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New Production Route of Magnesium Hydroxide and Related Environmental Impact

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Received: 4 September 2020; Accepted: 15 October 2020; Published: 23 October 2020

Abstract: The paper presents research on a method of obtaining magnesium hydroxide from magnesium sulphate salts and NaOH. In order to acquire the desired and controlled properties, the method of precipitating in aqueous solutions by introducing a NaOH solution into a solution of $MgSO_4$ has been applied. To get as stable a product as possible with graining, the introduction of NaOH takes place at a constant flow rate. In order to identify the environmental impact of the developed process, a life cycle assessment (LCA) has been made. The use of the proposed method for the synthesis of $Mg(OH)_2$ incorporating washing with 25% ammonia solution and acetone enabled a product with a high specific surface area. The $Mg(OH)_2$ obtained was characterised by a higher specific surface area than commercially available magnesium hydroxides that are used as additives for flame retardants in polymeric materials. This allows the material to be used as an anti-pyrogen for a wider group of polymeric materials. For the LCA analysis, two scenarios were assumed, from which the basic one included recovery of ammonia and acetone. The environmental analysis carried out confirmed the validity of this assumption, as it was stated that the main part of the impact was connected with the supply chain for the process examined.

Keywords: magnesium hydroxide; anti-pyrogen; polymeric; LCA; environmental assessment

1. Introduction

Polymeric materials are widely used, with uses including the production of plastics, paints, adhesives, and varnishes, and more advanced technologies such as piezoelectric elements, non-linear optics, and temperature indicators. Their global production currently exceeds USD 500 billion a year, and every day the statistical consumer is in contact with more than 50 products whose operation to a greater or lesser extent is based on the use of plastics.

According to the best available technology for the Production of Polymers [1], circular economy and the creation of new, more environmentally-friendly polymer products, including less use of halogenated flame-retardant compounds, are desired. Polymers increasingly replace traditional construction materials and permit the manufacture of machine elements and mechanisms [2]. The dynamic development of this market contributes to the search for potential new applications of polymers. One of the main barriers to their further development is the need to reduce flammability. The low fire resistance of polymeric materials contributes to the need for flame retardant additives where recently halogen-free flame retardants were mainly used. They enable the minimum oxygen index required by the standards PN-ISO 4589-2 and ASTM-D-2863 of 28% ($21 < OI < 28$ self-extinguishing plastic) to be achieved when the filler content of 10–20% by weight has already been reached. The main advantage of these flame retardants is their high efficiency, while the disadvantage is the significant amount of highly toxic and carcinogenic compounds released during burning, such as hydrogen chloride, hydrogen bromide, metal halides and halides, chlorinated and brominated dioxins, etc. The organic antipyrins used so far have been successively withdrawn from use in accordance with Directive 2002/95/EC of the European Parliament (the so-called RoHS-Restriction of Hazardous Substances Directive). Alternatives to halogen flame retardants are non-toxic inorganic compounds, which, however, have lower efficiency than equivalent organic flame retardants [3,4]. In order to obtain a comparable flame-retardant effect, inorganic retardants should be used in amounts two or three times larger than the halide materials. Such large amounts of flame retardant adversely affect the mechanical properties of the material. Legislative changes requiring the production and use of environmentally friendly products (REACh-Registration, Evaluation, and Authorization of Chemicals, SVHC list of substances of very high concern, European Chemicals Age—Substances of Very High Concern, RoHS Directive—Restriction of Hazardous Substances, Stockholm Convention on Persistent Organic Polluta—Persistent Organic Pollutants—POPs) have influenced the structure of the demand for anti-pyrogen.

Despite the relatively high demand for flame retardants based on aluminium hydroxide in Europe, research is being carried out on the production of other flame-retardants, e.g., magnesium hydroxide. This is due to the fact that the decomposition temperature of aluminum hydroxide is about 200 °C and is relatively low for a flame-retardant additive, and that is why it is not used as a fire retardant on a wide scale [5,6]. Magnesium hydroxide, whose decomposition temperature is about 100 °C higher, is more and more commonly used [7,8]. However, in order for these substances to be used, they must have high purity and a consistent and very fine grain size. The process for obtaining magnesium hydroxide with the desired and controlled properties includes the cleaning of the solution prepared from the sulphate (VI) and then the precipitation of its hydroxide (Figure 1).

The purification step is basically to remove iron, zinc, and lead compounds by the precipitation method [9].

Magnesium hydroxide, due to its different chemical nature, is not suitable for direct application to all plastics [10]; therefore, there is a need to develop improved methods for obtaining magnesium hydroxide and its composites with organic compounds [11–13]. Recently, well known organic chlorine, bromine, or fluorine compounds have been used for this purpose. However, due to negative environmental impact and costs associated with their production and use, inorganic additives based on metal hydroxides such as aluminum or magnesium are increasingly being used. The organic antipyrins used up to now have been successively withdrawn from use in accordance with Directive 2002/95/EC of the European Parliament (the RoHS Directive).

Magnesium hydroxide is commonly obtained using precipitation methods involving the use of soluble magnesium salts and strong bases. It is also possible to synthesise it from magnesium oxide; however, the low efficiency of this process and production costs limit the industrial application of this method. The magnesium salts used are mainly $MgCl_2$ or $MgSO_4$ (rarely magnesium nitrate), which depend on the availability of the base material. In coastal countries (e.g., USA, Israel), $Mg(OH)_2$ is mainly obtained from chloride salts that are a by-product of the desalination of seawater [14]. There are also methods for obtaining magnesium hydroxide directly from seawater as shown, for example, in the work of [15]. Due to the availability of other magnesium raw materials in Poland, mainly $MgSO_4$ of waste origin [16], the production of $Mg(OH)_2$ can be carried out successfully on the basis of purified waste material. According to the tests, the $Mg(OH)_2$ obtained was characterised by high purity (about 99,9%) and a higher surface area (about 115 m^2/g) when compared to magnesium hydroxide obtained from magnesium chloride (about 10–20 m^2/g) [17]. $MgSO_4$ is also used to obtain $MgSO_4$, as has been demonstrated in [18–20]. In recent years, a more and more dynamic development of research on the synthesis of $Mg(OH)_2$ with nano- and microstructure has been observed. The main raw material used to obtain such structures is $MgCl_2$, due to the fact that the majority of research is carried out in countries which obtain this compound from the desalination of seawater [8,21]. In domestic conditions, the magnesium raw material that would generally be used for this purpose is $MgSO_4$.

