Sustainable multifunctional fertiliser – combining bio-coatings, probiotics and struvite for phosphorus and iron supply

Deliverable 6.5

Public Summary of the

Report on the life cycle impact of SUSFERT fertiliser production and GHG emission reduction

Due Date:	31/12/2023
Submission Date:	28/12/2023
Dissemination Level:	Confidential
Lead beneficiary:	University Antwerpen
Main contact:	Marc.spiller@uantwerpen.be
Other contributors	Julia Santolin, Enrico Roets, Tim Van Winckel, Michele Moretti, Elisabeth Mevis

Project acronym: SUSFERT	Project Number: 792021
Start date of project: 01.05.2018	Project duration: May 2018 – December 2023

This project has received funding from the Bio Based Industries Joint Undertaking under the European Union's Horizon 2020 research and innovation programme under grant agreement No 792021.

Publishable summary

Introduction

The industrialisation of fertiliser production has been a major turning point in history, enabling rapid population growth over the last hundred years. In just one century, our global population has grown from approximately 2 billion to more than 8 billion people (Figure 1, left) (United Nations, 2022). This population explosion has resulted in a drastically increased demand for food (Walling & Vaneeckhaute, 2020). High performance agricultural fertilisers are a key enabling factor for this growth. Without them, almost half the world's population would not be alive today (Harford, 2017). Accordingly, the global consumption of agricultural fertilisers has risen over the years (Figure 1, right).

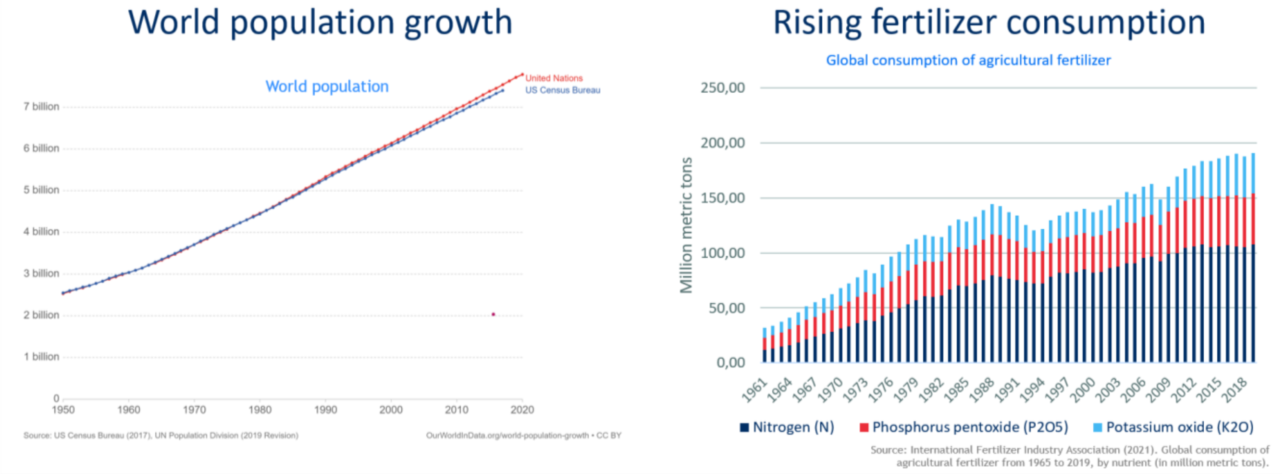

Figure 1. World population growth 1950-2019 (United Nations Population Division, 2019). Rising agricultural fertiliser consumption 1961-2019 (International Fertiliser Industry Association, 2021).

However, fertiliser use comes with environmental consequences. Specifically, phosphorus (P) fertilisation causes freshwater eutrophication and contributes to the transgression of our planetary boundaries (Richardson et al., 2023) (Figure 2). The mining of P from phosphate rock causes air and water pollution, land degradation, and soil contamination through cadmium and uranium (de Boer et al., 2019). The P rock deposits are geographically restricted to a few countries (e.g. China, Morocco) and Europe imports 46% of its demand, which threatens the stability of food prices (Fertilisers Europe, 2023). The overall increasing demand for P, together with the supply risk has led the European Commission to declare phosphate rock as a critical raw material in 2014 (European Commission, 2014). Furthermore, phosphate is a finite resource, and while estimates of full depletion ranges between 50-400 years, it is certain that the quality of the resource will decrease, and that costs of the resource will rise (Cordell & White, 2014; Sena & Hicks, 2018).

