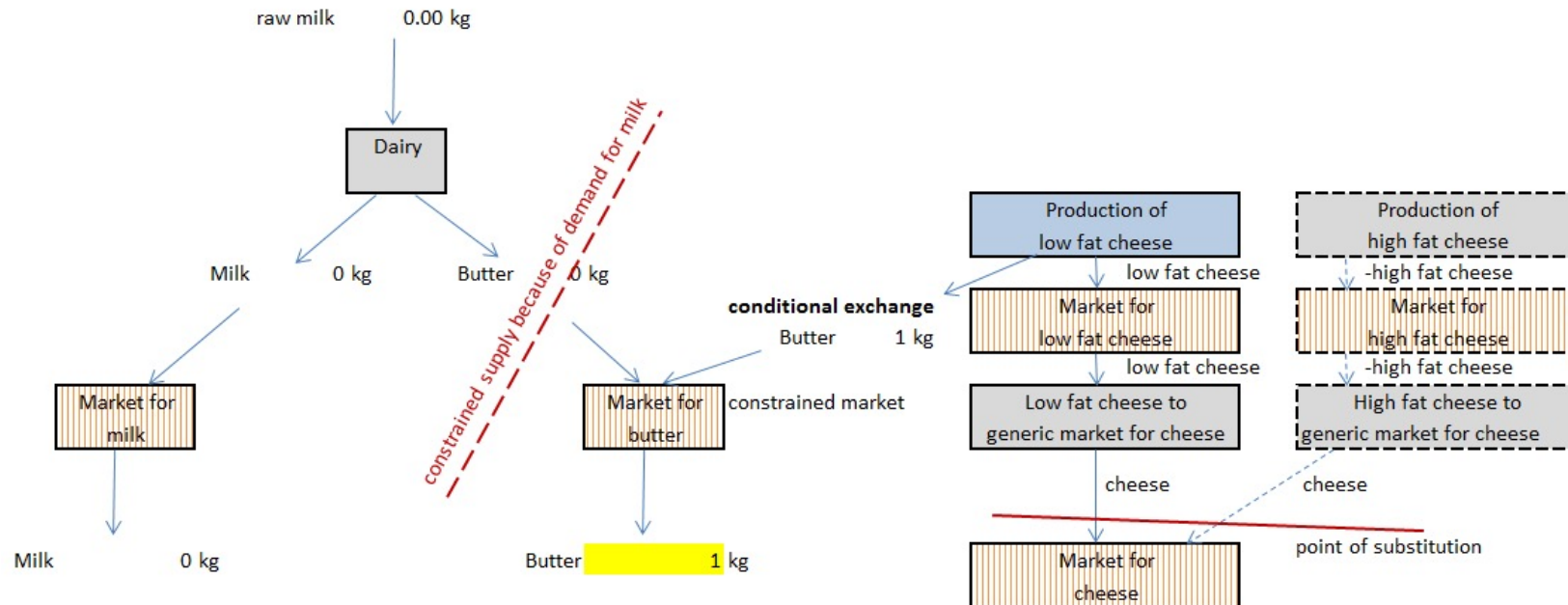
The challenge

- Milk and butter are co-produced in dairy
- When modelling life cycle emissions related to **butter**, it is crucial to determine how the dairy production reacts
- Conceptually, there are 4 different ways that system can react to demand:
 1. If **both milk and butter are both determining** co-products: Demand for 1 EUR butter will cause the dairy production to supply 1 EUR products (milk+butter)
 2. If **milk is determining and** high-fat cheese is substituted by low-fat cheese
 3. If **milk is determining and** milk fat in milk powder is substituted by vegetable oil
 4. If **butter is determining**: Demand for 1 kg butter will cause that the dairy to supply 1 kg butter (+ a lot of additional milk)

