Sustainability-oriented assessment of external thermal insulation composite systems: A case study from Poland

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Abstract: External Thermal Insulation Composite System (ETICS) technology is commonly used to insulate buildings to increase the energy efficiency of external building envelopes. The ETICS is a construction product whose use has a significant impact on the environment and which itself is subject to an environmental impact assessment. The paper presents the impact of producing all ETICS components on the natural environment using the life cycle assessment method. The data used in the calculations, related to 2012 and 2017 real production, were obtained from the externally verified inventory from five manufacturing plants located in different regions of Poland. Life Cycle Assessment (LCA) of the examined products covered modules from A1 to A3 (Cradle-to-Gate) according to EN 15804 standard. That includes raw materials extraction, processing of secondary material, transport to the manufacturer, and production up to the finished, packed product at the factory gate. In the period of 2012–2017, the negative impact on the natural environment for most environmental indicators for the entire ETICS (all of its components), has

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PUBLIC INTEREST STATEMENT

Every year around 250 million square meters of External Thermal Insulation Composite Systems (ETIC) are produced in Europe and used to insulate the outer walls of buildings. For ETICS, mechanical resistance, and stability, safety in case of fire are widely known. Despite the importance of ecological problems, up to now, environmental issues have been designated for ETICS as insufficient. One of the few tools for implementing the principles of sustainable development following the policies of the European Commission is Environmental Product Declarations. Based on externally verified inventory data from manufacturing plants they provide brief quantified information about the product life cycle, allowing a comparison between products that perform the same function, further supporting the consumer decision-making process to minimize the negative impact on the environment. The comparison of the environmental impact of the production of ETICS in 2012 and 2017 shows how this product has changed over the 5 years due to the manufacturer’s actions to reduce the environmental burden.
been significantly reduced. For the first time, changes of such indicators as GWP, ODP, AP, EP, POCP, ADP, ADP, PERT, PENRT over 5 years period for ETICS have been presented.

Subjects: Sustainable Engineering & Manufacturing; Composites; Concrete & Cement; Pollution

Keywords: Global Warming Potential (GWP); environmental impact; Environmental Product Declaration Type III (EPD); Life Cycle Assessment (LCA); External Thermal Insulation Composite System (ETICS)

1. Introduction
Degradation of the natural environment and climate change present an existential threat to the world. According to the European Environment Agency's (EEA) report (EEA, 2019b), Europe will not achieve its 2030 goals without urgent action during the next 10 years. The main problems are an alarming rate of biodiversity loss, increasing impacts of climate change, and the overconsumption of natural resources. Due to that, recently, the EU Commission has announced the new strategy to overcome this challenge - The European Green Deal (EC, 2019b). The document sets out how to make Europe the first climate-neutral continent by 2050. The construction, use, and renovation of buildings require significant amounts of energy. In the European Union, buildings are consuming 40% of all energy (EC, 2019a). Heating and cooling account for about two-thirds of energy consumption in buildings. Energy efficiency issues are fundamental to the energy policy of the EU, and the External Thermal Insulation Composite System (ETICS) is essential to achieve Europe's ambitious goals (Kienzlen et al., 2014). The application of ETICS improves the energy efficiency of both new and existing buildings. ETICS are kit in the sense of the Construction Products Regulation (CPR) consisting of specified prefabricated components being applied directly to the facade on site (The European Parliament and the European Council, 2011). CPR defines the basis for assessing the performance of construction products.

According to the CPR, it is necessary to consider construction objects comprehensively while taking into account all the basic requirements: (1) mechanical resistance and stability, (2) safety in case of fire, (3) hygiene, health, and environment, (4) safety and accessibility in use, (5) protection against noise, (6) energy economy and heat retention, and (7) sustainable use of natural resources.

