FLEXIBLE MODELLING OF THE PORK PRODUCTION CHAIN

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Introduction

Pig production and pork processing are embedded in an increasingly complex system (the pork production chain) of interrelated production systems. Many developments in pork production cause major changes in one or more of these production systems that exercise their impact on the other elements of the pork production chain.

Causes of the increasing complexity of this system are industrialisation, internationalisation and diversification of the applications of the various parts of a pig's corpse.

Industrialisation of the pig growing process means that its environment, including climate, health care, feed supply and drinking water, is increasingly artificial and created by industrial processes that, in turn, are influenced by scientific methods. One of the novel, challenging scientific methods is biotechnology.

Internationalisation resulted in strong dependence of the pig industry on the global supply and delivery markets and, consequently, on developments all over the world, including substitution effects.

Diversification of applications of products and by-products is not new. Hair, hide, bones and some organs of the pigs are used in non food or pharmaceutic applications. Slaughterhause wastes are recycled to feed. Manures and sludges are applied for fertilising purposes.

Because of the large-scale effects of the growing of increasing numbers of pigs in a restricted area and of a rapid succession of changes in the chain there is a demand of more insight in causes and results and in the propagation of the results of change through the pork production chain. Moreover, from various angles of incidence the interactions between different elements of the chain are of increasing importance.

Recently, two developments put an increased emphasis on chain management and, consequently, chain information.

Firstly, a demand on *quality control* (ISO-9000) and information on quality, like the Dutch IKB. In relation to pigmeat, quality is considered in its most extensive definition including external aspects [1].

Secondly, increasing *environmental concern* complicates the chain and boosts requirement on chain information. For example, restrictions on the use of manure and sludge for fertilizer purposes stresses the need for novel applications and processing methods.

Energy analysis and LCA

A production process may be considered as a black box where flows of materials, energy, and information are transformed with intent to increase the value of the output with respect to the input. Because of matter and energy conservation, the output of matter and energy, apart from temporary storage effects, equals the respective input. In accordance with the second law of thermodynamics, the overall quality of the energy decreases (e.g. chemical and electrical energy is transformed in low temperature heat). The quality (range of applications) of a part of the material output increases with respect to the input, according to the objective of production. This part is the product flow. Besides products also by-products are generated. Although they may possess a positive value, they are not the objective of the process. Refuses are by-products with a negative value. They may be either further processed or discretely or diffusely emitted to the environment.

The input material flows of a production process consist of raw materials, material energy carriers, other utilities like water, and additional materials like those required for maintenance. Moreover, capital goods like machines and buildings should be appropriately apported among the product flow.

Energy flows are connected to each material flow. These enclose not only the chemical and potential energy of the flow, but also the energy that is required to make the flow available for the production process. The sum of

these energy flows is the Gross Energy Requirement (GER). The GER is calculated according to a standardized methodology [2, 3].
If a definite reference level is given, both quantity and quality of energy are unambiguously defined. Quality of energy is expressed in terms of exergy, equalling the theoretical maximum amount of mechanical energy that can be obtained from an amount of energy of a definite quality.
Material flows can be treated analogous to energy flows. In general, however, the quality of material flows can not be expressed in a simple characteristic number like exergy. There should be made a distinction between intrinsic and extrinsic properties, the former being important in process technology as compounded feed manufacturing or pig fattening, the latter in manufacturing technology. Slaughtering and meat-processing occupy an indermediate position between process and manufacturing technology.
Intrinsic properties are material properties like water content and fat composition, external properties are connected to shape, macrostructure and so on. For example, slicing of meat causes a change in external properties. The model described here is focused on transformations in internal properties.
For the description of material flows are no clear international standards, although the LCA method (Life Cycle Analysis, Life Cycle Assessment) is accepted worldwide [4]. According to the LCA method, material and energy flows connected to a particular product are studied from extraction to emission. Hence production as well as consumption and waste processing are included in the description. Problems arise in definition of the systems boundary as well as in the amount of environmental harm that is caused by the different emissions. This harm is not only determined by the toxicity of a flow, but also of the place, time and amount in relation to other emissions. Moreover, exhaustion of natural resources should be accounted for. These considerations make an evaluation of results of LCA a complex task with many possibilities for subjective interpretations.
The pork case illustrates the dilemma of how the chain to be studied should be defined: A quality-interested opinion leads to the choice 'from conception to consumption' (in Dutch: 'van fok tot kok'), whereas an environmentally-oriented opinion leads to the choice 'from extraction to emission', thus highlighting the principal material flows that are connected to pork production, namely feed ingredients and manure.
Both chains cross each other at the production process that is the most essential of pork production, namely pig fattening (see figure 1).