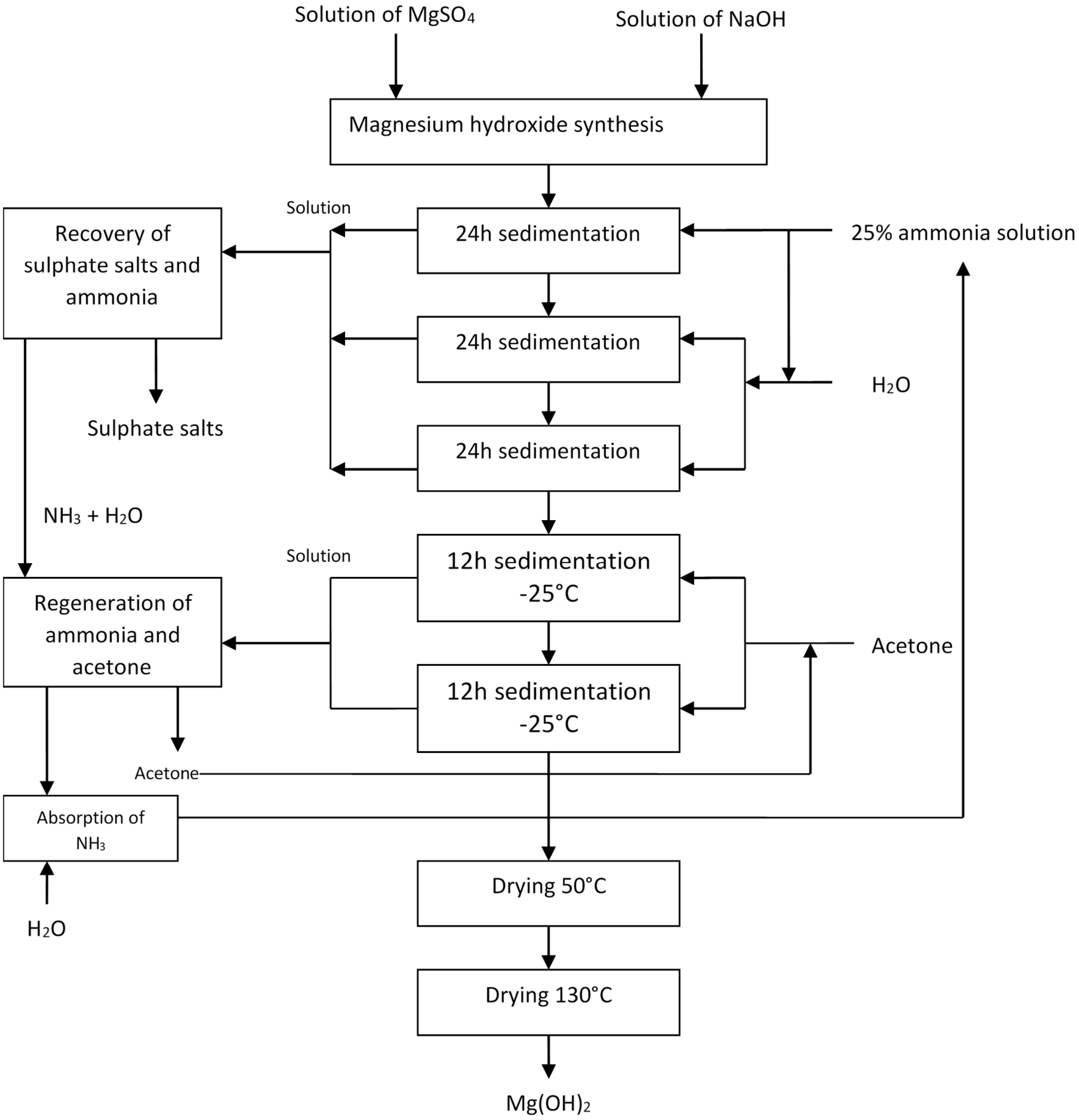

Figure 1. Flowsheet for the preparation of magnesium hydroxide with nanostructure.

In order to obtain a product of relatively constant particle size and suitable purity, it is necessary to apply a number of other unit operations as well as the introduction of other excipients to the solution [11]. It should be noted that magnesium salts are more and more frequently prepared from waste products, such as slip mud, spent zinc electrolysis solutions, etc. However, the magnesium feed obtained from these requires additional purification which potentially reduces the profitability of the process [22,23].

$Mg(OH)_2$ of high purity is also used in the medical and agricultural industries in addition to its use in flame-retardant polymeric materials. In medicine, $Mg(OH)_2$ is mainly used as a magnesium supplement and an agent to reduce acid in gastric juices [24,25], while in agriculture it is used as a magnesium supplement in the fertilisation of acidic soils and as a free-flowing additive to animal feed.

In order to use $Mg(OH)_2$ as a flame retardant, this compound must have an expanded active surface area and a very small and homogeneous grain size. In the polymer matrix, there are no chemical bonds between the polymer matrix and the $Mg(OH)_2$, so it is just dispersed in the mass of the polymer affected by these properties [26].

The base materials used as well as the precipitation conditions determine the purity and surface parameters of the product obtained. These parameters then determine the intended use of the $Mg(OH)_2$ and its price. The preparation of $Mg(OH)_2$ based on sulphate salts is analogous to that of other magnesium salts. Depending on the method used, the product is mainly obtained as a colloidal suspension in solution which, depending on its later use, can be filtered. $Mg(OH)_2$ obtained by this method, however, is characterised by variable surface properties and non-homogeneous grain composition, which disqualifies it for use as an addition to flame retardant polymeric materials [27]. Therefore, in recent years, I have been undertaking research aimed at obtaining magnesium hydroxides with a relatively constant granulation and adequate purity. This paper presents research on a method of obtaining magnesium hydroxide from magnesium sulphate salts and sodium hydroxide. An analysis was made of the impact of the process that has been developed on the environment using life cycle assessment.