While the first six basic requirements have been widely present for years (also under Directive 89/106/EEC) in the requirements that construction products are subjected to during conformity assessment before being placed on the market, the seventh basic requirement for sustainable development is still absent from the mandatory requirements. In 2004 CEN's Technical Committee 350 Sustainability of construction works was set up to provide a method for the voluntary delivery of environmental information for construction. CEN/TC 350 has developed standards for the sustainability assessment of buildings (CEN, 2011), as well as for relevant product information (CEN, 2019), which was, for the first time, released in January 2012 (in 2019 substantial revision of the standard took place). Environmental Product Declarations (EPD), developed under EN 15804 (CEN, 2019), are one of the few tools for implementing the principles of sustainable development following the policies of the European Commission (Sierra-Pérez et al., 2016). On the one hand, they can be considered as an essential tool for applying the principles of sustainable development; on the other hand, because they are voluntary, they are not common. The development of an EPD involves assessing the product by determining its characteristics expressed by a set of appropriately selected indicators relating to individual categories of environmental impact or ecological features. Type III Environmental Product Declarations are created based on the requirements of the following standards: ISO 14025 (ISO, 2006) and EN 15804 (CEN, 2019). EPDs are developed after a Life Cycle Assessment (LCA) following applicable Product Category Rules. Environmental Product Declarations are subjected to verification by an independent third party who has the required competencies and knowledge in this respect.
Independently verified declarations provide information on environmental impacts and aspects under the guidelines, i.e., objectivity, comparability, and reliability (Passer et al., 2015). In January 2019, over 6,000 Environmental Product Declarations were available from various EPD’s program operators from around the world, most of them published in Europe. Poland, with 69 EPDs issued by the Building Research Institute (ITB), was ninth-ranked (Anderson, 2019). Over the past year, the Polish institute has verified further environmental product declarations and currently has 95 EPDs available on its website (Building Research Institute, 2020).

EPDs are functioning primarily in B2B communication. They also are used in the certification of buildings in voluntary certification systems, such as, among others, LEED and BREEAM. It is also worth mentioning that there is another independent assessment system—Product Environmental Footprint (PEF) introduced by the European Commission in 2011. Both methods have recently been compared (Durão et al., 2020). Sustainable building management is a complex issue whose importance will become more and more important (Giama & Papadopoulos, 2012). In this paper, we have presented environmental indicators for ETICS determined for the first time in 2012, and then after 5 years. In this work, we focused on the environmental impact of ETICS as a system. For analysis, we chose one of the system variants with mineral renders, which have the lowest environmental impact among all types of studied renders (Michałowski et al., 2020). Taking into account the importance of EPD’s and that not so many of these documents have been created for ETICS so far, our work should be considered as innovative. A comparison of the changes in the environmental impact of ETICS that have occurred in 5 years is also creative. Besides, taking into account that the data based on which environmental indicators were determined come from five production locations in different regions of Poland and taking into account the significant production volume, the results obtained are real and representative of changes in the Polish ETICS market. We believe that the analysis of the results of environmental impacts is an essential part of the research area in construction (Czarnecki & Kapron, 2010).

2. Materials and methods

2.1. External Thermal Insulation Composite System (ETICS)

ETICS with rendering is a type of external cladding in which insulation boards are fixed to an outside wall with adhesive, anchors, rails, or a combination of adhesives and mechanical fixings. This technique was developed in Germany, and the first ETICS has been installed in a residential building in 1957 in Berlin (Künzel, 1975). Over the past 60 years, ETICS has been the most widely used solution to improve the energy efficiency of buildings in all EU Member States (Lengsfeld et al., 2015). Durability tests performed on a laboratory scale, as well as results and findings from construction projects, also confirmed the usefulness of systems in terms of durability (Griciutė et al., 2013). In Europe, more than 2 billion m² have already been installed - showing positive long-term experiences. ETICS has already contributed significantly to achieving Europe’s environmental objectives (Pasker, 2017).

In the EU, the ETAG 004 (EOTA, 2013) sets out the performance requirements for External Thermal Insulation Composite Systems for the use of external insulation of building walls. ETAG 004 specifies the verification methods used to examine the various aspects of performance, the assessment criteria used to judge the performance for the intended use and the presumed conditions for the design and execution.

In Poland, construction products can be laying down on the market with the CE marking or in the system on the national level with the construction mark B. In the case of the domestic order, the document setting the requirements in the field of performance is the guideline for issuing national technical assessments) (Building Research Institute, ICiMB & IMBiGS, 2018).

ETICS components are adhesives, thermal insulation material (mostly expanded polystyrene (EPS) or mineral wool), anchors (if required), base coat, reinforcement (glass fiber mesh), finishing coat/topcoat with system primer and/or paint coating, less often accessories, e.g., fabricated corner beads, connection, and edge profiles, expansion joint profiles, base profiles, etc. ETICS
significantly reduces thermal transmission through outer walls, therefore helps to reduce the costs for heating and cooling by 50% or more (Künzel et al., 2006). The choice of insulation material has a considerable impact on the environment (Sierra-Pérez et al., 2016).