This project has received funding from the Bio Based Industries Joint Undertaking under the European Union's Horizon 2020 research and innovation programme under grant agreement No 792021.

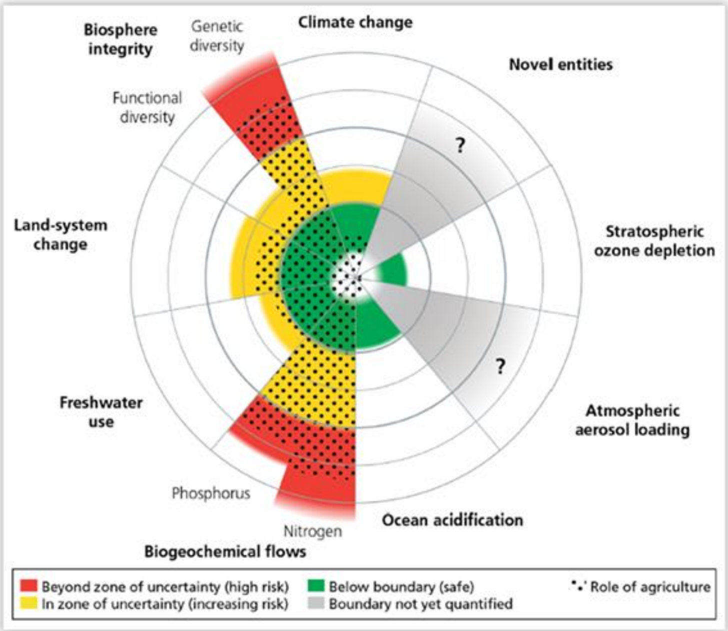

Figure 2. The nine planetary boundaries' status overlaid with the estimate of agriculture's role in that status (black dots) (Campbell et al., 2017).

Considering this context, efficient use of P is essential to preserve remaining stocks and avoid environmental pollution. One way to realise this is to maximise the nutrient use efficiency (NUE) of P. In the agricultural production system of European countries (Spain, Germany, Netherlands, Switzerland, France, and Norway), this NUE is currently 55.5% on average (Biswas Chowdhury & Zhang, 2021). NUE can be increased by controlling the release of nutrients or mobilising nutrients already available in the soil. Many slow or controlled release fertilisers are coated synthetic polymers to mediate the nutrient release pattern (Chen Lopez, 2023). It is estimated that 100,000 metric tons of micro-plastics enter the soil every year as a result of fertilisation (Erickson, 2022). Therefore, the EU has set goals to phase out plastic coatings and other plastics. This is regulated under the Fertilizing Product Regulation, where only biodegradable components will be allowed from 2026 onwards (Fertilisers Europe, 2023b).

Another means to increase NUE is to use growth promoting substances, or so-called biostimulants. Biostimulants are substances or microorganisms that are applied to plants or soil to enhance nutrient uptake, nutrient efficiency, tolerance to abiotic stress, and overall plant growth and development (du Jardin, 2015). Unlike fertilisers, which provide essential nutrients directly to plants, biostimulants work to improve the plant's physiological processes and promote its natural mechanisms for nutrient assimilation. Finally, reducing runoff and dislocation of water in the root zone can help to keep nutrients available to plants and thus increase NUE and avoid environmental pollution. Soil organic carbon can assist this water holding capacity as it improves soil structure and, as result, can reduce runoff and leaching. Therefore, research efforts focus on enhancing this soil organic carbon through agricultural practices and product innovations.

With all these innovations to improve fertiliser performance, it is important to ensure that environmental burdens are not simply shifted from, for example, pollution of watercourses with phosphorus, to other environmental domains such as climate, human toxicity, land use, fossil resource depletion, or land acidification. Therefore, the following objective is formulated.