2. Materials and Methods

2.1. Substances Used in the Research

- magnesium sulphate(VI), production technology of Arkop, Ltd. (Kolejowa 34A, 32-332 Bukowno, Poland),
- sodium hydroxide, p.a., produced by Avator,
- 25% ammonia solution, produced by Avator,
- acetone technical grade, produced by Avator.

2.2. Experimental

Magnesium hydroxide was obtained by the method of precipitating in aqueous solutions by introducing a 0.75 mol/L NaOH solution into a solution of $Mg(SO)_4$ of the same concentration. To get as stable a product as possible with graining, the introduction of NaOH takes place at a constant flow rate. The dosing took place using a laboratory piston pump and was carried out until the precipitating agent was exhausted. The precipitating agent was used with an excess of 10% to ensure the highest possible yield of the precipitation process. Then, after the end of the process, 25% ammonia solution was added to the suspension thus obtained. NH_3 was added at a rate of 1 mL per g $Mg(OH)_2$. The suspension of the hydroxide from the solution was carried out by means of periodic sedimentation (the total sedimentation time was about 12 h). The remaining suspension, after separation from the clear solution, was again refilled with demineralised water with the addition of 25% ammonia solution. The washing process with water and ammonia was carried out twice. After removal of the reaction residues from the solution, the suspension obtained was separated from the clear liquid and made up to 1 L with acetone (calculated as 0.1 dm^3 per g $Mg(OH)_2$), and then cooled to −25 °C. This process was also carried out for 12 h. Another action to stop this was the re-separation of the mixture by sedimentation. After the second cooling, the resulting suspension was separated by vacuum filtration. The precipitate thus obtained was then dried in two stages. The first step involved gentle drying at about 50 °C, and then the $Mg(OH)_2$ was dried at 130 °C. Gentle drying was aimed at slowly removing the residue of acetone and ammonia from the samples obtained, and the basic drying, removing residual moisture contained in the sludge. The hydroxide thus obtained was a free-flowing product with both a developed specific surface area (115 m^2/g, determined using the BET isothermal method) and high purity (Figure 2; Figure 3). The process was also carried out by omitting the washing with 25% ammonia solution and acetone step; however, the product obtained in this way was characterised by a lower specific surface area. Moreover, the sample obtained in this way was characterised by inhomogeneous graining due to the sticking of $Mg(OH)_2$ conglomerates (based on SEM observations).

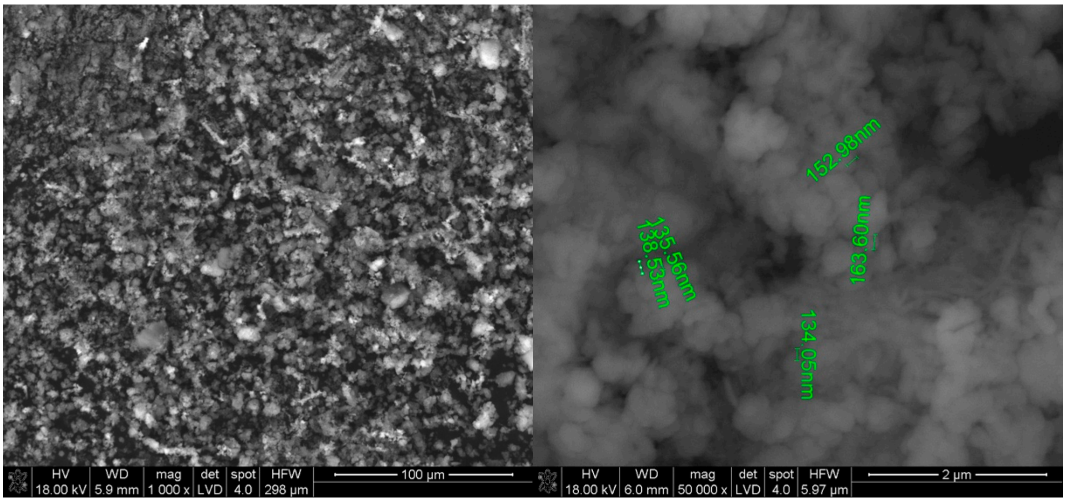

Figure 2. SEM of $Mg(OH)_2$ sample with a specific surface area of 115 m^2/g obtained using the developed multi-stage drying method.

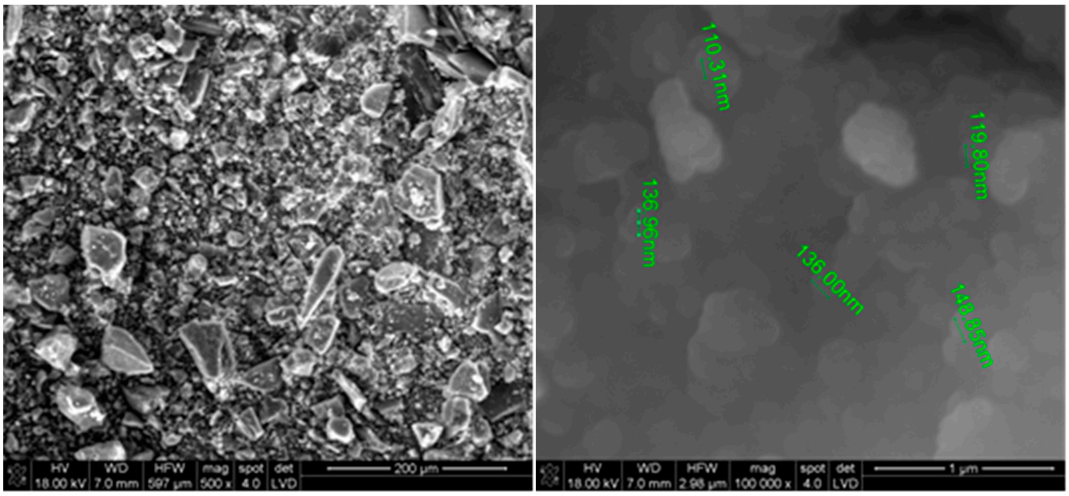

Figure 3. SEM of $Mg(OH)_2$ sample obtained without multi-step drying. Specific surface area of the sample 64.4 m^2/g.