Passive versus active LCA

The philosophy of the LCA method is based on the implicit assumption that the production process is in essential linear and static over a considerable period of time. If a raw material may originate from different sources, for instance from primary or secundary production, a fixed ratio between the respective material flows is supposed. In more advanced calculations such a ratio can be treated as a parameter. Changes of such a parameter can be included in the calculation.
As figure 2 shows, the pork production chain is complicated and can not be considered as linear. The model presented here is strongly simplified. Firstly, the production system that provides energy to the pork production chain is omitted. Secondly many boxes, like the box 'agriculture', involve a variety of different processes that take place in different countries all over the world. Thirdly, a substitution effect is present. When the price of some commodity increases, consumers tend to replace it by an alternative. This is valid in relation to pork consumption but also to feed ingredients, technical processes, energy carriers and other.
If one applies the conventional (passive) LCA method [4], then external changes in supply, technological progress, legislature, and demand result in a change of some parameters and, consequently, a change in environmental impact of the production process. The production process however, will also change internally and this effect is not included in passive LCA. Let us consider, as a case, the introduction of a restriction of manure application as a fertilizer, based on the minerals contents of the manure. This measure has clearly the objective of decreasing the emission of excess minerals to the atmosphere, the groundwater and the surface water. This objective will only be obtained if the production chain will react on this measure in an appropriate way.
Many reactions in the production chain may occur, for instance:

- Boosting transport of manure to regions where a relative shortage of minerals exist. There the manure may replace artificial fertilizer, albeit recepted by the crop at a lower efficiency.
- Stimulating manure processing on an industrial or a semi-industrial scale to improve transportation and application of the nutritients.
- Adapting the farm management and the equipment to increase the dry-matter contents of the manure.
- Applying manure to other then fertilizing purposes, for instance as a matrix in biotechnological production of feed ingredients.

- Enhancing the efficiency of feed conversion; application of additives to the feed to improve conversion results.
- Changing the feed composition by substitution of mineral (nitrogen-, phosphorus-) rich ingredients by ingredients that contain less minerals.
- Adding essential amino acids, vitamins, and other additives to obtain a better balanced feed.
- Increasing cost of pork production may lead to concentration and upscaling of pig production units to suppress costs.
- Increasing prices of pork may lead to substitution of locally produced pork by imported pork, or by other food products.

These reactions will, in general, occur simultaneously. Their influences to the production chain add in a complex and often non-linear way. For instance, changing feed composition may lead to changes in the efficiency of feed conversion that partially annihilate the beneficial effect that was intended.
The production processes in the chain take place in enterprises or business units. Their behaviour is characterized by optimization of the value added of the processes involved. The pig farmer, for instance, will try to obtain a maximum revenue (by quality and quantity of the production) at minimum sacrifices. According to this criterion the choice of feed is made. Of course this is an oversimplification: decisions at the level of an individual enterprise are substantially determined too by tradition, available capital goods, uncertainty and subjective factors, leading essentially to a retardation effect.
But in modelling the introduction of 'idealized enterprises', that act according to the optimization of revenues, offers a possibility to adapt the model structure to changing external circumstances.
To obtain a model of a production chain, de models of relevant production systems should be coupled according to their input and output of material and energy flows. Each flow should be characterized by its price and other characteristic numbers that are not calculated by the model. As an example electricity can be mentioned. Electricity is required in the pork production process but the generation of electricity from various resources is not included in the model. The price and data on the environmental impacts of electricity generation are included as characteristic numbers. Of course, in the model the values of these numbers can be varied, so the impact of, for instance, enhancement of the effectivity of power plants on the Gross Energy Requirement (GER) of pork can be studied [2]. The power generation itself belongs to the passive periphery of the model.
To the periphery too will generally belong processes that take place outside of the geographic region that is studied. With the pork production system in the Netherlands studied it evident that many materials that flow between production systems will be branched. Import flows are added and export flows are subtracted and what happens with these is not included in the model (unless the World pork production system is studied). Materials flows branch also to other purposes as the pork production system: compounded feed ingredients (like cereals) have also other applications. Compounded feed is also applied to cattle, poultry and other animals.
In the model one should therefore use an alternating sequence of activities (production systems) and commodities that flow between them (fig. 3).
Because the model contains idealized enterprises that act according to simplified economic regularities, substitution will also be of importance. There is *internal substitution*, for instance, compounded feed ingredients compete each other, Ther is also *external substitution*, that implies that products from the pork production chain compete other products. This involves meat, but also hide, bones, blood and by-products like manure and sludge. This substitution not only possesses economic but also physical aspects. The need for fertilizer, for instance, depends on the amount of agriculture production, the soil and so on and is a given function of the agricultural production. There is competition with artificial fertilizer, manure from other animals, sewerage sludge, industrial by-products and others. It will be clear that many of these commodities should be externalized to keep the model within reasonable proportions without complete neglection of interaction of the pork production system with other production systems.
With these considerations in mind it is possible to build a model for the pork production system. It is formed of a set of linear or non-linear mathematic relations that can be solved using mathematical optimization methods like linear programming (LP) or non-linear programming (NLP).

