"CNP flows interactive model" for illustrating impacts of policy scenarios on the entire manure / crop / feed cycle and forming basis for executing good governance

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EU policies for improved nutrient management in farming has been enforced through three decades and has due to the climate been extended with an increasing focus on farms' carbon management. Considering the development and current status of nutrient balances in EU farming, the effects of related policy frameworks appears disappointing. A "CNP flows interactive model" has been developed in order to illustrate the effects of CNP management at farms. The model can be used for observation of the combined effects in the entire manure / crop / feed loop of on-farm measures, such as employment of various livestock manure processing technology. Typically, such technology is validated for its impact alone in a narrow scope, such as the ease of transporting the end product, but omits impacts elsewhere in the CNP flows at farms. The "CNP flows interactive model" is using a set of Key Performance Indicators, including CNP farm gate balances, NP Nutrient Use Efficiencies (NUE's) and greenhouse gas (GHG) emissions for evaluation of the impacts of various on-farm measures. A NVZ Baseline Scenario describing the situation at livestock farms in Nitrate Vulnerable Zones of EU, meaning the most environmentally regulated part of EU's livestock farming, shows that around half of nitrogen (N) and phosphorus (P) nutrients are lost to the environment, and a carbon (C) loss is threatening soil fertility and represents greenhouse gas emissions. Both C, N and P losses means economic losses for the farming sector. This Research Note is using the "CNP flows interactive model" for analysing the impacts of two selected manure processing technologies. Comparing CNP flows of slurry separation and composting scenarios with that of a NVZ Baseline Model illustrates clearly that these two manure processing technologies represents "low hanging fruits" with respect to introduce policy measure in support of the goals of EU's Farm-to-Fork strategy concerning N and P nutrients as well as EU's climate goals concerning greenhouse gas emissions. Slurry separation is a simple, cheap and straightforward solution for obtaining full recycling of P in farming, whereas composting should be banned for is massive N and P pollution of the environment and its devastating climate effect due to large emissions of greenhouse gases.

Policy targets and efficiency in reaching these

EU's Green Deal and its Farm-to-Fork strategy[1] has set clear policy goals for improved recirculation and reduced losses of plant nutrients in the primary food production. The Farm-to-Fork strategy says specifically that the loss of nutrients shall be reduced with 50% and the use of fertilisers reduced with 20% until 2030. Also, In April 2021, the Council's and the European Parliament's negotiators reached a provisional political agreement setting into law the objective of a climate-neutral EU by 2050, and a collective, net greenhouse gas emissions reduction target of at least 55% by 2030 compared to

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[1] https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en

1990[2]. These goals are linked with several related policy goals, among other dealing with air and water quality, biodiversity, greenhouse gas emissions and Critical Raw Materials[3].

The policy focus on plant nutrient regulation related to agriculture and livestock production started with the Nitrates Directive (91/676/EC) in 1991. The most important policy framework today comprises the Water Framework Directive (2000/60/EC), the Industrial Emissions Directive (2010/75/EC) and the Emissions Ceilings (NEC) Directive (2016/2284/EU). Best Available Techniques (BAT's) related to the Industrial Emissions Directive are defined in the Reference Document on Intensive Rearing of Poultry and Pigs and its related Implementing Decision (EU/2017/302). Mandatory Cross Compliance criteria to strengthen the enforcement of among other the Nitrates Directive was introduced under Council Regulation No 1782/2003 in connection to the Common Agricultural Policy (CAP) reform in 2003, which also sets the frames for supporting farm-level measures to reduce nutrient losses.

Other complex EU policy areas, such as for instance the Single Market[4], have been effectively implemented. However, this seems not to be the case for the use of N and P in farming. Despite the mentioned policy measures to create improvements over the last three decades, the European Environment Agency (EEA) (2020) reports that the total ammonia emissions in 2018 were slightly higher than in 2010. According EEA[5], the gross nitrogen balance was 51 kg N per ha UAA in 2015, which is higher than in 2009. According Eurostat[6], the gross phosphorus balance for the EU was 1.2 kg per hectare per year in the period 2013-2015, but several Member States, among other Denmark has gross phosphorus balances above 5 kg per ha UAA. It should be noted that the gross phosphorus balance by Eurostat is calculated as an average for the Member States and includes as such balances of specialised crop production farms without livestock. The list of environment-related infringement procedures raised by EU against its Member States for missing implementation is very long[7].

