LIFE CYCLE ASSESSMENT (LCA) AND ENVIRONMENTAL PRODUCT DECLARATION (EPD) OF AN IMMUNOLOGICAL PRODUCT FOR BOAR TAINT CONTROL IN MALE PIGS

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Recently, a leading manufacturer of veterinary medicines applied the LCA approach to the production and use of an immunological product for male pigs for the reduction of boar taint. The LCA study involved the facilities where the immunological product is manufactured, a sample at global level of farms where it is used and where the standard method of physical castration for boar taint reduction is adopted to define a benchmark and, finally, a sample of abattoirs where the final product (pork) is produced for human consumption. The analysis was carried out for two doses of immunological product that is necessary to reduce boar taint in the male pig and, additionally, for the unit mass of pig (so called “live-weight”), pig carcass and boneless/fatless pork meat (so called “lean meat”). The saving of carbon footprint respect to the physically castrated pig system is 3.7% in terms of kg live-weight. All the other life-cycle impact indicators show a reduction relative to the benchmark system (physical castration) as well. Scope of this paper is to present the results of this LCA study; complete results are also reported in the publicly available Environmental Product Declaration (www.environdec.com)

Keywords: LCA/EPD immunological product for the swine sector.

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Introduction

Agriculture, animal farming and related sectors are facing the environmental sustainability challenge by means of advanced analysis tools such as Life Cycle Assessment (LCA) with the goal of understanding the origin of their environmental burden and to propose solutions for mitigation of impacts. Recently, a leading manufacturer of veterinary medicines applied LCA methodology to some innovative products, with a first case-study on an immunological product; the interest in LCA has been driven recently by the development of innovative products that have the potential also to contribute to environmental impact mitigation; in fact, this product for male pigs (1) provides farmers with an alternative way to avoid the problem of boar taint, (2) by doing so allows male pigs to be reared more efficiently, and (3) was hypothesised to provide significant life-cycle environmental benefits. The LCA methodology applied and summarised in this manuscript provides supportive evidence for this third assertion and it has been used as the main scientific background to develop an Environmental Product Declaration (EPD) registered and published (on January 30, 2012) into the EPD International System portal (www.environdec.com), an accredited ISO 14025 Program Operator (ISO 14025, 2006). This means, in particular, that the full LCA report was also verified by an independent third party (Bureau Veritas International) according to ISO 14040/44 (ISO 2006) and ISO 14025 (ISO 2006) requirements.

The immunological product can be used in pig management as an alternative to physical castration of young piglets for the control of boar taint, an offensive odor and taste caused by specific compounds that can accumulate in the fat of entire male pigs following the onset of puberty. Although not a food safety issue, effective control of boar taint is essential for the pork market because of its potential negative effect on perceptions of meat quality (Allison et al., 2009).

Physical castration is currently the most common method of controlling boar taint; worldwide, more than 95% of male pigs are estimated to be physically castrated. For practical reasons, the procedure is performed in the first weeks of life. Although successful in reducing boar taint, physical castration has a negative effect on the growth performance of pigs. Specifically, when compared to entire male pigs (boars), castrated pigs (barrows) are less efficient at converting food into body mass and tend to have lower quality carcasses with more fat and less lean meat. In addition, physical castration is associated with increased mortality.

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1 An “entire male” (not castrated) pig is also called a “boar”.

P. J. U. de Moraes et al.
among male piglets and is an animal welfare concern to many members of the public.²

The product under study works by causing a temporary, immunological suppression of testicular function. It is as effective as physical castration in controlling boar taint in pork but being administered only a few weeks prior to the time of slaughter, it allows male pigs to grow naturally and more efficiently as boars for most of their lives. As a consequence, there is an indirect, beneficial impact on pig production as animals, on the immunological product program, naturally eat less feed, create less waste (manure), and have carcasses with a greater percentage of lean meat than barrows. This improved efficiency, in turn, was hypothesised to provide both direct and indirect environmental benefits, principally due to reductions in feed consumption and slurry (manure) generation.

The scope of this paper is to describe the LCA project “from cradle to pork meat availability” to explain the role of the immunological product in the pork meat production chain and to highlight environmental and animal welfare benefits with

![Fig. 1. The main systems involved by the LCA study. Packaging, distribution, consumer usage and packaging disposal were not included in the system boundaries (see text for explanation).](image)

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² In the European Declaration on alternatives to surgical castration of pigs of December 2010, major actors of the pig sector committed on a voluntary basis to stop routine surgical castration of pigs by 1 January 2018.
respect to the current practice of physical castration to avoid boar taint (in Fig. 1 a view of the considered systems — the immunological product and the pork meat).

**A global project**

This immunological product is already approved and at present distributed in 63 countries worldwide, from South America to the US and from Europe to Australia, including the world leader in swine production, China. A meaningful LCA study required the collection of reliable data about the life-cycle environmental burden of an average farm that uses the product and an average farm that does not use the product. This allows us to understand any possible environmental benefit of the immunological product’s application, benchmarking with usual existing traditional practices and then proceeding to eventual dissemination activities, including green marketing tools such as the already published EPD.