Magnesium content in samples was determined using Atomic Absorption Spectroscopy (AAS)—after their mineralization in HNO_3 p.a. High-resolution scanning electron microscope Jeol JSM-5400 with an EDS (energy dispersive spectrometer) attachment was used for microscopic observations of the obtained $Mg(OH)_2$ samples (Figure 4). Specific surface area was determined using a Micrometrics ASAP 2020 sorptiometer. Density measurements were made using a helium method using a Micrometrics AccuPyc 1330 helium pycnometer and a weight method using a pictometer and acetone (as a medium of known density).

Regardless of the method of obtaining $Mg(OH)_2$, convergent results of EDS analysis were obtained. Chemical analysis showed magnesium content in $Mg(OH)_2$ samples, regardless of the drying method at the level of 41.66% ± 0.02 with a hypothetical magnesium content of 41.675%, which corresponds to 99.99% obtained product purity.

It is characterized by a density of 2.5885 g/cm^3, and products obtained directly from the suspension (without multi-stage drying) by a 2.6088 g/cm^3. In the case of analysis using a classic pycnometer, the obtained values were respectively 2.21 g/cm^3 for $Mg(OH)_2$, obtained by multistage drying and 1.86 g/cm^3 for product obtained directly. The lower density is related to the large size of the conglomerates and the difficulty of acetone penetration into the deeper material fragments.

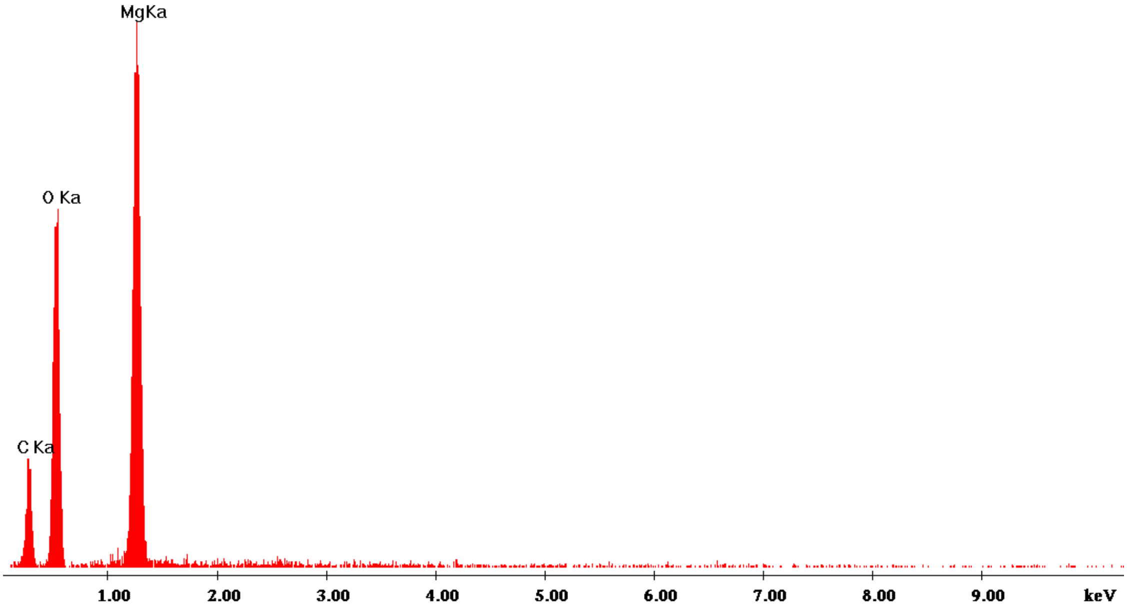

Figure 4. Results of EDS analysis of $Mg(OH)_2$ sample obtained after multi-stage drying.

The solutions obtained by collection from the sediment (first sedimentation) after the evaporation of ammonia (by heating) are used for the recovery of sulphate salts, which are by-products of the process. Of the remaining solutions, ammonia (in the form of ammonia water with an NH_3 content of about 20–25%) and acetone were recovered in two stages after washing with ammonia water and acetone. The products obtained were again recycled in the process, which resulted in a reduction in the amount of auxiliary substances consumed and lower environmental costs in the product life cycle.

2.3. Environmental Analysis—Purpose and Scope

The aim of the life cycle assessment (LCA) analysis was to assess the potential environmental impact of the process of synthesising $Mg(OH)_2$ from $MgSO_4$ and NaOH. It allowed the impact of the production process on particular aspects of the environment to be determined and compared with alternative scenarios (baseline and without recovery of ammonia and acetone). In order to determine in an unambiguous and measurable manner the scope of the analysis, a functional unit consisting of the production of 1 kg $Mg(OH)_2$ was adopted. The evaluation is carried out on the so-called "cradle" to "gate" basis, i.e., from the extraction of raw materials to the final product. The LCA analysis takes into account both the direct environmental burdens resulting from the production process, including emissions generated, as well as indirect environmental burdens resulting from the supply chain. The production process was a set of unit processes belonging to the foreground system, for which data came directly from laboratory tests (foreground system). The indirect impacts belonging to the product supply chain, i.e., the materials, energy, are represented by the background system.

In the case of the sodium sulphate produced as a co-product, the approach adopted is based on the expanded system boundaries and the inclusion of sodium sulphate as an avoided product, because it is a full-value product with a market value. The boundaries of the system analysed are shown in Figure 5, and in detail in the production process in Figure 1.

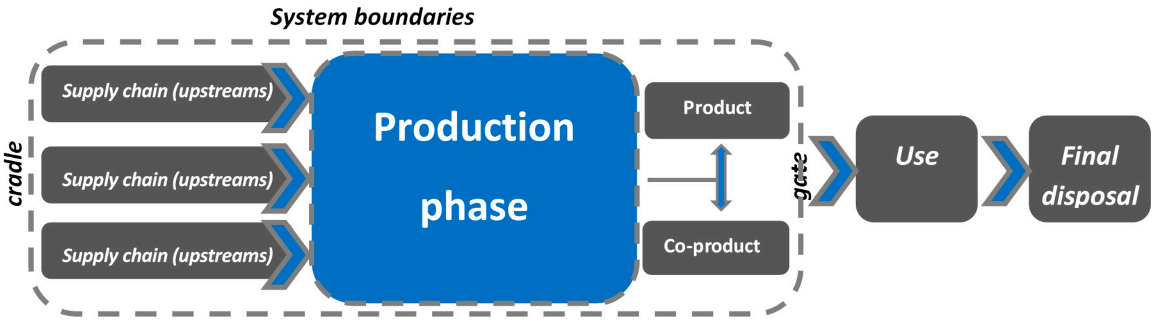

Figure 5. The boundaries of the system analysed.