It is on this background that EU's Farm-to-Fork strategy emphasizes on higher use efficiency of N and P. The question is how policies shall be designed to avoid a continuation of the development during the last decades, which largely can be described as side stepping?

Describing CNP flows at livestock farms

Manure management is fundamental for good governance concerning N and P Nutrient Use Efficiency (NUE) in farming and avoiding losses to the environment, and farming is also accountable for a considerable share of the carbon flows in our societies and seen as a part of the solution for reach of policy goals for reducing greenhouse gas emissions.

A "CNP flows interactive model" is developed to illustrate the impacts of employing various management practices and technologies on N and P farmgate balances as well as greenhouse gas emissions. The dynamic EXCEL file model is freely accessible from AgroTechnologyATLAS (https://www.agrotechnologyatlas.eu). The model includes references that documents the relevance

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[2] https://www.consilium.europa.eu/en/policies/climate-change/

[3] https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en

[4] https://ec.europa.eu/growth/single-market_en

[5] https://www.eea.europa.eu/airs/2018/natural-capital/agricultural-land-nitrogen-balance

[6] https://ec.europa.eu/eurostat/statistics-explained/index.php/Agri-environmental_indicator_-_risk_of_pollution_by_phosphorus

[7] https://ec.europa.eu/environment/legal/law/press_en.htm

of the used default figures for C, N and P. The documentation for the C flow figures is less substantiated and has for some of the shown figures until further character of guesstimates. C flows at farms are in comparison with N and P flows more dependent on the chosen livestock type and employed practices and technologies.

The "CNP flows interactive model" aims at providing a pedagogical presentation of the flows. It uses a main cycle to associate livestock farming with a circular economy – see Figure 1. The scope of the model is the mentioned cycle, which represent the farm gate, and all that is inside the cycle, including livestock and livestock housing, manure storages and crops is inside the farm gate. Manure processing is on the border of the cycle as this can happen both as on-farm processing and outside the farm at regional processing plants. Arrows symbolise CNP flows over the farm gate. Red arrows symbolise flows that should or can be minimised, as these flows generally represent losses with negative impact on farm economy, environment and climate. The green arrows are vice versa flows that should or can be optimised by higher recycling efficiencies to the benefit of farm economy, environment and climate. The starting point for the CNP flows is the amounts ex animal, estimated by use of standard figures for livestock manure according mass balance principles. An estimation of a scenario requires that the variable user-input figures to the model is balanced to the mentioned ex animal values, whereas the model otherwise will give a warning.

Thus, the intention of the "CNP flows interactive model" is to represent the climate and environmental impact of farming.

Manure processing technologies, including Best Available Techniques (BAT's) are normally used for reducing the environmental impacts of livestock farms. Such technologies are often characterised by their environmental impact at one stage in the manure / crop / feed cycle, whereas their impact on the entire environmental and climate load of the farming remains unclear. It is possible to perform Life Cycle Assessments (LCA's), but the LCA methodology is mainly relevant for products, and it is a complicated methodology, alone mastered by specialised scientists. Furthermore, LCA results are often presented in un-pedagogic ways in research reports, not accessible to normal citizens, typically dealing with rather specific scenarios and holding a number of reservations for the validity of the conclusions.

The "CNP Interactive Model" behind Figure 1 is intended for giving a possibility for a quick understanding of the environmental and climate impact of a practice or technology for the entire livestock farm in a given policy scenario, for instance setting the Nitrates Directive limit of 170 kg N in manure per ha brought to the field as fertiliser as criteria.

The "CNP flows interactive model" is a further expansion and refining of a model for describing nutrient flows at livestock farms, developed through several years by Foged (2012, 2016, 2019).

The new development is that the model is made interactive and freely accessible, C flows is added, and references are listed in the model to document the relevance of default figures.

The model can be used for a farm or a region of a given size in terms of Utilised Agricultural Area and number of livestock. The model has some limitation and can in its present form for instance alone operate with up to three different types of livestock. Also, the model is concentrating on major impacts on CNP flows, and is for instance not so refined that it by default calculates the impact of soil tillage and field management on laughing gas (N_2O) emissions, such as for instance larger N_2O emissions by slurry injection. The model is in this connection using a constant for N_2O emission from fields.

The "CNP flows interactive model" is despite these limitations ideal for illustrating the incremental impacts of various scenarios.

