Life cycle assessment and sustainable development of mineral fertilizers production

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Abstract. Using the life cycle assessment methodology, this article analyzes the potential for developing a responsible production process for mineral fertilizers. By way of an example, the composition of the production facilities at a vertically integrated company is considered, and the main factors that negatively affect on the atmospheric air, waterbodies, and soils are identified. Based on the analysis of the best available and promising technologies, the main ways to mitigate the negative impact on the environment, human health, and natural resources are defined. It is concluded that the application of product life cycle assessment approaches makes it possible to identify priority environmental aspects at each stage and take them into consideration when developing and implementing programs to improve the resource and energy efficiency, as well as environmental performance of product production and consumption.

1 Introduction

The development of the mineral fertilizers industry has always been closely linked to the agro-industrial complex. It was the needs of agriculture that determined the necessity of developing technologies, creating new products, and increasing productivity. As soon as the concept of mineral nutrition of plants was formed, the search for substances and products that can provide this nutrition began. The initial use of natural materials (Chile Saltpetre, phosphorite meal) and by-products (basic slag, ammonium sulphate) showed the effectiveness and expediency of the use of fertilizers, but was limited by their availability, assortment and efficiency. Further development of the industry was aimed at removing these restrictions: the development of ammonia, sulphuric, nitric and phosphoric acids technologies production, the development of phosphate and potash raw materials deposits and technologies for their enrichment have made the mineral fertilizers industry one of the largest in the chemical industry.

The presence of close economic and product links makes industries interdependent, and life cycle assessment approaches can be effectively applied in planning development and increasing production efficiency.

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2 Materials and methods

The study used the life cycle assessment (LCA) method, which consists of accounting and evaluating the input and output flows of the production system, as well as its impact on the environment at all stages of the life cycle [2].

The purposes of using LCA in this study are:

- Identification of opportunities to improve the environmental performance of production and application of fertilizers.
- Determination of priorities for the development of production plants, the creation of new brands of fertilizers, considering the needs of the agro-industrial sector and the introduction of agrochemical technologies.
- Search for the most effective measures aimed at increasing the resource and environmental efficiency of fertilizer production and application.
- Improvement of marketing activities (for example, development and dissemination of product environmental declarations, open reports, working out measures to improve the company's image, etc.).

3 Mineral fertilizers industry in the Russian Federation

Based on the pattern of the main mineral fertilizers producers, it is possible to conceive the structure of the industry, consisting of:

- Extraction and production of phosphate raw materials.
- Extraction and production of potash raw materials and fertilizing potassium chloride.
- Ammonia production.
- Production of inorganic acids used in the production of mineral fertilizers (sulphuric, orthophosphoric, nitric).
- Production of mineral fertilizers (nitrogen, phosphorus, potassium, mixed, organomineral).

Co-products production – feed and technical phosphates, and purified acids – also falls within the fertilizer industry. Using the example of phosphorus-containing fertilizers production and application the main factors of negative impact on the environment throughout the life cycle are identified (Figure 1). The stages of extraction of phosphate raw materials as well as production and application of mineral fertilizers are shown in Figure 1 as the initial and final stages of the life cycle.

Based on the analysis of the represented structure and life cycle assessment, it is possible to identify the main means of reducing the negative impact on the environment, humans and natural resources (Table 1) [12-13].