2.4. LCI—Life Cycle Inventory

In the first phase of LCA research, the product system was defined (constituting the so-called LCI model). In the second phase, inventory data (inputs and outputs) were prepared. The data in the system being analysed have come from our own laboratory tests as well as available LCI (Ecoinvent) databases. Data can be considered representative in territorial and temporal terms because they come from places where the processes are currently carried out. Their completeness was verified by carrying out a material balance (quantitative comparison of inputs and outputs). Analyses using the LCA method are carried out for entire product systems, which include sets of unit processes with material and energy flows between them. In the case of this analysis, the environmental impact is related to the inputs and outputs shown in Table 1. These only include products/goods processed by man (exchange between the product system and techno-sphere/systems of other products). In the foreground system, the only elementary stream occurring is the waste heat resulting from the drying process. The water used for the analysis came from secondary sources, i.e., the water supply system. Each of the materials already processed, e.g., electricity, has its own technological history implying the consumption of further materials and the generation of emissions. Thus, in order to conduct a full analysis of the product life cycle, it is necessary to have data on the life cycles of those products that have already been processed. The Ecoinvent database (v.3.5), containing inventory information on the production of materials, energy, processes, and related emissions was used for this purpose. Table 1 presents data for the production of 10 g of the final product; however, in the analysis, this data was reported for production of 1 kg constituting the functional unit.

Table 1. Data used for life cycle assessment (LCA) analysis of the synthesis of 10g $Mg(OH)_2$, based on magnesium sulphate salts and sodium hydroxide.

Consumption of Fuel, Electricity and Heat	Value [Unit]	
Electricity (mixing of incoming solutions)	0.176 [kWh]	
Electricity (sedimentation)	0.102 [kWh]	
Electricity (drying)	0.01 [kWh]	
Consumption of materials		
NaOH (dry)	14.40 [g]	
$MgSO_4$ (dry)	20.64 [g]	
Water (sedimentation)	1.2 [dm^3]	
Water (ammonia recovery)	0.045 [dm^3]	
25% ammonia solution	5 [1]	20 [2] [kg]
Acetone (liquid)	100 [1]	800 [2] [g]
Emissions to water/soil		
Industrial waste water—all water in the process is re-used		
Co-products		
Na_2SO_4	23.45	g

[1] Base variant with recovery of acetone and ammonia. [2] Variant without recovery of acetone and ammonia.

3. Discussion

The analysis was carried out in the SimaPro 8 program, and the life cycle assessment was made using the ILCD (International Reference Life Cycle Data System) 2011 method (V1.10/EU27 2010, equal weighting). The method was developed as part of the initiative to create the International Reference Life Cycle Data System by the Institute for Environment and Sustainability (IES) of the Joint Research Centre, JRC. As part of this expertise, different methods of impact assessment were analysed. The ILCD method is recommended for use as a representative LCIA (Life Cycle Impact Assessment) method for European conditions. As part of the JRC work, two versions of the ILCD method were developed: the intermediate points (midpoint) and endpoints (endpoint) approaches. In the case of this analysis, the results at the level of endpoints were used.

The use of the method that was developed for the synthesis of magnesium hydroxide including washing with ammonia water and acetone enabled a product with a high specific surface area, reaching values above 100 m^2/g, to be obtained. The production process based on sulphate salts of magnesium and sodium hydroxide contributes to an environmental impact of 1.9 mPt (base variant). With no recovery of acetone and ammonia, this index increases to 11.2 mPt. Recovery of ammonia and acetone contributes to a nearly six times lower cumulative environmental impact indicator.

The results, divided into individual impact categories (environmental aspects), are presented in Table 2 and Figures 6 and 7. The values shown in Figure 7 below the *X*-axis represent the environmental benefits obtained from recovering individual materials and not having to use them from the primary market.

Table 2. Results of the cumulative eco-indicator for individual impact categories [Pt].

Impact Categories	**Eco-Indicator mPt**		
	Base Scenario	**None Recovery Scenario**	**Difference**
Climate change	0.26	1.42	1.16
Ozone depletion	0.01	0.01	0.00
Human toxicity, cancer effects	0.21	0.39	0.18
Human toxicity, non-cancer effects	0.57	2.28	1.70
Particulate matter	0.29	1.57	1.27
Ionising radiation HH (human health)	0.15	0.16	0.01
Photochemical ozone formation	0.25	1.57	1.32
Acidification	0.28	1.53	1.25
Terrestrial eutrophication	0.13	0.66	0.53
Freshwater eutrophication	0.14	0.57	0.43
Marine eutrophication	0.11	0.61	0.50
Freshwater ecotoxicity	0.09	0.47	0.39
Land use	0.01	0.02	0.01
Water resource depletion	0.15	0.45	0.30
Mineral, fossil resource depletion	0.14	0.32	0.18
Total environmental burden [mPt]	2.79	12.02	9.23

The qualitative structure of the impact on the environment in the baseline scenario is dominated by five categories of impact: Climate change, Human toxicity- non cancer effects, Particulate matter, Photochemical ozone formation, and Acidification. The total impact under these five impact categories represents about 59.5% of the total value of the cumulative eco-indicator of the base variant and 69.5% for the non-recovery scenario. Detailed analysis for the dominant impact categories is presented in Table 2.