NVZ Baseline Scenario

Figure 1 illustrates CNP flows of the manure / crop / feed cycle at a livestock farm, modelled to have a livestock production that produce exactly 170 kg N after storage, the maximal amount that according the Nitrates Directive can be spread per ha in a Nitrate Vulnerable Zone (NVZ). All shown figures are per 1 ha Utilised Agricultural Area The figure shows where carbon C and NP nutrients are lost in the loop. Red arrows illustrate flows that should be minimised, and green those that should or could be maximised. The figure is intending to present realistic figures for the given scenario.

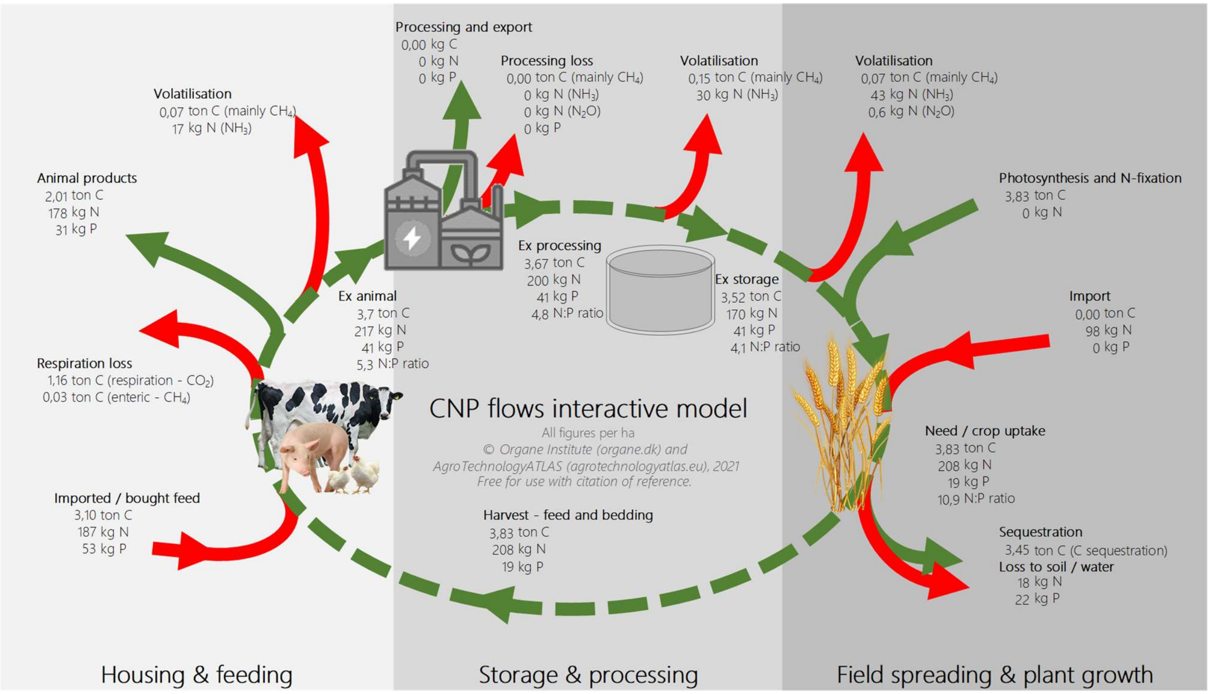

Figure 1: NVZ Baseline Scenario of CNP flows at a modelled, mixed livestock farm, producing exactly 170 kg N in livestock manure per ha, the maximally possible according the Nitrates Directive.

The "CNP flows interactive model" includes a calculation of Key Performance Indicators (KPI's) for the given scenario. For the illustrated scenario, the farm gate balance is 107 kg N and 22 kg P her ha. The Nutrient Use Efficiency (NUE) of N and P is 51 and 46%, respectively. The total CO_{2e} emissions are 8,7 ton.

It is noted that the NP farm gate balances calculated by use of the "CNP flows interactive model" are considerably higher than the above referred gross nutrient balances, informed by EEA and Eurostat. The reason for this is that the calculation method behind the Eurostat and EEA information is to be considered rather as a field balance that does not take into account the nutrient losses in housing, feeding, storage and processing.

The NP farm gate balances would be expected to be higher and the NUE's lower for livestock farms situated outside NVZ, such as in Member States with a low coverage of NVZ, for instance in Italy, where it is allowed to spread up to 340 kg N in livestock manure per ha outside NVZ areas. An important factor is also that livestock farms outside NVZ’s most typically are not met by so strict demands to capacity and quality of manure storage facilities.