The reduction of carbon footprint represents a valid perceived advantage for the agricultural and food sector and, for this reason, the Global Warming Potential (GWP) is the major impact category of interest here discussed; of course, it was not the only parameter to be investigated and other LCA relevant impact categories are also discussed in this paper to provide a comprehensive view of the life-cycle impacts of the product. In detail, these are energy use (total energy consumption), acidification, eutrophication, stratospheric ozone depletion, and photo-oxidant creation (low level smog formation). To calculate the impact category indicators, we applied valuation systems from the Ecoinvent database (Ecoinvent, 2010) such as IPCC 2007 for the GWP and “The International EPD Cooperation supporting annexes” (IEC, 2008), which recalls the most recognized systems such as CML 2001 (Guinée et al., 2001) for the others.

About the ecotoxicology and human toxicity issues, the approval protocol by public agencies where the product is legally registered and distributed represents the evidence of the safety of the product and for this reason they have not been explicitly considered in the LCA study (for further details see the section “LCA model related to the immundosical product use”). It is important to note also that a Life Cycle Assessment and the Environmental Product Declaration can also be used to support the results of an Environmental Impact Assessment (EIA). An EIA is required for Marketing Authorisations in the EU for food-producing species. The EIA contains information on environmental fate and the ecotoxicity of the active ingredient of the product or metabolites of the active if these compounds are excreted by the target species. In the case of the Immunological Product for boar taint Control in male pigs here presented, there are no excreted metabolites as documented in the information contained on the European Medicines Agency webpage for this product. However, in
cases where, an EIA is required and environmental tests must be conducted, then the results of an LCA could be used to augment the conclusions reached in an EIA conducted in accordance with the VICH\textsuperscript{3} Phase II risk assessment guidelines.\textsuperscript{4}

Finally, water consumption and direct electricity use at plants level were calculated as well and reported separately in the Environmental Product Declaration (that, as already said, is available for downloading from www.environdec.com).

The identification of the typical farm that uses and that doesn’t use the immunological product was done according to a sampling procedure as later explained, with the availability of data collected directly in the field by interviewing swine producers.

Never-the-less, it has to be pointed out that describing the performance characteristics of this sector with the goal to have a representative global picture is extremely difficult because of the nature of pig farming operations. It is in fact very fragmented, including farms with a limited capacity and quite craftsmanlike practices to farms organised and managed very similarly to industries (European Commission, 2003). For this LCA, it was decided to consider only “industry-like” farms, with intensive pig rearing. The animals are expected to be a maximum 30 weeks old at the time of slaughter, with an average weight of about 111 kg.

The task to inventory (collecting data) from typical “industry-like” farms was assigned to local region/country coordinators. Each coordinator managed a defined macro-region contributing to data collection on a global scale covering the following countries: Australia, Belgium, Brazil, Canada, Colombia, Chile, China, Denmark, France, Germany, Japan, Mexico, Netherlands, Spain, UK and the USA.\textsuperscript{5}

For each of these countries, the relevant coordinator and support were given the mandate to collect data from farms that use and don’t use the immunological product, and also from abattoir operations by means of a customised LCA questionnaire. In addition, information about the product use at the farm level was obtained from specific efficacy trials that were conducted to demonstrate efficacy of the product consistent with the regulatory requirements of each country or region. Results from these studies were verified by third parties, in which diet composition, feed intake, weight of animals to be slaughtered and other data relevant to the LCA were available. A summary of these results are available in Table 1 (see section “Pig farm and abattoir (downstream processes)”).

\textsuperscript{3}International Cooperation on Harmonization of Technical Requirements for Registration of Veterinary Medicinal Products.


\textsuperscript{5}For Australia and USA, two already existing country specific LCA studies on the swine industry have been adopted and their data integrated in our LCA model: Wiedemann et al., 2010, Frank et al., 2010. In addition, for Australia, direct data collected from swine producers have been used as well.
Table 1. A summary of the study trials information used for the LCA project. *Feed conversion is defined as the weight of feed eaten to produce the same weight of live pig weight. A reduction is therefore an improvement in efficiency: the average conservative figure used for LCA calculations is –6%.

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</table>
**Functional unit and system boundaries**

The immunological product works with the pig’s immune system. Its function is to eliminate boar taint by preventing the accumulation of the boar taint compounds andrestenone and skatole in male pigs. The mode of action is referred to as immunological castration and it is an alternative practice to physical (surgical) castration.

There are a number of different positive effects and consequences of its use, some of which are also likely to produce benefits from an environmental point of view. Among others, it allows male pigs to be reared as functional boars until the second dose. Boars deposit more lean tissue and less fat than barrows, particularly at higher weights. Boars are also more efficient in converting food to body tissue (feed conversion efficiency) than barrows.