Atlas ETICS is a trading name for External Thermal Insulation Composite System, which comprises an insulation board (bonded or bonded and mechanically fixed) with reinforced undercoat and decorative finishes, as described in the National Technical Approval ITB AT-15-9090/2014 (Building Research Institute, 2014b) and ATB AT-15-9090/2016 (Building Research Institute, 2016). It is worth noting here that the national technical approvals issued before 1 January 2017, are valid until the end of 2021. The system is complete and equipped with a vast selection of adhesives, base coats, renders, and decorative coats of various colors (Figure 1).

2.2. LCA methodology related to environmental product declarations

The environmental impact was assessed using the LCA method for a complex thermal insulation system described in the National Technical Approval AT-15-9090/2014 (Building Research Institute, 2014b) and AT-15-9090/2016 (Building Research Institute, 2016). The insulation system described in the above-mentioned AT’s releases allows the use of many variants of material solutions. For this publication, the results obtained for one of the options (identical in the aforementioned AT versions from 2014 to 2016) containing expanded polystyrene panels of three different thicknesses: 10, 15, and 20 cm with a mineral render as a finishing layer were analyzed.

The data used in the calculations related to 2012, EPD issued in March 2014 (Building Research Institute, 2019), and 2017, EPD issued in March 2019 (Building Research Institute, 2019), for five production plants located in Poland (Bydgoszcz, Dąbrowa Górnicza, Piotrków Trybunalski, Suwałki, and Zgierz). The production sites mentioned above are located in different regions of Poland. It is also worth noting that during 2012 and 2017, the production volume of ETICS system components was comparable and corresponded to approximately 10 million square meters of insulation of the external walls of buildings. In the locations mentioned, all ETICS components except EPS, glass fiber meshes, and anchors were produced.
Type III Environmental Product Declarations - versions from 2014 to 2019 were developed by following EN 15804, and their content was verified per under ISO 14,025 by Building Research Institute experts. The life cycle that was the subject of the analysis covered modules A1 to A3, i.e., from the extraction of raw material to the finished product delivered to the factory gate, where A1 - extraction, and processing of raw materials, processing of secondary material, including recycling processes, A2 - transport to the manufacturer and A3 - production. The environmental assessment refers to the product unit, which is 1 m² of insulation made using a complex insulation system described in the National Technical Approval AT-15-9090 versions from 2014 to 2016. The impacts and consumption of raw materials for each production plant and the entire production were assigned to representative products through the application of mass allocation rules, i.e., the weighted average mass of given products. Impacts at individual production locations have been inventoried, assigned, and included in the calculations separately.

The environmental data on raw materials used in the analysis come from valid sources (data-bases) such as Ecoinvent, Ullmann’s, Plastics-Europe, ITB-Data, SPC, and selected type III environmental product declarations of components of complex ETICS.

3. Results and discussion
ETICS technology, previously known in Poland, also under the name BSO, as well as the “light-wet” method, is currently the most popular, commonly used method of insulating buildings. The Polish market estimated at around 40 million m² annually (Paszk, 2017) is one of the leading in Europe. Manufacturers of thermal insulation systems are continually modernizing their products to make them as durable, functional, and aesthetic as possible. Of course, in agreement with the applicable regulations, regardless of whether the product is placed on the market with the CE marking, or in the Polish national system with the construction mark B, a positive assessment of its performance with the essential characteristics is necessary (Building Research Institute, ICIMB & IMBiGS, 2018; EOTA, 2013). As mentioned earlier, ETICS, like other construction products, is not subject to mandatory assessment in terms of the basic requirement for the sustainable use of natural resources. In addition, EPD environmental declarations have been developed so far for a relatively small number of ETICS systems. In this work, the environmental characteristics of 1 m² of insulation made using one of the variants of the ETICS system specified in AT-15-9090 for a system with mineral plasters and expanded polystyrene thicknesses of 10, 15, and 20 cm published for the first time in 2014 (data from 2012) and re-verified for the analogous system in 2019 (data from 2017). Table 1 shows the environmental characteristics of ETICS with different thicknesses of EPS insulation material (10, 15, and 20 cm) and mineral renders as the finishing layer calculated for 1 m² of insulation, of:

- global warming potential (GWP),
- depletion potential of the stratospheric ozone layer (ODP),
- acidification potential of soil and water (AP),
- eutrophication potential (EP),
- formation potential of tropospheric ozone (POCP),
- abiotic depletion potential (ADP-elements) for non-fossil resources,
- abiotic depletion potential (ADP-fossil fuels) for fossil resources,
- total use of renewable primary energy resources (primary energy and primary energy resources used as raw materials) (PERT),
- total use of non-renewable primary energy resources (primary energy and primary energy resources used as raw materials) (PENRT) Table 1
**Table 1. Environmental impact of 1 m² ETICS described in the NationalTechnical Approval AT-15-9090 assessed in the year 2014 (data from 2012) and 2019 (data from 2017) respectively, with 10, 15, and 20 cm expanded polystyrene boards used as thermal insulation material, and mineral renders as a finishing layer**

| CRADLE-TO-GATE LIFE CYCLE ASSESSMENT* | 10       | 15       | 20       |
|---------------------------------------|----------|----------|----------|
| **THICKNESS** [cm]                    | 2012     | 2017     | 2012     | 2017     | 2012     | 2017     |
| **YEAR**                              |          |          |          |          |          |          |
| **GWP** [kg CO₂ eq.]                  | 11.2     | 8.70     | 14.5     | 11.0     | 17.8     | 13.4     |
| **ODP** [kg CFC 11 eq.]               | 1.07 · 10⁻⁶ | 5.01 · 10⁻⁵ | 1.10 · 10⁻⁵ | 5.01 · 10⁻⁵ | 1.14 · 10⁻⁵ | 5.02 · 10⁻⁵ |
| **AP** [kg SO₂ eq.]                   | 3.45 · 10⁻² | 2.57 · 10⁻² | 4.53 · 10⁻² | 3.10 · 10⁻² | 5.60 · 10⁻² | 3.63 · 10⁻² |
| **EP** [kg (PO₄)₃ eq.]                | 4.00 · 10⁻³ | 4.63 · 10⁻³ | 5.00 · 10⁻³ | 5.11 · 10⁻³ | 6.00 · 10⁻³ | 5.60 · 10⁻³ |
| **POCP** [kg Ethene eq.]              | 2.40 · 10⁻³ | 2.41 · 10⁻³ | 3.10 · 10⁻³ | 3.07 · 10⁻³ | 3.70 · 10⁻³ | 3.73 · 10⁻³ |
| **ADP** [kg Sb eq.]                   | 1.10 · 10⁻⁵ | 9.90 · 10⁻⁵ | 1.50 · 10⁻⁵ | 9.90 · 10⁻⁵ | 1.90 · 10⁻⁵ | 9.90 · 10⁻⁵ |
| **ADFP** (MJ)                         | 1.95 · 10⁻² | 1.55 · 10⁻² | 2.90 · 10⁻² | 2.23 · 10⁻² | 3.67 · 10⁻² | 2.90 · 10⁻² |
| **Environmental impacts, calculated per 1 m²** |          |          |          |          |          |          |

| **YEAR**                              | 2012     | 2017     | 2012     | 2017     | 2012     | 2017     |
| **PERT** [MJ]                         | 1.42     | 8.70     | 1.42     | 9.69     | 1.42     | 10.7     |
| **PENRT** [MJ]                        | 2.16 · 10² | 1.62 · 10² | 3.11 · 10² | 2.32 · 10² | 4.05 · 10² | 3.01 · 10² |

* GWP - global warming potential; ODP - depletion potential of the stratospheric ozone layer; AP - acidification potential of soil and water; EP - eutrophication potential; POCP - formation potential of tropospheric ozone; ADP - abiotic depletion potential (ADP-elements) for fossil resources; ADFP - abiotic depletion potential (ADP-fossil fuels) for fossil resources; PERT - total use of renewable primary energy resources (primary energy and primary energy resources used as raw material); PENRT - total use of non-renewable primary energy resources (primary energy and primary energy resources used as raw materials).

A comparison of environmental performance indicators for modules A1 to A3 (from the extraction of raw materials to the factory gate) for ETICS over 5 years illustrates the changes that have taken place at that time.

The subject of the assessment are changes in the extraction and production of raw materials and other materials necessary for the production, transport, and production process of all components of the ETICS. Table 2 specifies all components of the ETICS described in the National Technical Approval ITB-AT-15-9090/2016. To illustrate better the impact of the production volume of ETICS systems on the environment, Table 3 presents a comparison of the values of environmental performance indicators in the scope of modules A1-A3 calculated for 40 million m² (corresponding to the size of the Polish market of the external wall area in newly constructed and renovated buildings).