The aim of this report is to compare the environmental impacts of the SUSFERT products to conventional market alternatives, by using the life cycle assessment (LCA) methodology. Thereby, we aim at providing evidence that the innovations produced are beneficial in all environmental domains, or identifying the domains where this is not the case. The multifunctional SUSFERT products investigated combine biobased and biodegradable slow-release coatings (I), biostimulation through probiotics (II), Agrobiogels for improved water holding capacity (III), and novel nutrient sources – struvite and BioAgenasol® – and soil improvers for in-soil nutrient mobilisation – siderophores – (IV). (Figure 3)

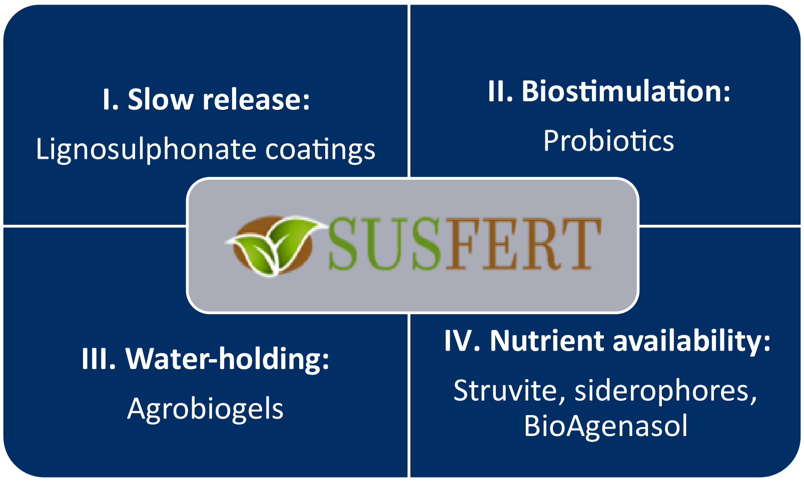

Figure 3. Different functions covered by each component and combined for SUSFERT multifunctional fertilisers.

I. Slow release

Lignosulphonate-based bioactive coatings, produced by SAPPI, were proven to be a biodegradable alternative to fossil-based or non-biodegradable coatings, with slow-release functions (Weiß et al., 2021). Lignosulphonates (LS) are wood-based water-soluble natural polymers. They are a by-product from the production of wood or paper pulp using sulphite pulping. LS bonds with essential plant nutrients like agricultural metal ions (potassium, calcium, magnesium, manganese, etc.), but also nitrogen and phosphorus. This allows a better nutrient use efficiency (NUE), as the nutrients are released in a slow and controlled way (Weiß et al., 2021).

II. Biostimulation

Probiotics, produced by ABiTEP, are biological stimulants of microbial origin that promote soil microbial biodiversity and enzymatic activity (Rajper et al., 2016). They can help unlock phosphorus as well as ensure that P provided in fertilisers is made available to plants (EMNZ, 2018).

III. Water holding capacity

Agrobiogels, produced by the Austrian company Agrobiogel, have a high water-holding function. It is a "100% wood-based gel that absorbs and stores water from irrigation or precipitation and slowly releases it back to the plants during dry periods". It protects plants from droughts, increasing the soil water holding capacity and staying active up to 5 years, depending on the soil. Agrobiogels also increase the productivity of soils by adding organic matter. (Agrobiogel, 2022)

IV. Nutrient availability and recovery

Struvite is a by-product of the waste water treatment industry, where it used to remove P from water. It is considered a slow-release fertiliser that contains about 12.6% P/kg dry weight. Siderophores are produced during fermentation. They act as a chelating agent with the ability to increase the Fe availability for plants. Finally, BioAgenasol® is an advanced type of distillation by-product (i.e. Dried Distillers Grains Solubles – DDGS) that obtains unique properties for nutrient supply from a combination of different fermentation feedstocks and additives.

These four functions will be provided separately or combined in the following SUSFERT products:

1. Agrobiogels that enhance water holding capacity of the soil
2. "Bio-based, fully biodegradable controlled release coating for fertiliser applications": slow-release function through lignosulphonate coating
3. "New microbial product": biostimulation function through probiotics
4. **"Siderophores": nutrient availability function through siderophores**
5. "Recovered P fertilisers as struvite
6. "BioAgenasol® product as specialised FE fertiliser with new demonstrated and validated iron capacity": nutrient availability function through BioAgenasol®
7. **"NPK into Nutrigels": combined water-holding and nutrient availability functions through NPK fertilisers and Agrobiogels**
8. **"Biobased fertiliser (BioAgenasol®) into Nutrigels": combined water-holding and nutrient availability functions through BioAgenasol® and Agrobiogels**
9. **"Agrobiogels and probiotics" to increase water holding capacity and unlock phosphorus in the ground**
10. **"Struvite+probiotics+lignosulphonates": combined slow-release, biostimulation, and nutrient availability functions through struvite, probiotics, and lignosulphonate coating.**

While results for all the products above are shown in the confidential report, only the results for the products in bold will be presented in this summary.