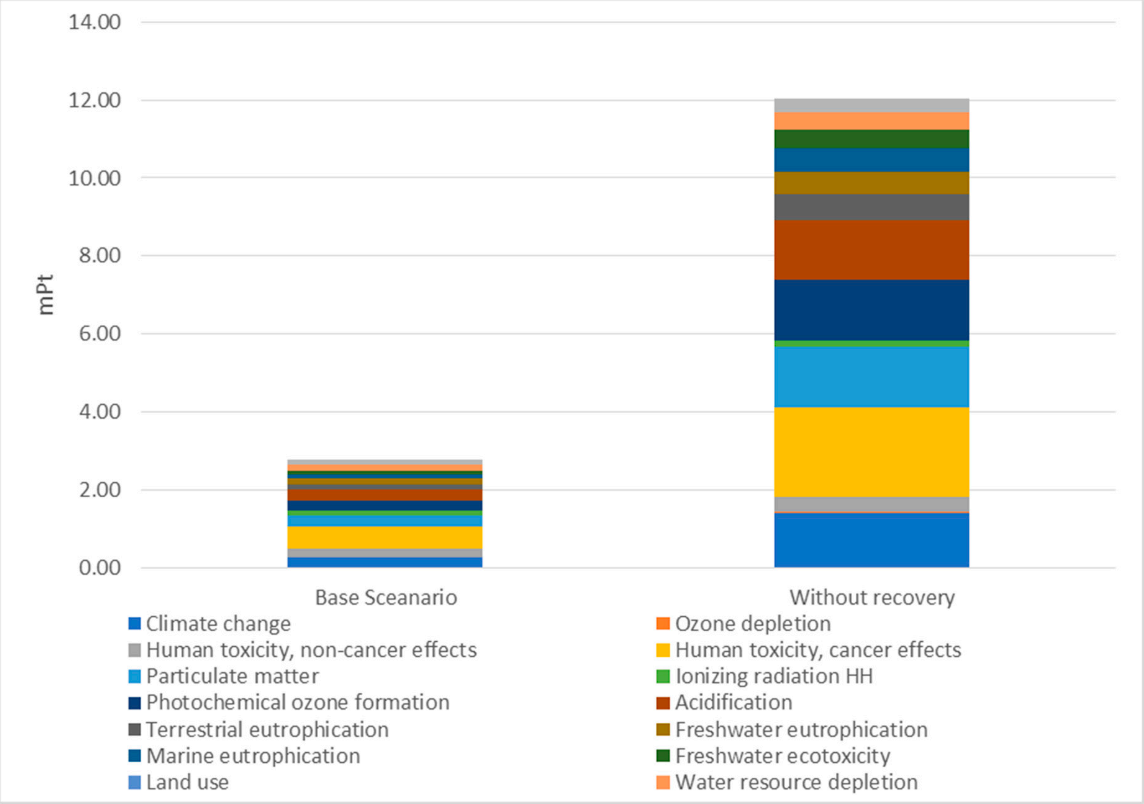

Figure 6. The results of the cumulative indicator, divided into individual impact categories, for the two scenarios analysed.

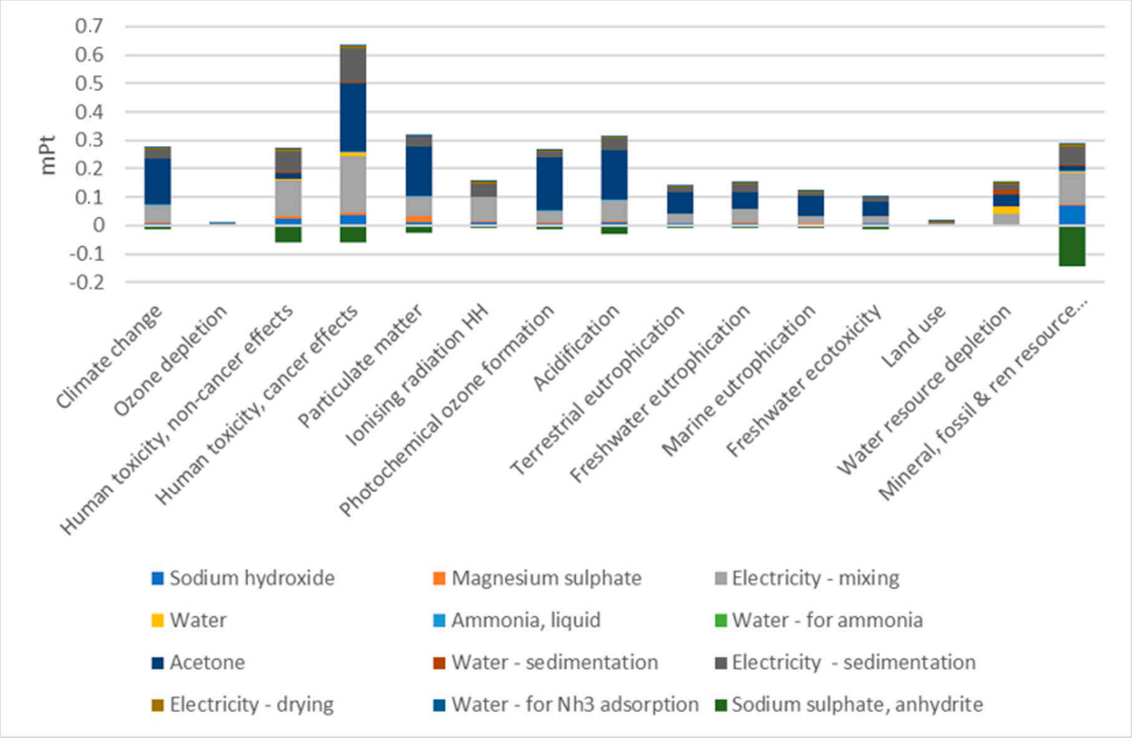

Figure 7. The results of the cumulative eco-indicator, divided into individual impact categories, for Table 2. Results of the cumulative eco-indicator for individual impact categories [Pt].