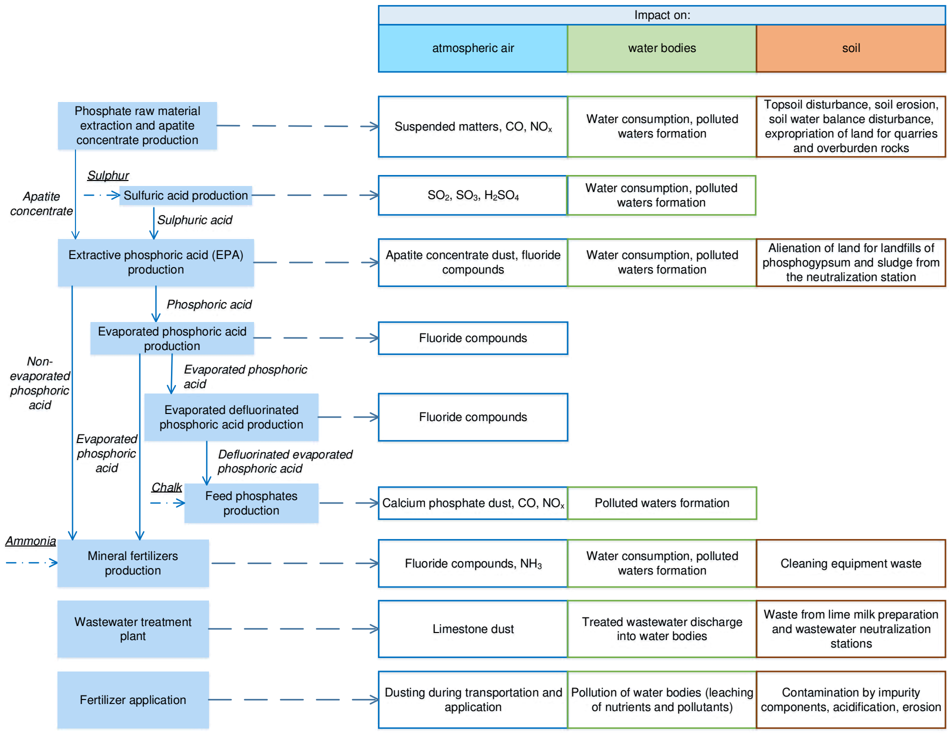

Fig. 1. Life cycle of phosphorus-containing fertilizers production and its negative environmental impact.

Table 1. The main means of reducing the negative impact on the environment, humans and natural resources.

Impact category	Potential solution to reduce the negative impact of fertilizer production	Potential solution to reduce the negative impact of fertilizer application
Climate change	Introduction of energy-efficient equipment and technologies, capture and use of CO_2 (production of commercial carbon dioxide, carbamide, conversion of phosphogypsum to produce calcium carbonate and ammonium sulphate, reduction of nitrogen hemioxide (N_2O) emissions from nitric acid production, and secondary energy resources usage	Development and application of new types of fertilizers: with controlled solubility, with nitrification inhibitors, effective complex fertilizers with micro- and meso-elements, microbiological and bacterial fertilizers containing highly active microorganisms that improve the nutrition conditions of crops, and plant growth stimulants
Release of substances toxic to humans into the environment	Use of phosphate raw materials with a minimum amount of concomitant toxic substances, minimization of emissions and discharges of pollutants, introduction of closed water cycles	Optimization of fertilizer application (application of more effective fertilizers, improvement of application techniques, development of individual chemicalization programs, land reclamation)
Release of suspended matters (dust) into the air	Implementation of methods for reducing emissions of suspended matters, such as local aspiration systems from overflows, crushing and sieving units, application of absorption systems, improvement of fertilizers production technologies to reduce dust formation, production and application of coarse apatite concentrate	Organization of optimal methods of storage and application of fertilizers, application of granular forms of fertilizers
Acidification	Development of new forms of fertilizers with a	Optimization of application techniques, the