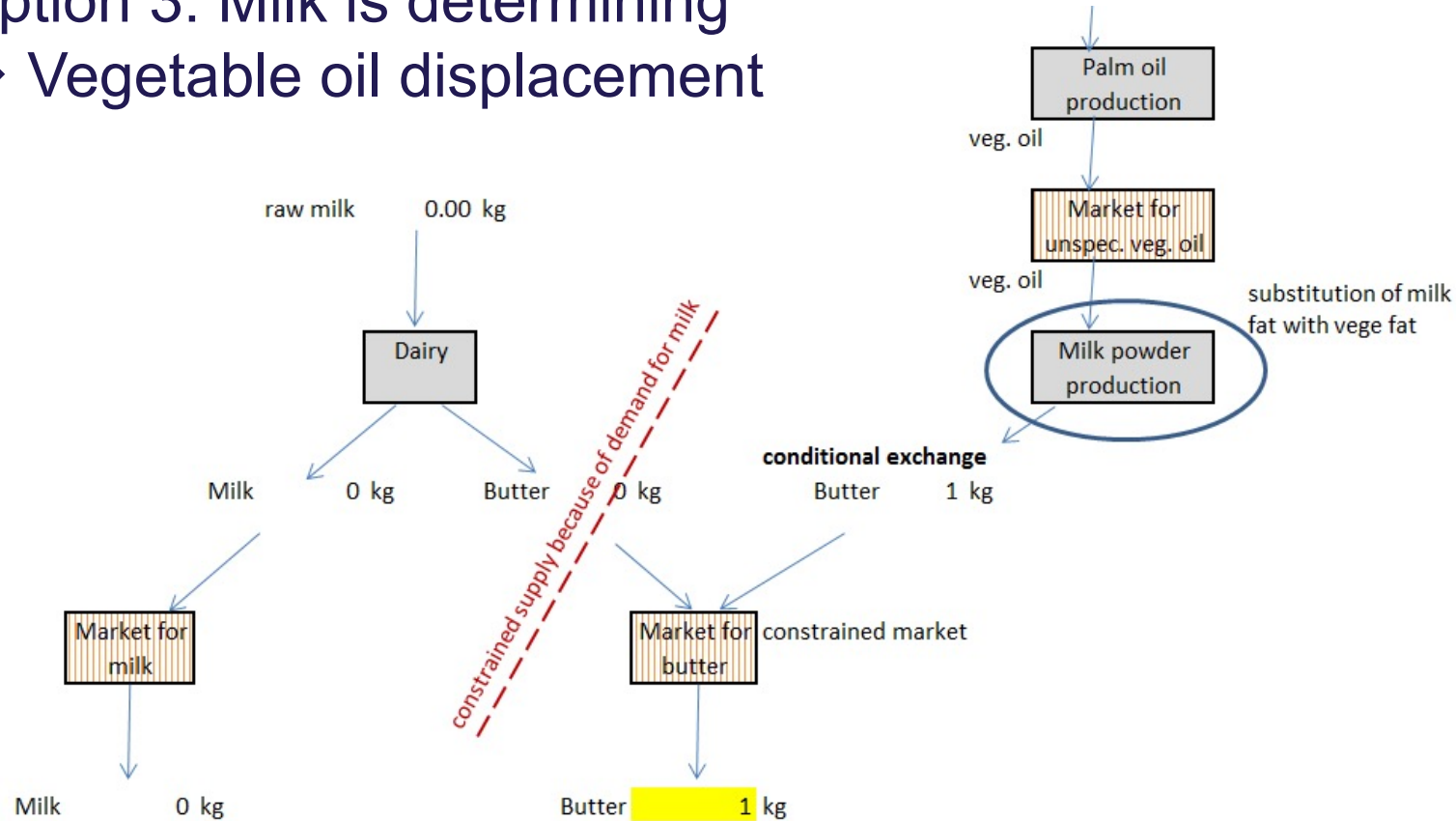
Option 1: Milk and butter are both determining