For the LCA, three main sub-systems were defined. The functions of each of these sub-system are depicted in Fig. 2.

UPSTREAM (suppliers of the immunological product manufacturing level), from cradle to the entrance gate of the facilities where it is produced; the functional unit is two doses of products. Two doses (2 ml/dose) represent the exact quantity of product that is the necessary to obtain the immunological castration for an animal at the end of its life. This functional unit here represents the key to interpret

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6 Barrow is a physically castrated male pig.
the LCA results from the manufacturing point of view, with regard to the suppliers that were involved in the study by means of customised questionnaires. In detail, primary data and information coming from direct suppliers were classified as specific or generic\(^7\) depending on their availability and take also into account substances that are covered by a trade mark. A single dose of immunological product contains: Gonadotropin releasing factor (GnRF) analogue-protein conjugate as active substance; Diethylaminoethyl (DAEE)-Dextran, an aqueous, non mineral oil based adjuvant and finally Thiomersal as excipient. The environmental burden due to energy, transportation, ancillaries and packaging materials used at supplier’s plants (declared by the suppliers in the questionnaires) come from professional LCA databases (generic selected data). Other generic data, used when data from public database are not available, contribute to the environmental burden of all the considered indicators for less than 10\(\%\), complying with the EPD System recommendations.

CORE (Facilities-immunological product manufacturing level), from gate to gate at plant level: the functional unit is the two doses of product again and data were collected by means of customised questionnaires in the three production facilities (Belgium, USA and Australia). Also in this case, the environmental load due to energy, transportation, ancillaries and packaging materials used at this stage come from professional LCA databases.

DOWNSTREAM, including the use phase of the immunological product, farming and abattoir operations: the functional unit here is the kg of pig ready for slaughter (called “1 kg live weight”) and the unit mass of the final product (either 1 kg pig carcass after dressing\(^8\) or 1 kg of lean meat) as additional information. As said above, for the farms/abattoirs where animals are raised, data were collected by means of customised questionnaires through the local coordinators and supporters, and eventually integrated using literature data as explained in the following points.

Extending the functional unit definition (1 kg live weight, either 1 kg pig carcass after dressing or 1 kg of lean meat) provides a complete overview of the system, from production of the immunological product to pork meat that is ready for transport to retail outlets. In other words, these functional units represent the

\(^7\)According to the EPD International System terminology (www.environdec.com), data used for the Life Cycle Inventory can be also classified in three different categories: specific data, that are equivalent to primary data and are directly collected at the production site, generic selected data from commonly available data sources and other generic data, from other sources.

\(^8\)Dressing refers to the process of preparing a pig carcass, including removal of offal. Lean meat is defined as “fat free lean”, which essentially means muscle tissue; the value is often expressed as a percentage of carcass weight. It is an important parameter in the industry and is often used as a basis for meat payment.
key to interpret the LCA results from the abattoirs, retailer and consumers point of
views, respectively. Packaging and transportation to retail outlets and to the
consumer as well as the cooking phase were not included in the analysis (please
note this has no influence for the benchmark of the immunological product system
with the baseline-physical castration scenario).9

The decision to include LCA results on mass of live-weight pig and mass of
pork meat reflects the opportunity to fully describe the immunological product
system with respect to the baseline scenario that is represented by the physical
castrated pig system. It is relevant to note that when considering the mass of pork
meat as a functional unit, the system automatically incorporates the two doses of
the immunological product as reference flow.

Data and Methods

Facilities and their suppliers (upstream and core processes)

The immunological product manufacturing (Fig. 2) is based on the use of a set of
specific substances, coming from a selected group of suppliers (upstream). Specific
data were requested from these suppliers for inclusion in the LCA.

Taking into account the annual production on a global level, at present 80% of
the product comes from Belgium, 15% from Australia, and 5% from the United
States. The environmental burden to transport the product from the three production
facilities to the farms where it is used has been taken into account in the study.

With regard to the production processes that are considered in the LCA model,
raw materials and semi-finished products used in the production plants are mixed
in specific aseptic machines using electricity for several services (e.g. mixing,
filling, packaging purposes, compressed air) and natural gas for general services
and for steam production.

Energy data have been provided by the ISO 14001 — compliant facilities and
obtained by allocating the plant total energy demand to the different bulk pro-
duction types: freeze dried and liquid. Since different products are manufactured in
the same plant, the specific number of doses produced (the liquid product type) has
been provided.

9From a study made by the University of Arkansas’ Applied Sustainability Center, the “National
Scan-level Carbon Footprint Study for Production of US Swine” (Frank et al., 2010, available on
their internet site), the retail refrigeration and at home cooking are rather significant contributors to
the overall carbon footprint. We recommend to read this study in case a quantification of the carbon
footprint of such phases is needed (this study, as already said, was reviewed as a valid support
against data collection of farms for the US LCA model).
From the point of view of the air and water emissions, the immunological product manufacturing process is characterised by not having direct emissions and for this reason, only indirect emissions due to energy fuels and the production of immunological product main components (processes developed at suppliers plants) have been included in the LCA model.