For this work, discussing the obtained results, we calculated them for 40 million m² to be able to easily compare them with the available data for the country and thus make the reader aware of the essence and validity of ETICS systems. Also, a reference to market size allows the reader to visualize better the dimension of the actions taken by manufacturers of all ETICS components over 5 years.
Calculations based on data from 2012 to 2017 were made for the ETICS system described in the National Technical Approval AT-15-9090 with 10, 15, and 20 cm expanded polystyrene boards (EPS) used as thermal insulation material, and mineral renders as a finishing layer.

| Component description | Quantity per m² |
|-----------------------|-----------------|
| Adhesive for bonding the EPS | 4.50 kg |
| Insulation | 1.35 kg |
| Adhesive for base coat | 5.5 kg |
| Glass fiber mesh | ≥ 0.15 kg |
| Key coat | ca. 0.2 kg |
| Finishing coat | 2.0–4.5 kg |
| Ancillary materials | - |

1Products from suppliers.
2EPS insulation is already in use for more than fifty years.

Calculations based on data from 2012 to 2017 were made for the ETICS system described in the National Technical Approval AT-15-9090 with 10, 15, and 20 cm expanded polystyrene boards (EPS) used as thermal insulation material, and mineral renders as a finishing layer.

| EPS THICKNESS [cm] | 10 | 15 | 20 |
|--------------------|----|----|----|
| Environmental impacts, calculated per 40 million m² |
| ASSESSED PERIOD | 2017–2012 | 2017–2012 | 2017–2012 |
| GWP [t CO₂ eq.] | -100,000 | -140,000 | -176,000 |
| ODP [t CFC 11 eq.] | +1.96 | +1.96 | +1.96 |
| AP [t SO₂ eq.] | -352 | -572 | -788 |
| EP [t (PO₄)³⁻ eq.] | +25.2 | +4.4 | -16 |
| POCP [t Ethene eq.] | +0.4 | -1.2 | -1.2 |
| ADP [t Sb eq.] | -4,004 | -5,604 | -7,204 |
| ADFP [GJ] | -1,600,000 | -2,680,000 | -3,080,000 |

Environmental aspects related to the consumption of raw materials, calculated per 40 million m²

| ASSESSED PERIOD | 2019–2014 | 2019–2014 | 2019–2014 |
|-----------------|-----------|-----------|-----------|
| PERT [GJ] | 291,000 | 330,800 | 371,200 |
| PENRT [GJ] | -2,160,000 | -3,160,000 | -4,160,000 |
The data in Table 1 and Table 3 show that over the considered period (5 years), for most indicators, the changes were associated with a decrease in the negative impact on the environment. After 5 years, the production of 1 m² of insulation (in the scope of modules A1-A3) associated with the reduction by 22.3%, 23.1%, and 23.1% for the EPS thickness of 10, 15, and 20 cm, respectively, of the greenhouse effect. Figure 2 shows the global warming potential (GWP) values calculated for 40 million m² ETICS in the three tested variants of the systems in 2012 and 2017. The comparison of values of global warming potential resulting from the production of 40 million m² of ETICS with greenhouse gas emissions realizes the dimension of the environmental burden associated with the manufacturing of insulation system components aware.

Total GHG emissions—excluding Land Use, Land Use Change, and Forestry (LULUCF)—in Poland amounted to 399.5 million tonnes CO₂ equivalent in 2012 (The National Centre for Emissions Management, 2018). Five years later, in 2017, total GHG emissions excluding LULUCF increased to 413.8 million tonnes CO₂ eq. (EEA, 2019a). As mentioned earlier, the global warming potential of manufacturing ETICS (modules A1-A3) decreased by around 23% between 2012 and 2017, while greenhouse gas emissions increased by 3.6%. Production in 2012 of all ETICS components with mineral plasters and 15 cm thick EPS panels (for 40 million m²) described in the AT-15-9090 meant emissions of 580 thousand tons of CO₂ equivalent, which was 0.18% of the total CO₂ emissions and 0.15% of the total greenhouse gas emissions in Poland (EEA, 2019b). Five years later, these values fell to 440 thousand tons of CO₂ equivalent, and contribution of 0.14% in the total CO₂ emissions and 0.11% in the total greenhouse gas emissions in the country (Muntean et al., 2018).