Method

To evaluate the environmental impacts of the novel fertiliser components, LCAs have been carried out. The international standards ISO14040 and ISO14044 were followed to analyse the environmental impacts of product systems. The software and database used for the analysis are SimaPro 9 and Ecoinvent 3.9 cut-off. Where possible and appropriate, market processes were chosen from the database to include transportation of input materials in the analysis. The impact categories investigated are: global warming, terrestrial acidification, freshwater eutrophication, marine eutrophication, human carcinogenic toxicity, land use, and fossil resource scarcity. Results for other impact categories can be accessed in the appendix. The system boundaries of the LCA are set from cradle to gate. System expansion is applied for multi-output systems. Avoided products, such as a reduced demand for mined P or reduced irrigation water demand, are accounted for by subtracting the impact of these products from the impact of the SUSFERT fertiliser production model. Due to the different functionalities of the fertiliser products, different functional units (FUs) were applied as specified in the confidential report. Another modelling assumption is that the assessment exclusively considers alterations to production systems. This aligns with the rationale that only innovations originating from within the SUSFERT project are evaluated. Consequently, factors such as the actual coating process or the production of the P fertiliser are not scrutinized, as they remain constant in both the business-as-usual and novel SUSFERT scenarios. The sensitivity of the results to different electricity production options is tested, as energy has been shown to be a key contributor to environmental impacts across all SUSFERT innovations. Specifically, the change for current electricity mixes to renewable energy from wind and photovoltaic has been evaluated. The processes use are shown in table

Results

Siderophores

The environmental impacts of siderophores' production and its avoided functional equivalent EDTA are presented in Figure 4. It can be seen that the production of siderophores has an avoided impact in the categories global warming (-7 %), marine eutrophication (-88%), and fossil resource scarcity (-33%). Contrary to that, for terrestrial acidification (69%), freshwater eutrophication (73%), human toxicity (20%), and land use (55%), its production is causing environmental impacts.