**Pig farm and abattoir (downstream processes)**

The use phase analysis of the immunological product was conducted using two sources of information. As part of the product development and government registration program, multiple controlled studies were conducted, comparing immunised pigs with physically castrated pigs on the same farms using experimental designs capable of identifying small differences in parameters such as feed consumption, which are economically and environmentally important in swine production. A composite result was derived from these studies using a meta-analysis approach (see section “(LCA model related to the immunological product use”) for further details). While providing specific comparative data, the same study reports lacked the more general information required for a broader, baseline analysis of the environmental impact of pig production. For this reason, in addition, the LCA model made use of customised questionnaires aimed at collecting specific data from within macro-regions about farm capacity and production, energy consumption, manure/slurry management, feed given to animals and other environmental life-cycle based information that was useful for this study. As already specified, this direct data collection at the farm level involved farms where immunised and physically castrated pigs are raised. Customised questionnaires were also used to collect specific data from within macro-regions about abattoirs. This data collection work was conducted by several external consultants worldwide during the 2007–2010 time period and in Table 1 a summary of the study trial results used for the LCA project are reported.

**Farming model**

To simplify the mass and energy balances accounting, the farm operational model for Life Cycle Inventory purposes was based on annual production of pig breeding and rearing. The cumulative impact of all inputs (e.g. energy consumption on the farm) was divided by the number of finished animals sent to the abattoir. In this way, the model takes into account the mortality of piglets.

With regard to the management of farms, the following contributions were taken into account: (1) energy consumption (in particular, electricity and fuel used); (2) consumption of raw materials (detergent and any other auxiliary
materials used); (3) slurry/manure production; (4) generation of waste and final destination. For each macro-region, a specific manure composition was taken into account.

**Feed crop production**

Feed crop production analysis started from the identification of the average ration given to pigs in all the macro-regions involved in the study at the global level. All data are referred to the entire life cycle of a pig and they were taken into account as the feed given to animals during the different rearing phases (pre-wean, nursery and growing phases). The contribution of sows was included as explained in section “Sow breeding” For every macro-region, the average ration given to pigs was linked to the local agricultural practices (including direct energy use of machineries for soil cultivation, organic and inorganic fertiliser production, average yield of cultivation, etc.) in order to build a detailed operational LCA model with a specific feed production chain back to the raw materials from the earth. In case of the lack of primary specific data related to the cultivation of feed directly produced in the sampled farms (i.e. corn, barley, soybean, etc.), the LCI was developed by means of information coming from LCA professional databases (e.g. Ecoinvent, in which agricultural practices are well reported for several cases), integrated by specific literature sources (in detail, it is relevant to remark that country specific data about cultivation practices were taken from FAO statistics and integrated into the LCA model). The CO₂ removed from the atmosphere during plant growth (carbon storage) was not considered in the assessment. This assumption is based on the fact that the cycle of carbon sequestrated is short relative to the subsequent emissions of CO₂ due to animal respiration and slurry/manure spreading (see below).

Table 2 shows the average composition of a ration given to pigs coming from the sampled farms for the macro-regions.

**Emissions from livestock facilities**

In the housing system, the urinary nitrogen (urea) is rapidly transformed into ammonia nitrogen with subsequent gaseous losses as ammonia. Data on nitrogen transformation have been adapted starting with data on monogastric nitrogen metabolism and excretion and from data on emission of ammonia from livestock housing facilities. In particular, the ammonia emission factor comes from the specific LCA studies (Wiedeman et al., 2010) which indicates NH₃-N volatilisation from a shed for each kg of weanling pig and finished pig ready for slaughter.
Starting from the assumption that the ammonia emission factor is related to slurry N content, for the farm model related to other macro-regions (where the slurry composition may be different) the emission factors have been calculated in a manner proportional to the N content.

**Emissions from pig enteric fermentation**

Enteric fermentation is an animal digestive process by which carbohydrates are broken down by microorganisms into simple molecules for absorption into the bloodstream; the process generates methane as a by-product. The amount of methane that is released depends on the type of digestive tract, age and weight of the animal, and quality and quantity of the feed consumed.

For pigs (mono-gastric livestock) the amount of methane emitted was calculated according to the IPCC Guidelines for National Greenhouse Gas Inventories, which provides an emission factor of 1.5 kg CH₄/head*y (IPCC, 2006).¹⁰

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¹⁰These Guidelines provides emission factors for both developed and developing countries. In any case, in the LCA model the most conservative factor is used for all cases.
Emissions from pig slurry management

At the farm level, manure management represents a key issue related to the environmental impact of pig breeding. It is usually associated with the emission of methane, nitrous oxide and ammonia to air and nitrate to water.