The NVZ Baseline Scenario does not include any form of manure processing technology, which otherwise typically happens as soon as the manure is removed from the stables. In the following is presented the impact of employing two technologies: 1) Slurry separation, which is not used very much despite being simple, easy to employ and relatively cheap in investment and operational costs. 2) Composting, which is used a lot, and having a high reputation for its ability to concentrate and stabilise manures and reduce weed seeds and contagious germs.

Slurry separation

The NVZ Baseline Scenario shows a large surplus of P, which is due to the fact that livestock manure contains more P than the crop needs. With few exceptions, the N:P ratio of crop needs is considerably higher than the N:P ratio of livestock manure used for fertilisation, among other due to N losses in the manure handling chain from animal to field. To counteract this situation, excess P can be removed by employing slurry separation, whereby slurry is separated into separation liquids containing the main part of the volume and N, and separation solids containing the main part of C and P. N and P in the separation solids are mainly organic bound, which means that these are nutrients with a low efficiency as crop fertiliser. Organic bound nutrients are mineralised along with decomposition of the organic matter after being applied to fields, which often happen at times without crop growth, wherefore the risk of losing these released nutrients to the environment is high. Therefore, separation solids are best utilised for anaerobic digestion, which partly degrade the organic compounds under controlled conditions and makes N and P more plant available in the digestate. On the contrary, N and P in separation liquids have high fertilising effects, which are comparable to that of nutrients in mineral fertiliser.

There are several slurry separation technologies, see AgroTechnologyATLAS[8]. The most effective slurry separation technology in terms of P is centrifuge separation. However, it is of livestock farms’ interest that the used separation technology is not removing too much P to the separation solids phase, but that an amount of P remains in the separation liquids to comply with the fertilising needs of the farm. For on-farm purposes, screw pressing is often the optimal choice because the investment costs are limited, the operation unproblematic, operational costs are low, and this separation technology allows to a certain extent an adjustment of the separation efficiency to fit the needs for P removal.

Figure 2 shows the Separation Scenario of CNP flows, based on employing slurry separation by screw pressing to the NVZ Baseline Scenario. It is anticipated that the separation efficiency is 15 and 54% for N and P, respectively, and that the solid fraction represents 20% of the original slurry volume. Although the ratios between organic bound and water-soluble nutrients is changed, the scenario assumes unchanged relative losses of nutrient via volatilisation and leaching, etc., whereas there in reality might be a little higher volatilisation of N and lower loss to soil and water.

It is seen from Figure 2, that the Separation Scenario means the farm gate balance and thus the net loss of P is zero. 25 kg N less, meaning 145 instead of 170 kg N in the livestock manure is brought to the field for fertilising, which also means a corresponding lower loss of N to air and water. To

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[8] https://www.agrotechnologyatlas.eu

compensate for these changes, 17 kg N more is purchased as mineral fertiliser compared to the NVZ Baseline Scenario.