The stratospheric ozone layer depletion potential (ODP), determining the quantitative impact of the ETICS on the destruction of the ozone layer, has risen in 5 years. Between 2012 and 2017 also an increase in eutrophication potential (EP) was observed. Eutrophication potential quantitatively determines the impact on the accumulation of organic matter in water. The growth of the ODP and EP indicators is mostly due to the introduction of sharpened changes in computational methodology. When considering the ozone layer depreciation, ODP, it is worth mentioning that no ozone-depleting substances as regulated by the EU, such as CFC or HCFCs, are nowadays used as blowing agents for the production of EPS (EUMEPS, 2017).

For the potential for soil and water acidification, a significant decrease in negative impact was recorded over 5 years. For the tested ETICS with thermo-insulation material with a thickness of 10, 15, and 20 cm, a decrease of acidification potential of soil and water (AP) of 25.5%, 31.6%, and 35.2% were observed, respectively. Production of ETICS components is associated with a relatively small impact on soil and water acidification. It cannot be considered as a significant factor in
changing soil and water acidification in Poland (Ochal et al., 2017). In the examined period of 5 years, small changes in POCP—formation potential of tropospheric ozone were noted. In the case of the ADP indicator (abiotic depletion potential (ADP-elements) for fossil resources), there were massive changes. In 5 years, a decrease in ADP potential of 91.0%, 93.4%, and 94.7% were observed for ETICS with thermal insulation material (EPS) 10, 15, and 20 cm thick, respectively. Also, in the case of the ADFP (abiotic depletion potential (ADP-fossil fuels) for fossil resources) indicator, the negative impact on the environment has been noted. The ADFP index for the tested ETICS systems with 10, 15, and 20 cm thick EPS boards decreased by 20.5%, 23.1%, and 21.0%, respectively, in the examined period.

Comparison of the ETICS component production between 2012 and 2017 shows: an increase of the total consumption of renewable primary energy resources (primary energy and primary energy resources used as raw materials), PERT, and, at the same time, a decrease in the total consumption of non-renewable primary energy resources (primary energy and primary energy resources used as raw materials), PENRT. Both changes are very desirable.

It is also worth noting that the decrease in the total consumption of non-renewable primary energy resources (PENRT) over 5 years was significantly higher than the increase in the total use of renewable primary energy resources (PERT). ETICS improves the energy efficiency of buildings.

It is essential to add that for buildings insulated with ETICS energy payback is depending on many factors, like insulation thickness, heating method, and energy source. Also, the original situation, as well as climate, are playing a crucial role. As a rule, the energy payback period of insulating materials is less than 2 years (Kienzlen et al., 2014). A study on ecological cost-effectiveness for the thermal insulation of building external vertical walls in Poland showed that the ecological payback period of thermal insulation investment in the range of 0–6 years depends on the studied variants (Robert Dylewski & Adamczyk, 2016). Besides, it is worth noting that it is cost-effective to use larger thermal insulation thicknesses than optimal for economic reasons. Then it is obtained more significant environmental benefits, with no significant decrease in economic benefits (Robert Dylewski, 2017). In general, environmental impact issues are inextricably linked to economic and social aspects. Sustainable development is, after all, equal treatment of economic, social, and ecological reasons. The purpose of this work was to show the environmental impact of the production of ETICS components. For the first time, the changes that have occurred in this area over 5 years are presented.

A comparison of indicators of environmental characteristics of modules A1 to A3 in the case of ETICS over 5 years is a measure of the changes that have occurred. Changes in the extraction and production of various raw materials, like expanded polystyrene boards, cement, sand, modified methyl cellulose ethers, redispersible polymer powders, cement setting time regulators, limestone fillers, and dolomite, but also water-based dispersions, hydrophobic agents, film-forming agents, biocides and many others. Moreover, changes in transport of raw materials, packaging, and other materials used necessary for the production and the manufacturing process itself of all components of the ETICS system, including thermal insulation material. These changes are the result of many processes, both genuinely thought out and directed to a positive environmental effect, and forced by other non-environmental factors conducted by all those involved in the chain of processes related to modules from A1 to A3. Among the deliberately held activities aimed at a positive environmental effect, it is worth mentioning CSR activities, which the manufacturer of ETICS systems has carried out and conducted consciously, subjecting them annually to evaluation by an external auditor and publishing them in CSR reports (Atlas, 2013; Atlas, 2018).