Different manure management systems result in different quantities of greenhouse gases (primarily methane and nitrous oxide) emitted to the atmosphere. The IPCC Guidelines (IPCC, 2006) was again considered as the main reference to develop the Life Cycle Inventory model, while country specific data were used to define the local manure management practice.

The methane produced in anaerobic conditions during the storage and treatment of manure was considered. These conditions occur most readily when large numbers of pigs are managed in farms where manure is disposed in liquid-based systems. The method used to evaluate the methane was based on the combination of 4 factors: (1) the volatile solids excreted by pigs, (2) methane (data used come from literature), (3) producing capacity for manure produced by pig (IPCC data) and (4) methane conversion factors for manure management system (Fig. 3).

With regard to the nitrous oxide (N₂O), the LCA model incorporates direct emissions resulting from the processes of nitrification (the oxidation of ammonia nitrogen to nitrate nitrogen) and denitrification of nitrogen contained in the pig slurry, as well indirect emissions deriving from volatile nitrogen losses that occur primarily in the forms of ammonia and NOx. The method used to evaluate the N₂O emission is extracted by the IPCC Guidelines for National Greenhouse Inventories (IPCC, 2006). It represents a simplified method based on IPCC default N₂O emission factors, default nitrogen excretion data, and default manure management systems data.

Emissions from pig slurry spreading

Slurry applied to land contains a considerable quantity of nitrogen. The amount of nitrogen available to the crops being grown is about 50% and varies according to the composition of manures, the handling and processing that is applied to the manure between production and spreading and the rate of bacterial activity in the soil which is a function of moisture and temperature. The assumptions that were considered in the LCA model on the nitrogen emission related to slurry spread over the soil are based on data about pig slurry composition (in terms of N contents) and conservative emission factors related to the percentage of N applied to land being converted into NH3 (emission factor estimated 26%) and NOx (emission factor estimated 30%). (Ecoinvent, 2007). The environmental impact due to land spreading was included in the system boundaries only when the slurry
**CH₄ Emission due to slurry management**

Slurry Composition — LCA Study Australian Government: Wiedemann et al. (2010)  
"Environmental Assessment of Two Pork Supply Chains Using Life Cycle Assessment"

<table>
<thead>
<tr>
<th>Slurry composition - DATA FROM Australian Report</th>
</tr>
</thead>
<tbody>
<tr>
<td>kg / phase</td>
</tr>
<tr>
<td>---------------------</td>
</tr>
<tr>
<td>total solids</td>
</tr>
<tr>
<td>volatile solids</td>
</tr>
<tr>
<td>Nitrogen</td>
</tr>
<tr>
<td>Phosphorous</td>
</tr>
<tr>
<td>Potassium</td>
</tr>
</tbody>
</table>

\[
\text{CH}_4 \text{ emission} = \text{VS} \cdot \text{Bo} \cdot \text{MCF} \quad \text{[kg CH}_4/\text{head yr]}
\]

**CH₄ emission factor = \text{VS} \cdot \text{Bo} \cdot \text{MCF} / 100**  
11,88

<table>
<thead>
<tr>
<th>CH₄ emission factor</th>
<th>VS (kg)</th>
<th>Bo</th>
<th>MCF</th>
</tr>
</thead>
<tbody>
<tr>
<td>VS</td>
<td>46.76</td>
<td>0.48</td>
<td>79%</td>
</tr>
<tr>
<td>Bo</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MCF</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

VS: Volatile Solid  
Bo: maximum methane producing capacity for manure produced by livestock category = 0.48 m³ CH₄/kg VS  
MCF: methane conversion factor for each manure management systems = 79% for uncovered anaerobic lagoon

Fig. 3. Example of how methane emissions related to the pig slurry management are calculated and added to the LCA model (the Australian case is here used as a reference — in the LCA model all the country specific cases from where data are collected have been used).

is used for agricultural activities declared by a specific farm for feed production; when database information about feed production were used, its impact was not accounted for to avoid double counting.

**Sow breeding**

The system at the farming level includes also the breeding sows phase; the LCA model is based on 1 year of sow’s life and the main elements considered are the ration of feed given to sow and the emissions related to sow slurry management (again, calculated according to IPCC Guidelines). Data related to 1 sow have been divided by the average number of piglets generated in 1 year (20–25) in order to evaluate the contribution of sow management in the growing pig life cycle.

**Abattoir process**

With regard to the abattoir process, energy consumption, detergent/sanitiser and any other auxiliary materials used during the process, water consumption, air
emissions, water discharges and emissions into water have been collected by questionnaires filled in at the macro-region level. Where the data were lacking, the European BREF document related to Slaughterhouses and Animal By-products Industries was used (European Commission, 2005).

The hypothesis related to the slaughter carcass yield comes from the overall analysis conducted by the authors. In particular, for a physically castrated pig, the mean yield considered was 78.2%, while for pigs treated with the immunological product, the percentage was 1.6% lower and equal to 76.6% (Allison et al., 2009).