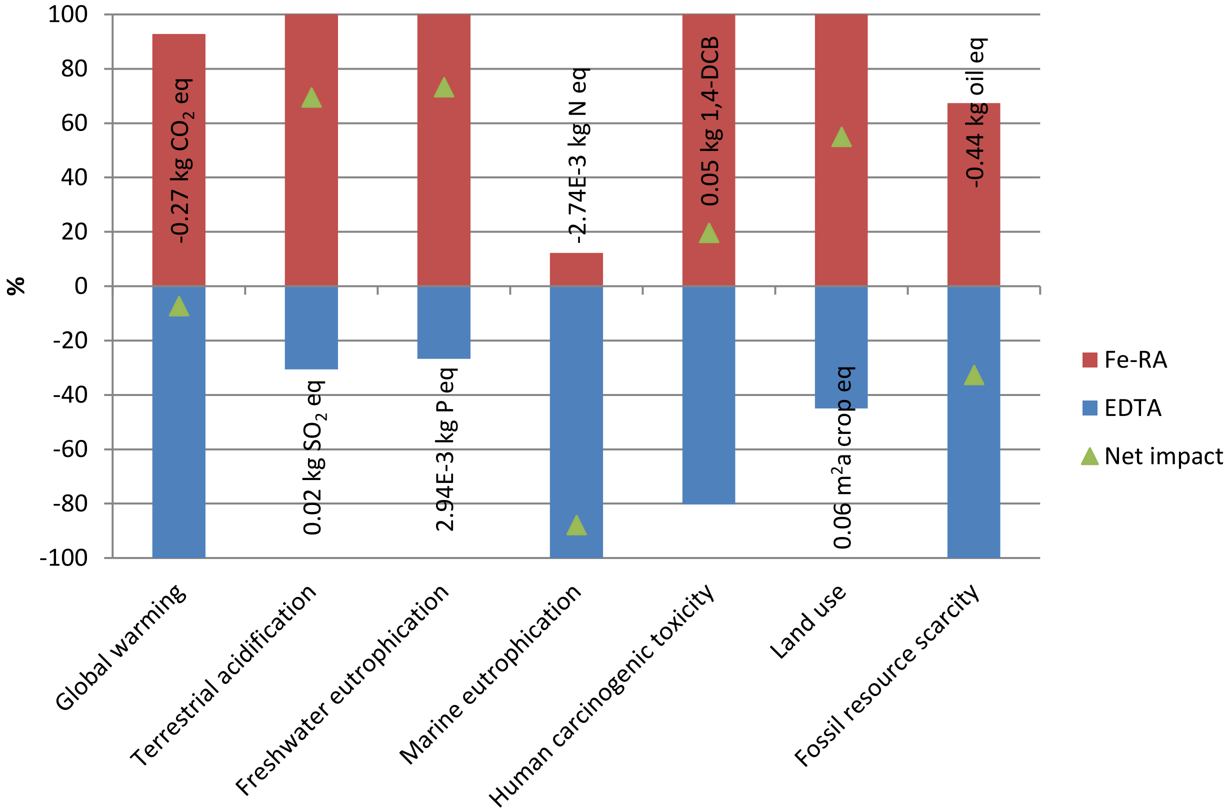

Figure 4. Impact comparison between 1 kg iron-loaded rhodotorulic acid (siderophores) and 0.85 kg of the market alternative EDTA (functionality equivalence on a molar basis).

NPK and Agrobiogels

The results for this combined product can be found in Figure 5. This product has a net negative (i.e. avoided) impact in all categories except for land use (wood chips are used to replace the sulphite pulp waste liquor burned in the paper production company, and the wood production needs land). The transport of the Agrobiogels from their production site (Austria) to the mixing facility (France) has a relatively low impact (1%-24%) across all impact categories. The NPK fertiliser is not visible in this analysis, as it is modelled in the same way in the business as usual and the SUSFERT models. Therefore:

$$NPK\ fertilizer_{business\ as\ usual} - NPK\ fertilizer_{SUSFERT\ innovation} = 0$$

This project has received funding from the Bio Based Industries Joint Undertaking under the European Union's Horizon 2020 research and innovation programme under grant agreement No 792021.

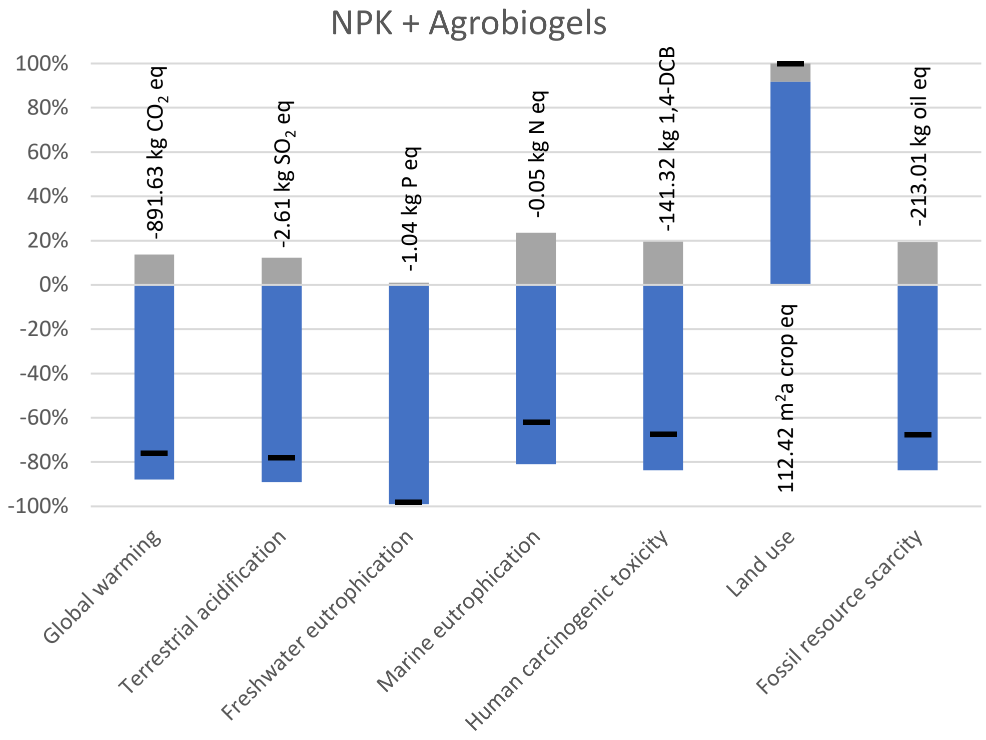

Figure 5. Environmental impacts of the product combining NPK + Agrobiogels.