The environmental impacts shown in Table 2 refer to all inputs and outputs within the scope of the product systems, thus taking into account not only the production process of magnesium hydroxide, but also all the products used and their supply chains. The dominant processes in all impact categories are the use of acetone (45.6% share in the total impact ratio) and electricity (54.6% share in the total impact indicator). The analysis takes into account the energy structure at European level, without Switzerland. The indirect emissions in the processes of production of acetone and electricity produce a burden in the above mentioned (main) impact categories. The CO_2 and CH_4 emissions (98% of the category indicator) are mainly responsible for the impact on climate change, which is mainly driven by the generation of electricity from lignite and hard coal in individual European countries. Chromium VI emissions (water, soil, and air, 92.6% of the category indicator) and dust (<2.5 µm) are responsible for the impact on human health in the Human toxicity, cancer effects category and SO_2 emissions are responsible for the interaction in the particulate matter category. In this case, this impact is caused by acetone and magnesium sulphate production process (a total of 65.4% of the impact of subprocesses in this category). NO_X and non-methane volatile organic compounds (NMVOC) emissions are impacts in the photochemical ozone formation category. Acidification is mainly the effect of SO_2 and NOx emissions (96.1% of the category indicator), which are accounted for by both acetone production and electricity generation from coal. The percentage share of major issues in the indicator of dominant impact categories is shown in Table 3.

Table 3. Sources of environmental impact for the five dominant categories.

Product	Dominant Emissions/Resources Affecting the Environment in a Given Impact Category	Share in the General Indicator of a Given Impact Category [%]
Base scenario	Climate change	
	Emissions to air: CO_2	84.7
	Emissions to air: CH_4	13.3
	Human toxicity, cancer effects	
	Emissions to water: Chromium (VI)	61.7
	Emissions to soil: Chromium (VI)	22.8
	Emissions to air: Chromium (VI)	8.13
	Particulate matter	
	Emissions to air: Particulates <2.5 µm	53.6
	Emissions to air: SO_2	42
	Photochemical ozone formation	
	Emissions to air: NO_X	59.8
	Emissions to air: NMVOC	30.9
	Acidification	
	Emissions to air: SO_2	69.9
	Emissions to air: NO_x	26.2

As mentioned, the dominant environmental impact is caused by the indirect impact resulting from the supply chain, in particular the production and use of acetone. In the analysis, the unit process for the production of acetone is based on the three-step method of obtaining phenol and acetone from benzene and propene (propylene). The high share of upstream processes in the final impact indicator contributes to a significant reduction of the environmental impact resulting from acetone and ammonia recovery processes, which can be seen in Figure 6. Environmental analysis confirmed, therefore, the correctness of the recovery of these components. This will emphasise the particular significance of environmental aspects in the design of the proposed technology on an industrial scale. The studies presented concerned only the laboratory scale; however, they can be the basis for investment decision-making and the design of the technology on an industrial scale. The use of electricity also had a large impact. As mentioned in the assumptions of the analysis, a (low voltage) energy mix was used based on European countries (without Switzerland) and in which almost half (48.7%) of net electricity generated in 2016 came from combustible fuels (like natural gas, coal, and oil). Thus, reducing the impact of the entire process on the environment can be achieved by reducing energy consumption or using greener energy, e.g., based on renewable sources. As mentioned above, the process analysed was related to laboratory-scale research, so upscaling it can contribute to the optimisation of energy consumption and thus the reduction of the environmental impact of the same unit of production.

For a more detailed analysis, at the level of individual impact categories, the results are also presented after the characterisation stage. In this stage, the results of the LCIA analysis present separate indicators for each of the impact categories analysed, taking into account the category unit defined in the characterisation model. Presenting them in this way allows them to be analysed within a given category, without comparing and summing up the results of different categories (other characterisation units). The results after characterisation are presented in a more measurable way, i.e., through the equivalent of a given issue, the impact of the system on a given environmental aspect. Table 4 shows them in a manner analogous to the remainder of the results, i.e., per 1 kg of product.

Table 4. Sources of environmental impact for the five dominant categories.

Impact Category	Unit	Base Scenario	Non-Recovery Scenario
Climate change	kg CO_2 eq	2.64×10^{-6}	195.9025
Ozone depletion	kg CFC-11 eq	1.66×10^{-6}	3.42×10^{-6}
Human toxicity, cancer effects	CTUh	3.17×10^{-7}	3.13×10^{-6}
Human toxicity, non-cancer effects	CTUh	0.02	126×10^{-6}
Particulate matter	kg PM2.5 eq	2.46	0.08921
Ionising radiation HH	kBq U235 eq	0.12	2.64411
Photochemical ozone formation	kg NMVOC eq	0.20	0.747045
Acidification	molc H+ eq	0.34	1.087174
Terrestrial eutrophication	molc N eq	3.09×10^{-3}	1.73
Freshwater eutrophication	kg P eq	0.03	0.01
Marine eutrophication	kg N eq	11.39	0.16
Freshwater ecotoxicity	CTUe	12.26	61.87
Land use	kg C deficit	0.19	19.33
Water resource depletion	m3 water eq	2.12×10^{-4}	0.55
Mineral, fossil resource depletion	kg Sb eq	2.64×10^{-6}	4.89×10^{-4}

Analysing the results at the level of characterisation (Figure 8), it can be seen that the dominant impact (over 50%) in 7 of 15 categories (Climate change, Particulate matter, Photochemical ozone formation, Acidification, Terrestrial eutrophication, Marine eutrophication, Freshwater ecotoxicity) are due to the consumption of acetone, and in the next 7 categories (Ozone depletion, Human toxicity-non-cancer effects, Human toxicity-cancer effects, Ionising radiation, Freshwater eutrophication, Land use, Mineral, fossil, and renewable resource depletion) by consumption of electricity at various stages of synthesis. The results presented confirm the main hot spots identified at the weighted level. The total share contributed by the impact of acetone production ranged from 58 to 74% in different categories, and electricity from 55% to 94% (Figure 8). The values shown in Figure 7 below the *X*-axis represent the environmental benefits obtained from recovering individual materials and not having to use them from the primary market.