The allocation rules applied for meat and by-products (part of carcass, bones, and waste not useful for pork meat production) were derived from abattoir activities. In the LCA model, precautionary conditions were applied, in particular, the total impact of pig breeding and slaughter has been allocated to the pig meat.

From the point of view of the slaughter waste, the LCA model used on the assumption that the mass of pig not useful for meat production (about 25%) was managed like animal waste and sent to incineration. In the absence of primary data, the European BREF document (European Commission 2005) related to Slaughter Industry has been used as a reference in order to consider the consequent global and local environmental impacts from air emissions (i.e. CO₂, NOₓ, SO₂, CO from animal carcass incineration). This is probably the most conservative assumption for the entire LCA model of the immunological product: there are in fact alternatives such as the production of pet food that may be considered instead of incineration, but, at present, information coming from the abattoir waste management is strongly country dependent and not supported by consistent published data.

**LCA model related to the immunological product use**

The LCA model related to the use phase was developed considering two main sources of information as stated above: primary collected data by means of questionnaires and trial reports. In detail, it is based on an average model developed starting from available data provided by farms where the pigs are vaccinated and the information related to the differences in terms of feed intake and slurry production between castrated pigs and immunised pigs coming from the study trials.

The trials provide the evidence that male pigs vaccinated eat less food to get to a given weight, or to produce a given amount of meat, when compared to physically castrated pigs. For those studies where the data allow such a comparison, the
% improvement in feed conversion (equivalent to the % reduction in feed intake to reach a given weight) is shown in Table 1. The mathematical average of 25 studies is -8.2% but it must be kept in mind that this parameter was generally measured only over the final (fattening) phase of the pig’s life. Applying a conservative approach, the figure used for the LCA model was −6%, representing the output of a specific “meta-analysis” (developed in June 2010 by F. Dunshea11 who reviewed and assessed the suitability of the studies available) and adjusted on the assumption that for the pre-fattening rearing stages (estimated at 20% of lifetime feed consumption) there was no difference in feed conversion efficiency between the groups.

With regard to the pig slurry reduction in the absence of direct measurement, it was assumed to be directly proportional to the reduction in feed intake. This can be justified given the overall input-output balance of a growing pig on a mass basis according to the following equation:

\[
\text{slurry output} = \text{feed intake (consumed)} - \text{retention of mass in pig (e.g., muscle, etc.)} - \text{exhaled mass of carbon dioxide}
\]

The logical steps considered start from the assumption that for a growing pig the major sources of output are faeces, urine and exhaled carbon dioxide; both faeces and urine become part of the slurry, as do any minor forms of excretion such as saliva and desquamation of skin cells.

Assuming that slurry output declines in proportion to feed intake implies that the total of retention and exhalation would also decline to maintain the same proportional relationship. Considering that male pigs vaccinated with the immunological product eat less food to get to a given weight than a physically castrated pig, the retention could be higher in vaccinated animals thus implying a relatively greater reduction in slurry than in feed.

A similar argument can be applied to exhaled CO₂, which is proportional to energy expenditure. It is known that boars (immunised pigs are boars for most of their lives) are more active than physically castrated pigs and the data available suggest that their maintenance energy requirements are also higher than those of castrated pigs at the same bodyweight. The assumption that exhaled CO₂ falls in

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11Frank Dunshea is a professor in agriculture and food system at the University of Melbourne in Australia. He has a research career spanning 25 years in farm animal and biomedical research; he performed the meta-analysis starting from the trials which are summarised in Table 1.
proportion to feed intake is again conservative and implies that the decline in slurry production could potentially be greater.\textsuperscript{12}

About the CO\textsubscript{2} from animal respiration, it can be considered biogenic because created from the degradation of carbon containing feeds which have grown by removing CO\textsubscript{2} from the atmosphere in the contemporary carbon cycle. Whereas the carbon cycle is very short, the assessment doesn’t account the CO\textsubscript{2} sequestration which may occur during plant growth, nor the emission of CO\textsubscript{2} derived from respiration of the animals.

Finally, about the eco and human toxicity issues, as required by legislation, it was specifically addressed in the product registration process. The antigen in the immunological product is a protein and the adjuvant is a polysaccharide; both are broken down to simpler compounds that enter the general metabolism of the pig and neither gives rise to specifically identifiable metabolites. The only compound of possible environmental concern is the preservative, thiomersal, which is used everywhere except in the United States. This is a mercury-containing compound, but the amount is very small (0.2 mg per dose) and it was not considered of concern by the authorities during the product registration.