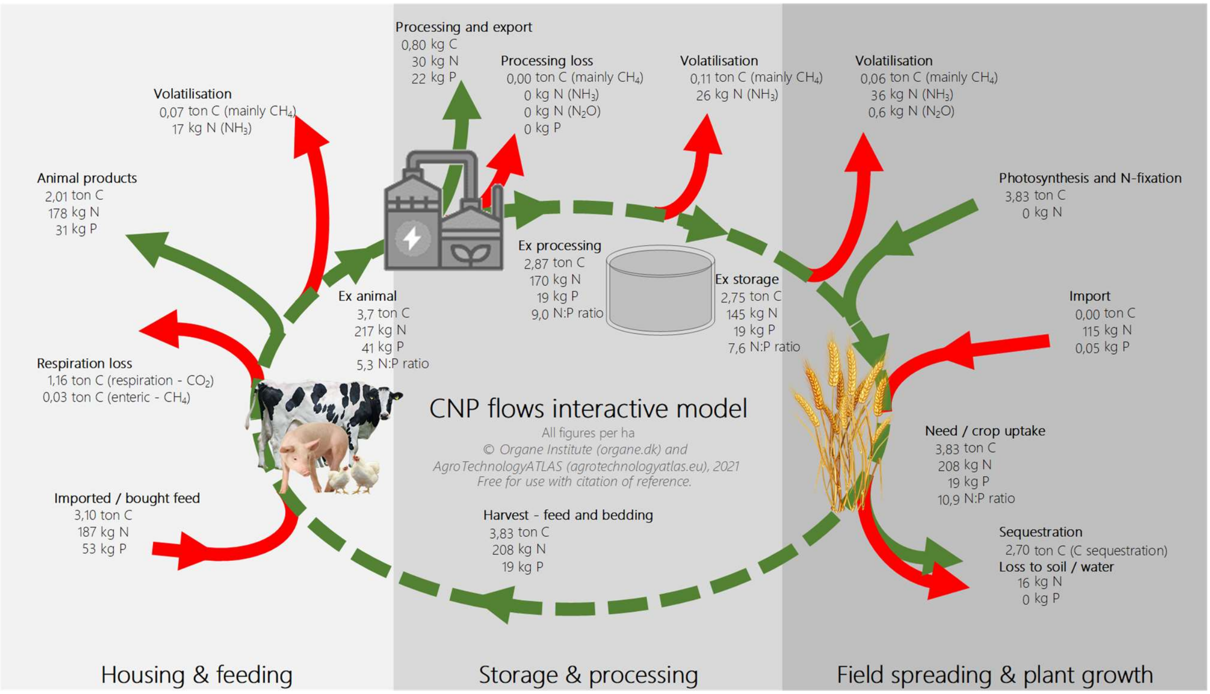

Figure 2: Separation Scenario of CNP flows, based on the NVZ Baseline Scenario, which is added slurry separation by screw pressing with a separation efficiency of 15 and 54% for N and P, respectively, and assuming that the solid fraction represents 20% of the original slurry weight.

The overall climate and environment performance of the Separation Scenario is that the N and P balances are reduced with 14 and 22 kg N and P, respectively, to 94 and 0 kg per ha. The use of slurry separation does not show any effect on the GHG emissions in the used CNP flows model, whereas some minor effects would happen in reality, for instance due to the higher use of nitrogen mineral fertiliser.

Composting

Composting is a popular manure processing technology, used in some countries more than in others, and it is praised for its resulting compost product that is characterised as being stable, much less voluminous than the manure it is made from, and therefore easier and cheaper to transport away from a farm or a region with nutrient surplus. Another benefit is that the composting process dramatically reduce the content of germs and weed seeds, which is not least important for organic farms that do not use synthetic pesticides. Many farms are therefore performing composting for use of the end product at their own farm.

Figure 3 presents the CNP flows of a Composting Scenario, which is based on conventional composting in windrows added to the NVZ Baseline Scenario. The scenario assumes a loss of C, N and P in the composting process of 46.5%, 49% and 31%, respectively, with is a medium of the losses that are reported in literature, which goes up to 63% C, 60% N and 39% P – see AgroTechnology ATLAS, which also contains literature references. This means, that the Composting Scenario assumes a good composting practice is used. It is further assumed that the compost stays on the farm and is used for fertilisation in stead of raw manure, as there is no excess of N on the farm in relation to the legal maximum according the Nitrates Directive and the fertilising needs of the crops.