BioAgenasol® and Agrobiogels

The results for the combined BioAgenasol® and Agrobiogels product can be found in Figure 6. The combined product avoids impacts for climate change, freshwater eutrophication, human carcinogenic toxicity, and fossil resource scarcity, but shows a positive impact for global warming, terrestrial acidification, marine eutrophication, and land use. The contribution of the Agrobiogels in the different categories varies between -75% (freshwater eutrophication) and 3% (land use), the contribution of BioAgenasol® between -44% (land use) and 98% (marine eutrophication), and the contribution of the transport between 1% (marine eutrophication) and 36% (human carcinogenic toxicity). The contribution of transport to the overall impacts is relatively minor, the highest impacts are 36% and 20% for the categories human toxicity and fossil resource use respectively.

This project has received funding from the Bio Based Industries Joint Undertaking under the European Union's Horizon 2020 research and innovation programme under grant agreement No 792021.

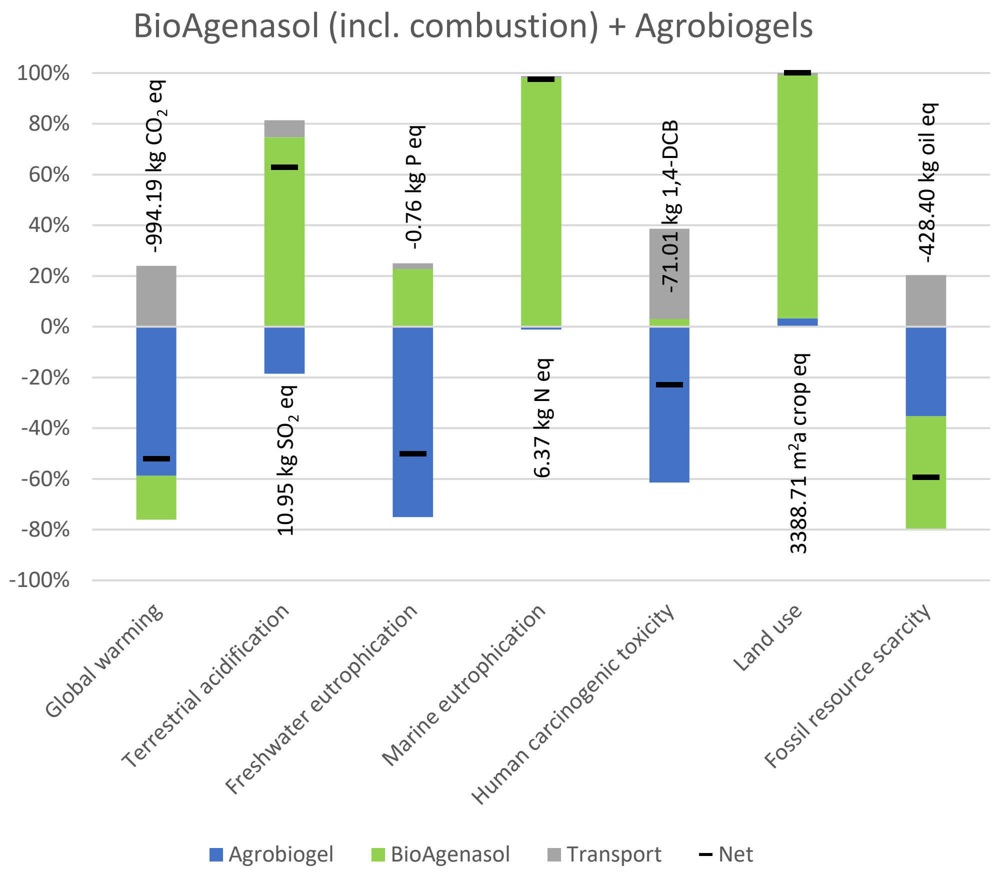

Figure 6. Environmental impacts of the product BioAgenasol® + Agrobiogel.

Agrobiogels and probiotics

The results for the product containing Agrobiogels and probiotics is shown in Figure 7. The probiotic product has avoided impacts for almost all categories (except for marine eutrophication). Similarly, the Agrobiogel system is mainly avoiding environmental impacts (except for land use) due to substantive irrigation savings. Therefore, as both partial products show avoided (or negative) impacts, the overall results, except for the land use category, also show avoided impacts. The contribution from the Agrobiogel component goes from -85% (global warming) to 77% (land use), and that of probiotics from -98% (freshwater eutrophication) to 0% (marine eutrophication). The transport of the two components to the processing facility has a maximum contribution of 19% (marine eutrophication).