The results of the calculations presented in the article are hardly available to the consumer who chooses the construction product. However, taking into account the importance of problems related to the impact of human activities on the environment, it seems that this situation will have to change significantly. The introduction of essential characteristics related to environmental impact to assess performance is a task that requires extensive coordination and active participation of all participants of the construction market.
4. Conclusions

The primary purpose of the work was to show the environmental impact of ETICS (all system components) in the scope of modules from A1 to A3 (from raw material extraction to the factory gate) using the LCA method. The estimation was made based on real data from five production locations located in Poland. The obtained results, assuming that the data collected for the examined system are representative for the whole market, were referred to the volume of greenhouse gas emissions and CO₂ emissions in Poland. A comparison of the estimated impact of the production of all ETICS components (in the scope of modules from A1 to A3) to the total national emissions of greenhouse gases and CO₂ demonstrates how beneficial ETICS are for the environment and its future. An estimation of the environmental impact of ETICS was made for the same products and the same production locations 5 years apart. A comparison of these data showed that the environmental burden associated with ETICS significantly decreased over the period considered. This decrease is the result of many changes, both consciously planned and not necessarily controlled. The results obtained show how much has changed, and changes in the industry, how producers are doing a lot to make their production cleaner and environmentally friendly.

Data on the environmental impact of ETICS, especially showing how this impact changes in subsequent years, can help better understand trends observed in CO₂ emission on the national level. Dissemination of data on the environmental impact of building materials, including ETICS, could also motivate consumers when making choices about which solution to use (Petrovic et al., 2019).

It is worth noting that this kind of calculation was made for the first time. According to the authors, the results obtained provide additional arguments for the widespread use of insulation of external walls of buildings as a very effective solution that saves energy.

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References
Anderson, J. (2019). ConstructionLA’s 2020 guide to environmental product declarations. Retrieved December 30, 2019, from infogram.com/construc tionlasc-2020-guide-to-epd-1h7g6k9p9z0okoyjlive Atlas. (2013). Corporate social responsibility report 2012. Łódź. Atlas. (2018). Corporate social responsibility report 2016-2017. Łódź.
Building Research Institute. (2014b). National Technical Approval ITB-AT-9090/2014 Zestaw wyrobów do wykonywania ościeżeń ścian zewnętrznych budynków systemem Atlas ETICS.
Building Research Institute. (2016). National technical approval ITB-AT-9090/2016 Zestaw wyrobów do wykonywania ościeżeń ścian zewnętrznych budynków systemem Atlas ETICS. Building Research Institute. (2019). Environmental product declaration Atlas ETICS External Thermal Insulation Composite System with expanded polystyrene boards (EPS). Building Research Institute (ITB).
Building Research Institute. (2020). General information about research building institute EPD program. Building Research Institute (ITB). Retrieved January 16, 2020, from https://www.itb.pl/epd.html Building Research Institute, ICIMB, & IMBiGS. (2018). Warunki oceny właściwości użytkowych wyrobów budowlanego WO-KOT/04/02 - Złożone zestawy izolacji cieplnej z wyprawami tynkarskimi (ETICS) z zastosowaniem wyrobów ze styropianu (1st ed.). Warsaw, Poland: Building Research Institute (ITB), Institute of Ceramics and Building Materials (ICIMB), & Institute of Mechanised Construction and Rock Mining (IMBiGS). CEN. (2011). EN 15978:2011 Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method. Brussels, Belgium: European Committee for Standardization (CEN).
CEN. (2019). EN 15804:2012+A2:2019 Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products. Brussels, Belgium: European Committee for Standardization (CEN).
Czarnecki, L., & Kapron, M. (2010). Sustainable construction as a research area. International Journal of the Society of Material Engineering for Resources, 17(2), 99–106. https://doi.org/10.5188/jsjmer.17.99 Durão, V., Dinis, J., Mateus, R., & Brito, J. D. (2020). Resources, conservation & recycling assessment and communication of the environmental performance of construction products in Europe - Comparison between PEF and EN 15804 compliant EPD schemes.
Resources, Conservation and Recycling, 156, 2019. https://doi.org/10.1016/104703

Dylewski, R. (2017). Ekonomiczne i ekologiczne koszty ogrzewania oraz optymalna grubość termoizolacji: Systemy Wspomagania W Inżynierii Produkcji, 6(7), 68–83. http://yaddo.icm.edu.pl/yaddo/element/bwmeta1.element.沼tech-ee7dbdb-0868-4663-982d-2185f6b6a747

Dylewski, R., & Adamczyk, J. (2016). Study on ecological cost-effectiveness for the thermal insulation of building external vertical walls in Poland. Journal of Cleaner Production, 133(January 2011), 467–478. https://doi.org/10.1016/j.jclepro.2016.05.155

EC. (2019a). Energy balance sheets. In The European Commission. Brussels, Belgium: European commission. https://doi.org/10.2785/10223

EC. (2019b). The European green deal. In The European Commission. Brussels, Belgium: European commission. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2019:640:FIN

EAA. (2019a). Annual European Union greenhouse gas inventory 1990-2017 and inventory report 2019. Copenhagen, Denmark: European Environmental Agency.