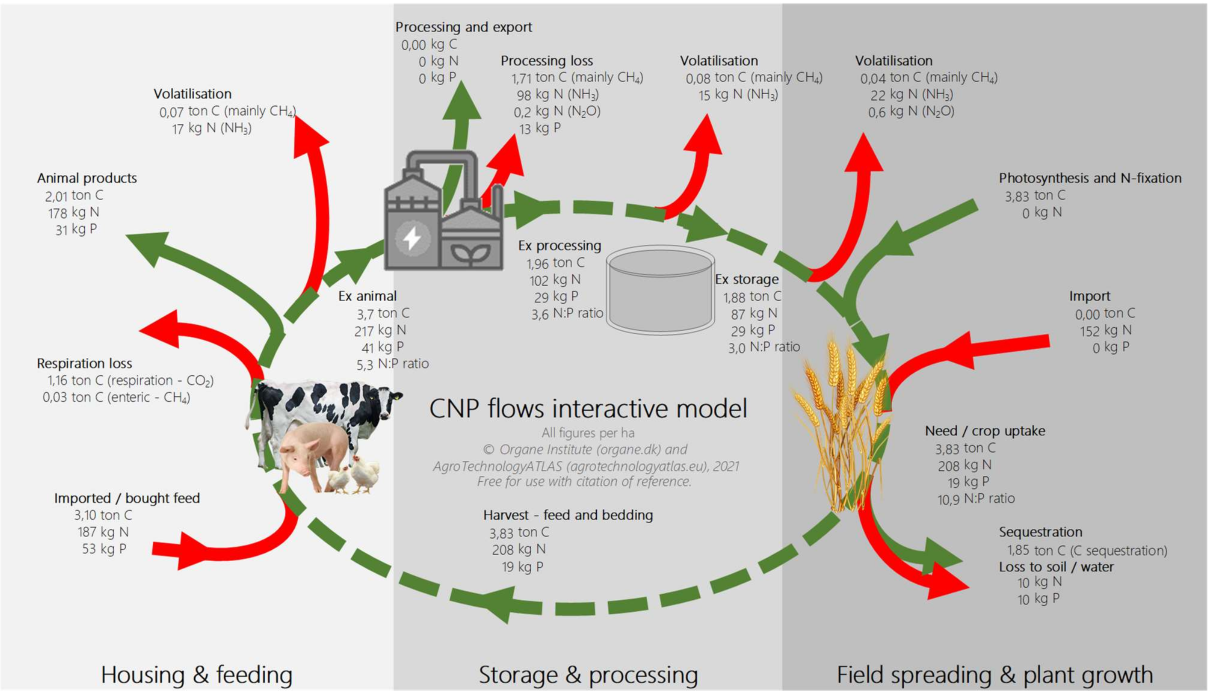

Figure 3: Composting Scenario of CNP flows, based on the NVZ Baseline Scenario, which is added composting in windrows. The scenario assumes the compost is used for fertilisation at the farm rather than raw manure.

The Composting Scenario mans an increase of the N farm gate balance to 162 kg per ha due to all the N that is lost in the composting process, whereas the P farmgate balance remains unchanged from the NVZ Baseline Scenario – the difference is that the main loss of P happens at the composting site rather than in the fertilised field. The GHG emissions increases with about 25% to 10.8 tons CO_{2e} per ha, due to a massive emission of methane and laughing gas as well as CO_2 during the composting process. The adverse climate impact of composting may be larger in reality because the emitted N shall be replaced by purchased mineral fertiliser. The Nutrient Use Efficiency is dropped with 25% to 26% for N, and remains 46% for P, compared to the NVZ Baseline Scenario.

Conclusion and discussion

The main performance indicators of the analysed scenarios are shown in Table 1.

It appears from the table that the NVZ Baseline Scenario, intending to describe the situation at livestock farms in NVZ's of EU, i.e. at the most regulated part of EU's livestock farms, means large losses of nutrients and greenhouse gases. Only around half of the nutrients in the manure / crop / feed cycle is recycled, whereas the rest is lost and allowed to pollute the environment and deteriorating farming economy. The current situation is despite EU's Nitrates Directive since 1991 has aimed at reducing loss of N to the environment, and the Water Framework Directive since 2000 the same for P. The scenario justifies well EU's Farm-to-Fork strategy and EU's goal of reducing greenhouse gas emissions for the sake of the climate, and for increasing the energy efficiency in food production.

The Separation Scenario shows that slurry separation is 100% effective for obtaining complete recycling of P in the manure / crop / feed cycle at livestock farms. Slurry separation is a relatively cheap manure processing technology, and the present use, estimated by Foged et al. (2011) to 3.1% of the manure production in EU, is largely happening on a voluntary basis by farms and manure processing plants. It is obvious to take political steps to give farms incentives for a wider use of slurry separation. Slurry separation is in no way a new manure processing technology. Already in 2010, Foged concluded that slurry separation is one of the five most relevant technologies for reducing the environmental impact of pig production.

Table 1: Main performance indicators of the scenarios analysed with the "CNP flows interactive model".

#	Scenario	Farm gate balance, kg/ha		Nutrient Use Efficiency, %		GHG emissions, ton CO_{2e} per ha
		N	P	N	P	
1	NVZ Baseline	107	22	51	46	8.7
2	Separation	94	0	50	100	8.7
3	Composting	162	22	26	46	10.8

The Composting Scenario shows that this is a heavily polluting practice that results in massive losses of NP nutrients and greenhouse gases. In addition, composting is rather expensive, and the simple form of windrow composting used in the scenario, costs more than 20€ per ton, manyfold more than screw press separation that typically costs less than 1€ per ton according scientifically validated information in AgroTechnologyATLAS. The loss of C due to composting is also representing an aggravation concerning the organic matter content of soils, which in especially the southern part of Europe is critically low and threatens the fertility of the soils, including their water binding capacity. To pick the "low hanging fruits" on the pathway to reach EU policy goals for climate, environment, water, air, etc., it seems a logic and straightforward solution to take political steps to ban composting. There exist more advanced forms of composting that does not cause the same loss of nutrients and greenhouse gases because they use closed containers - see for instance KCS Engineering[9]. However, this form of composting is far more expensive in investment and operational costs, and not realistic for manure treatment.

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