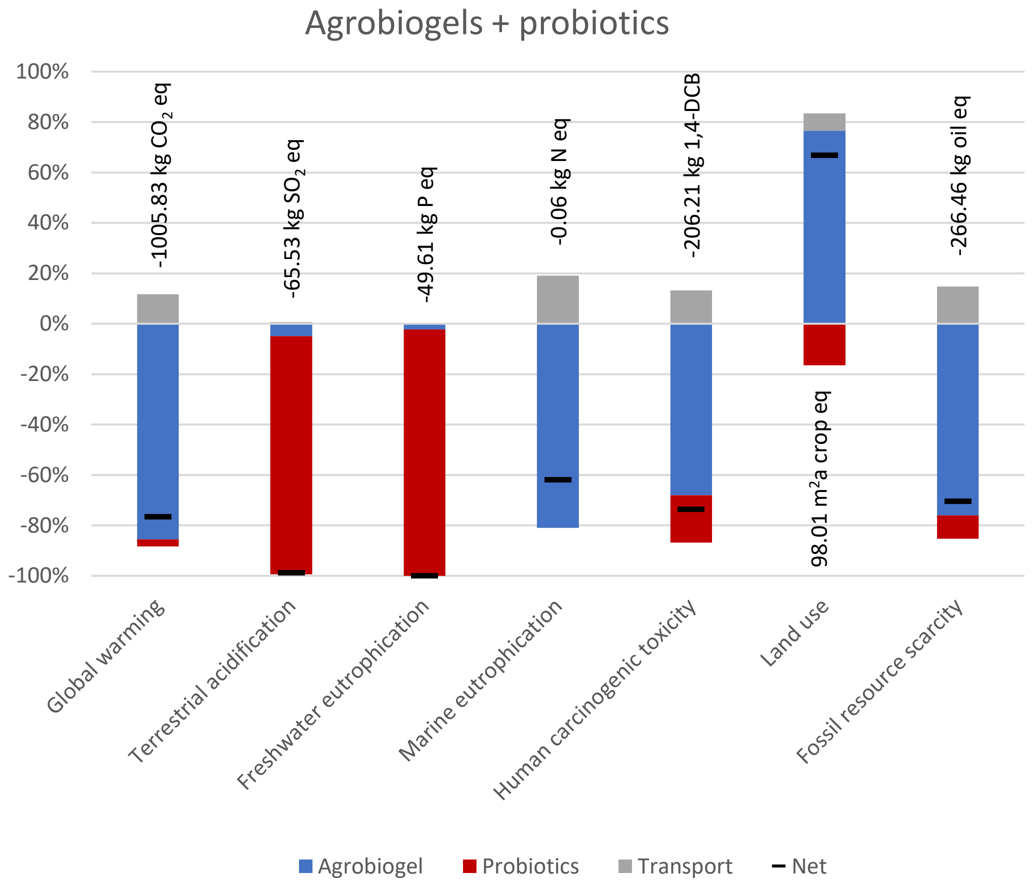

Figure 7. Impact of combined Agrobiogel + probiotic product.

Struvite, probiotics, and coatings

The results for the multifunctional fertiliser containing struvite and probiotics coated in lignosulphonates are shown in Figure 8. The combination shows avoided impacts for terrestrial acidification, freshwater eutrophication, and fossil resource scarcity. Even through struvite and lignosulphonates show avoided impacts in the component assessment, they have small impacts (1%) as combined products. This is related to the transport impact, which in this multifunctional fertiliser product system shows a relatively high impact (7%-83%), since it is assumed that three different components are transported from the Netherlands (struvite), Austria (coatings), and Germany (probiotics) to the mixing facility in France. The struvite contributes between -66% (fossil resource scarcity) and 44% (land use) to the final results, while the coating contributes between -6% (fossil resource scarcity) and 14% (land use), and the probiotics between -66% (freshwater eutrophication) and 0% (several categories).