\textsuperscript{12}The fact that boars eat less than castrates is well documented in the existing literature and may have several reasons, including behavioural differences, but a key point is that boars are more efficient creators of body mass. Pigs grow at a very rapid rate, sometimes averaging over 1kg of weight gain per day as they approach maturity, so compared to a species such as man an exceptionally high proportion of food intake is used for tissue creation. Because of the natural presence of testosterone and other male steroids in boars the efficiency of tissue formation is higher in boars than in castrates, which in the end means that less food is required to sustain growth and this effect outweighs any increase in energy requirement that might result from a higher level of activity. Boars do have a higher level of activity and, although not proven, it is quite likely that they will have some small increase in exhaled carbon dioxide as a result, but this is not quantified, so it is important that the consequent, default assumption of no increase is conservative in the context of the input-output balance and calculation of the impact of the immunological product use on slurry production. Slurry (manure) is one of the most important contributors to the environmental impact of pig production. We have no direct comparison between the slurry production of barrows and immunised pigs. There are, however, many studies with comparative figures for feed consumption and weight gain. The above reported input-output balance equation (section “LCA model related to the immunological product use”) is the justification for assuming that the reduction in carbon output in slurry will be at least as great as the reduction in feed intake. In fact this assumption is conservative, as unless the amount retained in the pig and the amount excreted as CO\textsuperscript{2} also decline in proportion to feed intake, the outcome will be a proportionately greater reduction in slurry than feed.
Results

Since the Global Warming Potential is probably one of the most interesting impact category taken into account in this study, in Table 3 the Inventory of greenhouse gases emissions related to the product system is provided. In Table 4 are then reported other relevant LCIA results for the immunological product system divided by upstream and core processes (functional unit: 2 doses) and downstream processes (functional unit : 1 kg pig live weight). Further detailed results are available in the EPD document, that is published on www.environdec.com website.

Table 3 shows that the production phase of the immunological product (upstream and core processes) is negligible compared to the use phase at the farm.

Table 3. Main air emissions related to the immunological product system and related impact category. The list of processes that are included in the upstream, core and downstream are reported in Point 1.2. For each emission listed below, the absolute figure and its contribution to each phase (upstream, core and downstream) is given.

<table>
<thead>
<tr>
<th>Air emission (g)</th>
<th>Upstream processes</th>
<th>Core processes</th>
<th>Downstream processes (data for kg of pig live weight)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>2.86</td>
<td>26.01</td>
<td>1691.40</td>
</tr>
<tr>
<td>Global Warming Potential irreversible</td>
<td>0.05%</td>
<td>0.49%</td>
<td>31.55%</td>
</tr>
<tr>
<td>CH₄</td>
<td>0.01</td>
<td>0.06</td>
<td>74.37</td>
</tr>
<tr>
<td>Global Warming Potential irreversible</td>
<td>0.00%</td>
<td>0.03%</td>
<td>34.67%</td>
</tr>
<tr>
<td>Photosmog</td>
<td>0.00%</td>
<td>0.02%</td>
<td>0.12%</td>
</tr>
<tr>
<td>NH₃</td>
<td>0.01</td>
<td>0.00</td>
<td>26.63</td>
</tr>
<tr>
<td>Acidification</td>
<td>0.02%</td>
<td>0.00%</td>
<td>74.66%</td>
</tr>
<tr>
<td>Eutrophication</td>
<td>0.01%</td>
<td>0.00%</td>
<td>18.59%</td>
</tr>
<tr>
<td>NOₓ</td>
<td>0.01</td>
<td>0.04</td>
<td>9.92</td>
</tr>
<tr>
<td>Acidification</td>
<td>0.01%</td>
<td>0.04%</td>
<td>8.69%</td>
</tr>
<tr>
<td>Eutrophication</td>
<td>0.00%</td>
<td>0.01%</td>
<td>2.57%</td>
</tr>
<tr>
<td>Photosmog</td>
<td>0.02%</td>
<td>0.07%</td>
<td>16.16%</td>
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<tr>
<td>N₂O</td>
<td>0.01</td>
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</tr>
<tr>
<td>Global Warming Potential irreversible</td>
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<td>0.00%</td>
<td>26.53%</td>
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<td>Eutrophication</td>
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<td>1.90%</td>
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<tr>
<td>CO</td>
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<td>0.02</td>
<td>2.41</td>
</tr>
<tr>
<td>Photosmog</td>
<td>0.00%</td>
<td>0.03%</td>
<td>3.78%</td>
</tr>
<tr>
<td>SOₓ</td>
<td>0.01</td>
<td>0.05</td>
<td>9.29</td>
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<tr>
<td>Acidification</td>
<td>0.01%</td>
<td>0.09%</td>
<td>16.29%</td>
</tr>
<tr>
<td>Photosmog</td>
<td>0.02%</td>
<td>0.15%</td>
<td>25.95%</td>
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<tr>
<td>NMVOC</td>
<td>0.00</td>
<td>0.01</td>
<td>0.76</td>
</tr>
<tr>
<td>Photosmog</td>
<td>0.08%</td>
<td>0.49%</td>
<td>44.38%</td>
</tr>
</tbody>
</table>
level (downstream process) with regards to the main LCA environmental impact indicators.