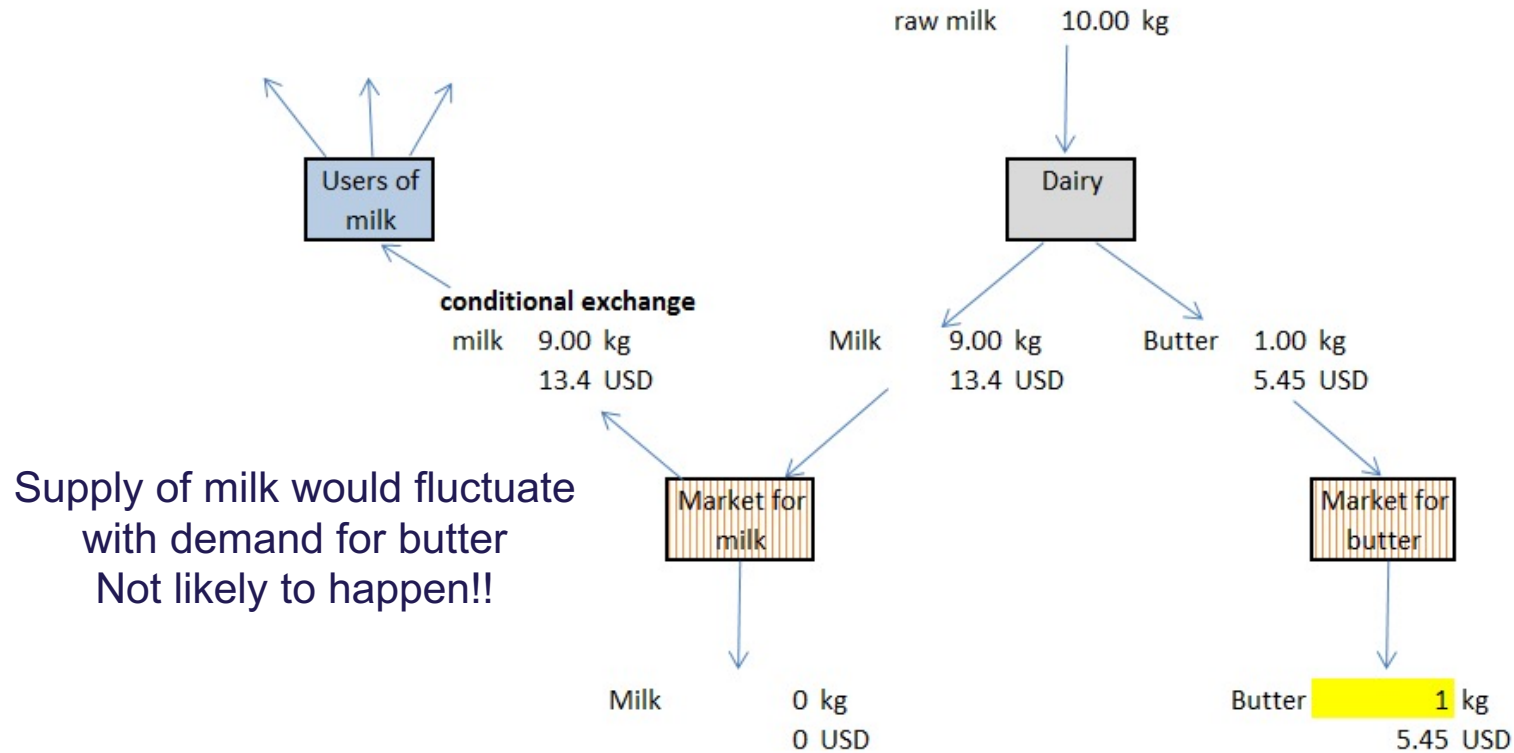
Option 2: Milk is determining → Cheese fat displacement



Option 3: Milk is determining → Vegetable oil displacement



Option 4: Butter is determining



Modelling a change in demand for butter

- What was the outcome?

- Based on expert consulting with production economists at the Arla dairy:
 - **Milk is determining**
 - A change in demand for butter is supplied as:
 - **25% of butter from** substitution of fat-content in milk powder by vegetable oil content
 - **75% of butter from** substitution of high-fat cheese with low-fat cheese

THANKS FOR YOUR ATTENTION