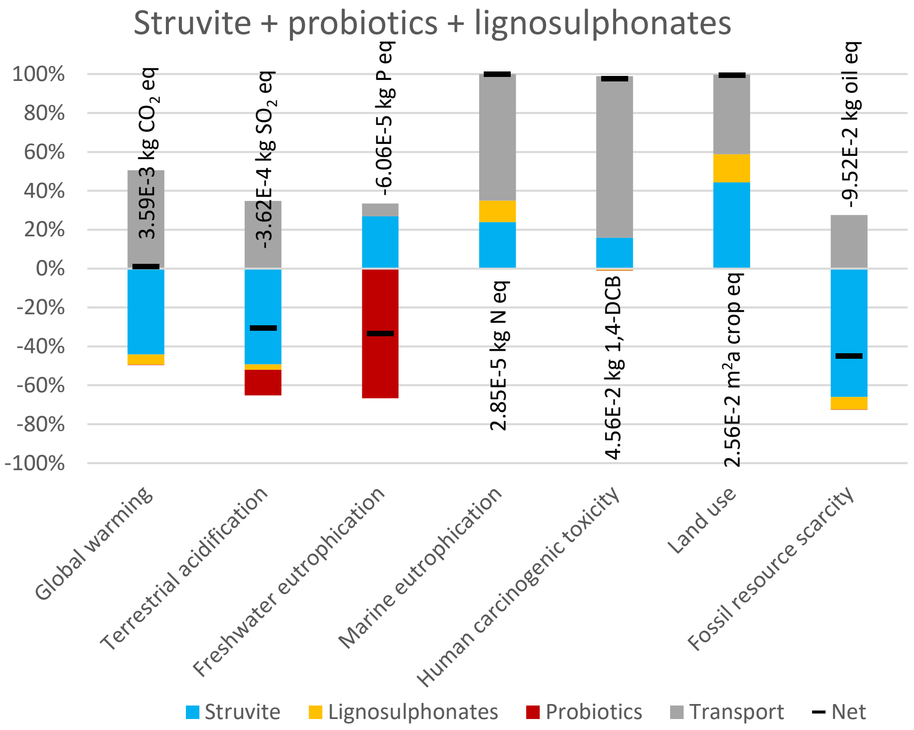

Figure 8. Impact of combined struvite + probiotics + lignosulphonate product. The FU is a multifunctional fertiliser containing 1,000 g of struvite, 20 g of lignosulphonates, and 50 µg of probiotics.

Discussion

In general, it can be observed that in all processes a large share of the impacts is derived from electricity or heat demand. This is a direct consequence of processes that require the refinement of organic (biobased) materials into value added products. An increase in energy demand, and here in particular the demand for electricity, is however not negative as such, it rather indicates a trend that is in line with the electrification agenda of the EU (European Commission, 2023). Thereby, this contributes to a climate neutral EU economy by 2050 with net-zero greenhouse gas emissions. The reduction of the environmental impacts under renewable electricity scenarios (wind and photovoltaic) has been assessed. This shows that, for example for probiotics, CO_2 eq. emission reductions could amount to 62%, and for struvite up to 71%, therefore further increasing the positive environmental impacts of these products when compared to current market alternatives.

A point of concern is however that in several processes heat is a major contributor to environmental impacts (e.g. BioAgenasol®). Production of (high-grade) heat from renewable energy sources is currently less widely implemented and should therefore be an attention point. The use of low-grade waste heat for drying processes for instance could further reduce environmental impacts (Ling-Chin et al., 2018).

As one may expect, the use of biobased products can increase the demand for land. In SUSFERT, this is again often related to electricity use, but also to the feedstock that can no longer be used for energy generation (i.e. LS coating materials), or because a feedstock for the fermentation is required (siderophores, BioAgenasol®, note that several feedstocks are based on by-products, for which no adequate representation in the background database could be identified). Increasing land use may not only put pressure on the EU's land availability, but it may also have environmental consequence in relation to indirect land use changes that have not been evaluated in this report. In summary, this concept suggest that domestic land use can induce changes in land demand elsewhere in the world to satisfy global demand for food and other materials. However, it should also be noted that in some cases the land use of SUSFERT products is overestimated due to the limited availability of background data that does not adequately reflect the use of by-products.

Conclusion

It can be concluded that nearly all the SUSFERT products reduce environmental impacts in most of the investigated impact categories, but BioAgenasol®, siderophores and struvite show exceedance in several impact categories. Major impact throughout the investigated products originated from electricity, thermal energy demand, the required feedstock for biological processes, or the diversion of feedstock from valorisation as an energy source. Overall, it appears that the biobased products investigated rely heavily on electric energy and hence back the transition to electrification of the EU. As a result, it was shown that a transition to more electric energy sourced from renewables does further reduce the environmental impact of the products by up to 71% for CO2-eq. emissions. Transport of partial products to the production site in France often has no major impact, with the exception of the most complex products that are composed of three ingredients (NPK+probiotics+struvite).