Focusing on the GWP indicator, the contributions of the different phases analyzed in the LCA model are illustrated in Fig. 4. It should be noted that only 0.01% of the total GWP is due to the immunological product manufacturing, while the main contributions to the GWP are related to production of feed given to pigs and pig slurry management.

![GWP Main Contributors](image)

Fig. 4. Contributions to GWP indicator related to the different phases analyzed in the LCA model.
The Acidification Potential is affected mainly by the slurry management, the housing system (due to the ammonia emission from slurry) and the feed production (use of fertilisers), while the Eutrophication Potential is mainly influenced by the field emission (slurry and fertiliser spreading on field for feed production).

Results for immunised vs castrated pigs
As anticipated, the immunological product use phase model has been developed starting from the analysis of the baseline model and adopting the assumption related to the differences in terms of feed intake and slurry production coming from the black trials. An extensive literature review was done to qualify the results of the baseline scenario. From several published reports and studies (for instance: Basset-Mens et al., 2005, Basset-Mens et al., 2006, Cederberg et al., 2004, Frank et al., 2010, Wiedeman et al., 2010), the global model used as benchmark in our LCA is aligned when main LCIA indicators are considered.13

![Diagram](Image)

**Fig. 5. Summary of carbon footprint results of vaccinated respect to physically castrated pigs. The functional units here refer to 1 kg of animal live-weight and to 1 kg of pig carcass after dressing.**

13Taking into account the GWP results, the range is from 3,0 to 11,2 kg/ CO₂ equivalent/kg carcass weight (RIRDC, 2010).
This approach has allowed evaluation of the difference in the main environmental indicators between castrated pigs and immunised pigs. The LCA results demonstrate a clear environmental benefit for important impact indicators for the immunological product system. Figure 5 illustrate the different results expressed in term of the GWP.

**Final Remarks**

The results of the LCA analysis of this immunological product for boar taint control in male pigs shows that the production phase (upstream and core process) is negligible compared to the use phase at the farm and abattoir levels (downstream process).

The LCA study shows a benefit for important environmental impact indicators for the immunological product system vs. the physical castration. When such a comparison is made, the data demonstrate that, because the use of the immunological product to reduce off-odor in meat of male pigs allows farmers to discontinue physical castration, the immunological product system has the added value of a reduced environmental life-cycle burden with respect to the traditional scenario (Fig 5).

In particular, the LCA study shows that there is a considerable reduction in terms of GWP with respect to the practice of physical castration. The carbon footprint of the immunised pig system with respect to the castrated pig is lower of 3.7% (data per kg live-weight) and of 5.0% when a unit mass of lean meat is considered as product ready to be delivered to the final consumer (Table 5).

Taking into account other impact indicators, there is a 3.0% reduction in the total energy consumption compared with the baseline scenario of physical castration.

<table>
<thead>
<tr>
<th>Impact Indicators</th>
<th>1 kg of pig live weight</th>
<th>1 kg of pig carcass after dressing</th>
<th>1 kg of lean meat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global Warming Potential (GWP)</td>
<td>5.4</td>
<td>7.0</td>
<td>12.8</td>
</tr>
</tbody>
</table>

Table 5. Carbon Footprint for the three functional units considered in the LCA of the immunological product (rounded data).

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14 It is possible to claim these relatively small percentage differences because the comparative aspect of the LCA is predominantly based on experimental study data, interpreted using a documented, conservative approach. Although the changes are numerically small the potential environmental benefit is large in the context of global swine production.
Overall, taking into account an average of 111 kg of pig live weight, the use of the immunological product over the baseline scenario of physical castration results in a reduction of GWP of more than 23 kg CO₂ equivalents per pig (data calculated considering a reduction of 0.21 kg CO₂ per kg live weight pig according to Fig. 5). Given the annual production of pigs reared globally for protein consumption (about 500 M males), this carbon footprint reduction is incrementally significant and supports the adoption of the immunological product over the traditional approach of castrating boars.

Finally, the availability of the Product Category Rules (PCR) on “Vaccines for human or veterinary medicine, whether or not put up as medicaments” provides a transparent procedure to apply the LCA methodology to this product group. It is the first time an EPD on this is proposed and the pork meat sector can now use the results as additional information to address carbon footprint reductions.

References


15Product Category Rules (PCR) are provided for specific information modules “gate-to-gate”, or so called core modules. The structure and aggregation level of the core modules are defined by the United Nations Statistics Division - Classification Registry CPC codes (http://unstats.un.org). The approved PCR for this product group is available on www.environdec.com.


Ecoinvent (2010). v2.2, Swiss Centre for Life Cycle Inventories.


www.environdec.com, Environmental Product Declaration for Improvac, CPC 35270, Vaccines for human or veterinary medicine, whether or not put up as medicaments. Revision 0 of January 30, 2012. Certification No SE00250-1 Valid until: 30/01/2015.