<u>*Examples*</u>

In reference [5] two models have been worked out.
- The model given in fig. 4 represents a strongly simplified chain model. It involves 'compounded' feed that here consists of cereals and meat meal tankage that is produced from slaughterhouse wastes. Cereals are

grown using artificial fertilizer, untreated animal slurry or industrially processed manure in the shape of pellets. Pig breeding and pig fattening are included, the former producing manure with a lower dry matter content than the latter. The effectivity of fertilizer absorption by the crop differs for each type of fertilizer. Each production process has its proper gross energy requirement and the objective of the model is minimization of over-all GER. In this simple model only two decisions can be taken: whether or not industrial manure processing should be applied to the two qualities of animal slurry that are produced whithin this system. Even this simple model, that is kept linear, can be applied to evaluation of a variety of measures, for instance what the effects of enhancement of the dry matter content of manure are, and to what extent the energy effectivity of manure processing should improve to make manure processing attractive from an energy point of view.

A much more detailed model has been elaborated of a restricted part of the production chain. It involves the compounded feed industry with respect to pig feed, and pig fattening. Manufacture of feed ingredients is externalized and some characteristic numbers including nutritional parameters, price and some environmental impacts are attached to each of them. This means that the characteristics of feed ingredients are externalized. Besides bulk ingredients also some additives are included in the model like a number of essential amino acids. Nutritional and technical requirements of the pig feed are introduced as constraints. The model of the compounded feed industry is linked to a retention model of fattening pigs [6], and a link has also been made to an existing model that determines the composition of fattening pig manure [7].
This model is a weakly non-linear one, although the models of the production systems are linear. This is due to the introduction of the costs related to the retention as the objective function. It is possible to study with it the impact of increasing restrictions of nitrogen contents of the feed in relation to manure composition, nitrogen effectivity, costs of one unit of retention, and availability of restricting essential amino acids as an additive (fig. 5).
The model returns the optimum composition of the feed but also some characteristics that are uncorrelated to nitrogen, like GER.
With the same model it is possible to study a range of other effects, as the influence of price variations of some ingredient, or of energy, on the production chain. Such a study is necessary, because in the most cases many parameters are changing, may be fluctuating or with a characteristic trend, boosted for instance by technical progress. Also the impact of political decisions, like GATT, can be evaluated.

A more general description method

The model that accounts for material and energy flows is an instrument to arrive at a more complete view of the production chain, that leads to a valuable instrument for management optimisation. To that purpose information flows should be included.
Figure 6 presents a crude model of a module of such a system, namely a slaughterline.
It distinguishes between *process* information and *product* information. Process information is generated e.g. for environmental purposes. Financial information has been taken apart according to its crucial role in management. Energy enters in the shape of material energy carriers as well as in immaterial ones (electricity). Energy is carried away to the atmosphere or by cooling water.

Information on entering and leaving energy and material flows is necessary for information systems for the complete production chain, according to, e.g., LCA methodology.
Product information is not only provided for environmental purposes, but also for quality control. Therefore interfaces are required between the different processes in the chain. This is indicated in figure 6 by exchange of information on raw materials (here: livestock) and the principal products (here: carcasses).

Conclusion

Although a problem exists in obtaining appropriately detailed information on products and processes, it is possible to construct models of at least parts of production chains. These generate results that are useful in obtaining better understanding of complex production chains. It should be of great importance to obtain databases of products and processes in an uniform way, that can be implemented in more extended models of production chains. It is demonstrated that, more than 'passive' LCA methods, these models offer much more flexibility and can be applied in evaluation of a broad spectrum of changes in production systems on a wide variety of criteria.

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