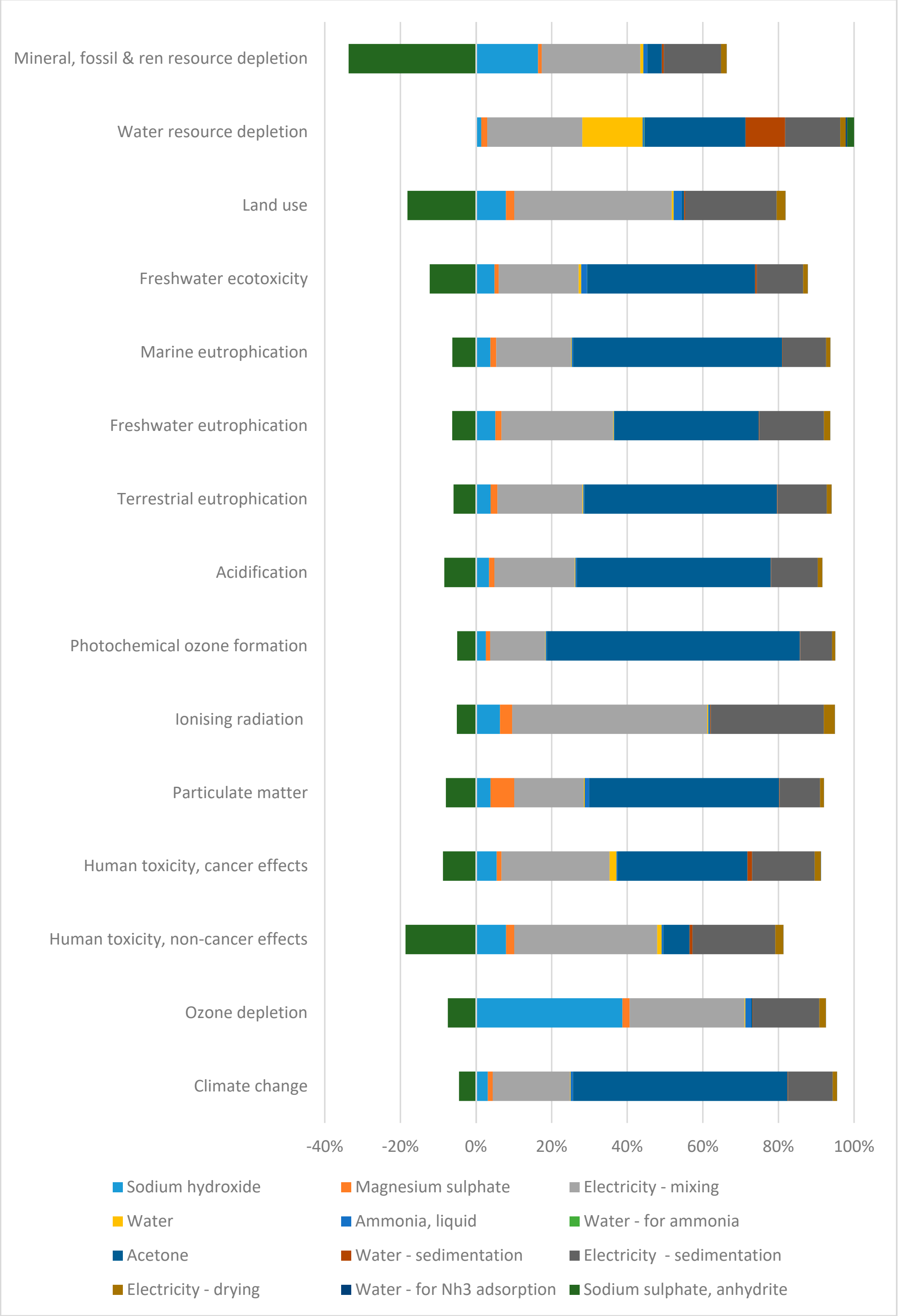

Figure 8. Shares of individual unit processes for the synthesis of 1 kg of product—after the characterisation stage [%].

4. Conclusions

The use of the method that has been developed for the synthesis of $Mg(OH)_2$ incorporating washing with 25% ammonia solution and acetone enabled a product with a high specific surface area to be obtained, reaching values above 100 m^2/g. When the washing process was omitted, a non-homogeneous grain size product was obtained. The non-homogeneous product is the result of the $Mg(OH)_2$ conglomerates sticking.

The $Mg(OH)_2$ obtained was characterised by a higher specific surface area than commercially available $Mg(OH)_2$ that are used as additives for flame retardants in polymeric materials where the specific surface area is in the range of 1.5–40 m^2/g [7]. This allows the material to be used as an anti-pyrogen for a wider group of polymeric materials. In addition, the application of inorganic salts as flame retardant additives reduces the need for organic chlorine or bromine compounds. The method of synthesis and drying which has been developed for $Mg(OH)_2$ allows the re-use of substances after their regeneration. The sulphate salts obtained as a co-product are also a full-value commercial product due to their high purity (after crystallisation from solutions). The resulting sodium sulphate can be used, for example, for the production of glass or dyes and in anhydrous form as a drying agent.

The environmental analysis showed the dominant influence of acetone and electricity on the final impact indicator. Two scenarios were assumed, from which the basic one included recovery of ammonia and acetone. The environmental analysis carried out using the LCA method confirmed the validity of this assumption, as it was stated that the main part of the impact was connected with the supply chain for the process examined, i.e., with the energy carriers and materials used, mainly acetone. The process of obtaining $Mg(OH)_2$ based on $MgSO_4$ and NaOH mainly contributes to environmental aspects such as Climate change, Human toxicity, Cancer effects, Particulate matter, Photochemical ozone formation, Acidification, and Freshwater ecotoxicity. However, due to the fact that there was a large share due to the use of electricity in the final impact indicator, it should be expected that the inclusion of a more environmentally friendly energy mix may cause a decrease in the environmental impact of the process, especially, a reduction in SO_2, NO_x, and dust emissions [27].

Author Contributions: Conceptualization, A.J. and P.R.; methodology, J.K.; software, L.L.; validation, L.L., J.K., and A.J.; formal analysis, P.R.; investigation, P.R.; resources, P.R.; data curation, L.L.; writing—original draft preparation, L.L. and P.R.; writing—review and editing, J.K.; visualization, L.L.; supervision, A.J. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Polish National Agency for Academic Exchange (NAWA) as the part of the project "International Cooperation for Rational Use of Raw Materials and Circular Economy" (COOPMLN), which is conducted in the Division of Strategic Research in the MEERI PAS (2019–2020), project no. PPI/APM/2018/1/00003. This research was also supported by AGH University of Science and Technology in Cracow and EIT InnoEnergy Teacher Award Grant.

Conflicts of Interest: The authors declare no conflict of interest.

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