of soils	lower application dose, delayed solubility in soil solutions	use of effective fertilizers with a lower dose of application, carrying out reclamation measures: plastering, liming
Eutrophication of fresh waterbodies	Development of new forms of fertilizers with a lower dose of application, development of long-acting fertilizers with controlled solubility	Optimization of application, the use of effective fertilizers with a lower dose of application
Transformation of natural (uncultivated) lands	Reduction of waste and by-product formation and storage, introduction of recycling and beneficial utilization methods (e.g. phosphogypsum utilization – introduction of conversion processing methods, application in construction and agriculture. Utilization of sludge of the acid wastewater neutralization station – application in cement production)	Optimization of application, land reclamation measures (e.g. liming, plastering) using secondary resources (phosphogypsum, conversion chalk)
Depletion of ore and non-metallic minerals	Reduction of waste and by-products formation and storage. Integrated use of resources (production of apatite and nepheline concentrates, production of iron ore, apatite and baddeleyite concentrates) Utilization of halvans and tailings of the previous enrichment. Integrated use of phosphate raw materials, e.g. production of fluorinated products (fluorosilicic acid, sodium fluorosilicate, aluminium fluoride), extraction of rare earth elements.	Application of highly effective fertilizers with controlled release of nutrients (prevention of leaching), the use of microbiological and bacterial fertilizers and fertilizers with nitrification inhibitors (reduction of nitrogen losses)
Depletion of energy resources	Implementation of energy-efficient processes and equipment: reconstruction of ammonia production facilities with reduced fuel consumption, use of secondary energy resources for heat and electricity generation (generation of thermal and electric energy in sulphuric and nitric acid production industries)	Application of highly effective complex fertilizers that require lower resource costs for use
Depletion of water resources	Optimization of the water balance of the enterprise. Implementation of closed water cycle systems. Implementation of effective wastewater treatment systems	Introduction of agro-technologies, appropriate fertilizers and ameliorants for application on arid soils and reduction water consumption (optimization of soil structure using fertilizers and ameliorants, the use of drip irrigation and appropriate water-soluble fertilizers, the use of fertilizers that promote plant resistance in adverse climatic conditions)

Most of the techniques used to minimize the negative effects of fertilizer production are documented in the sectoral Reference Documents on Best Available Techniques. Sectors covered include: production of ammonia, acids, and fertilizers; production of solid and other inorganic chemicals; production of electrical and thermal energy; general processes and methods aimed at improving resource efficiency and environmental performance).

In addition to the measures described in Table 1 to reduce the negative environmental impact associated with the production of phosphorus-based fertilizers, companies have also implemented universal solutions:

- Formation of its own scientific departments and cooperation with scientific centres in order to modernize existing technologies and develop new ones, create new highly effective forms of fertilizers, address issues of reducing emissions and discharges of pollutants, formation and use of waste and secondary resources, limiting greenhouse gas emissions, increasing environmental, energy and resource efficiency, etc..
- Performance of work on evaluating the effectiveness and impact of new and existing forms of mineral fertilizers on the characteristics of soils and agricultural products, development and improvement of agrochemical technologies for various crops.

- Implementation of environmental and energy management systems [20-21], development of open non-financial reporting, improvement of interaction with concerned parties [22].
- Implementation of automatic control systems for emissions and discharges of pollutants [23], development of industrial environmental monitoring practices.
- Implementation of various consulting systems for agricultural enterprises in terms of optimizing the use of mineral fertilizers and ameliorants, implementation of new agricultural technologies, development of nutrition systems based on the real state of soils [24].

Application of life cycle assessment principles is well coordinated and complemented by the concept of resource efficiency of fertilizer production as an integrated vector of the company's development.

Most approaches used to reduce the negative environmental impact are based on the idea of enhancing resource efficiency [15]. In relation to the company's activities, resource efficiency includes the efficiency of using raw materials, energy, and water. However, when considering the sustainable development of a business as an integrated assessment of its economic, social, and environmental initiatives, as well as evaluating the life cycle of products, using the criterion of resource efficiency for all types of company-used resources (material, human, financial, informational, and time) is advisable.

4 Results and discussion

The application of life cycle assessment techniques allows identifying key environmental issues at each stage of a product's life – from the extraction of raw materials and energy production to water treatment and the development of methods to minimize the release of nutrients into natural water bodies. This is particularly significant when using phosphorus-based fertilizers, as phosphorus is a limiting factor in the development of eutrophic processes in freshwater ecosystems.

Each study using LCA approaches has both theoretical and practical significance. In the context of the development of responsible production and consumption, the achievement of international sustainable development goals and national goals of the Russian Federation, the LCA makes it possible to expand the "responsibility framework" of industrial companies, ensure increased resource efficiency, reduce negative environmental impacts and form a closed-loop economy.

The publication of LCA results in the open non-financial reporting of vertically integrated mineral fertilizers companies, as well as specific (industrial and agricultural) facilities contributes to the advancement of public discourse in the area of sustainable development, increases transparency in decision-making processes and creates the necessary conditions for the implementation of sustainable development initiatives, including green projects.

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