EAA. (2019b). The European environment - state and outlook 2020. Knowledge for the transition to a sustainable Europe. In The European environment agency. Copenhagen, Denmark: European Environmental Agency. https://doi.org/10.2800/96749

EOTA. (2013). ETAG 004: Guideline for European technical approval of External Thermal Insulation Composite Systems (ETICS) with rendering. European Organisation for Technical Approvals, Brussels, Belgium. https://www.eoto.eu/en-GB/content/etags/267

EUMEPS. (2017). Environmental product declaration - expanded polystyrene (EPS) foam insulation. Institut Bauen und Umwelt e.V., Berlin, Germany. www.ibu-epd.com/https/epd-online.com

The European Parliament and the European Council. (2011). Regulation (EU) no 305/2011 of the European parliament and the council of 9 march 2011. Official Journal of the European Union, L 88/5(A. 4.2011), 5-43. https://doi.org/10.2785/10223

Giarno, E., & Papadopoulos, A. M. (2012). Sustainable building management: Overview of certification schemes and standards. Advances in Building Energy Research, 6(2), 242–258. https://doi.org/10.1080/17512549.2012.740905

Griculje, G., Blaždžius, R., & Norvaišienė, R. (2013). The durability test method for external thermal insulation composite system used in cold and wet climate countries. Journal of Sustainable Architecture and Civil Engineering, 1(2), 50–56. https://doi.org/10.5755/j01.ase.12.2.2778

ISO. (2006). ISO 14025:2006 Environmental labels and declarations — Type III environmental declarations — Principles and procedures. International Organization for Standardization, Geneva, Switzerland.

Kienzlen, V., Erhorn, H., Krapmeier, H., Lutzkendorf, T., Werner, J., & Wagner, A. (2014). The significance of thermal insulation Arguments aimed at overcoming misunderstandings (Third.). KEA Climate Protection and energy Agency of Baden-Wurtenberg GmbH, Karlsruhe, Germany. http://www.buildup.eu/sites/default/files/content/the_significance_of_thermal_insulation.pdf

Künzel, H. (1975). Außenseitige Wärmedämmung und Witterungsschutz (External Thermal Insulation and Weathering Protection). Gesundheits-Ingenieur, 96 (5), 132–139.

Künzel, H., Künzel, H. M., & Sedlbauer, K. (2006). Long-term performance of External Thermal Insulation Systems (ETICS). Architectura, 5(1), 11–24. https://www.bdb.com.pl/upload/f0c239842a1781f02a0ec22bdbc529465.pdf

Lengsfeld, K., Kruis, M., Künzel, H., & Helmkt, K. (2015). Assessing the long-term performance of applied External Thermal Insulation Composite Systems (ETICS). Fraunhofer Institute for Building Physics IBP, Stuttgart, Germany.

Michalowski, B., Marcinek, M., Tomaszewska, J., Czerńik, S., Piasiecki, M., Gerylo, R., & Michalak, J. (2020). Influence of rendering type on the environmental characteristics of expanded polystyrene-based external thermal insulation composite system. Buildings, 10(3), 47. https://doi.org/10.3390/buildings10030047

Muntean, M., Guizzardi, D., Schaaf, E., Crippa, M., Solazzo, E., Olivier, J. G. J., & Vignati, E. (2018). Fossil CO2 emissions of all world countries – 2018 Report. In Publications Office of the European Union. European Commission, Brussels, Belgium. https://doi.org/10.2760/30158

The National Centre for Emissions Management. (2018). Krajowy raport Inwentaryzacj2018 Inwentaryzacji gazów cieplarnianych dla lat 1988-2016. Institute of Environmental Protection - National Research Institute, Warsaw, Poland.

Ochal, P., Jodczyszn, T., Jurgo, B., Kopinski, J., Matyko, M., Madej, A., & Lysiak, M. (2017). Środowiskowe aspekty zakwaszenia gleb w Polsce. Pulawy.

Pasker, R. (2017). The European ETICS market - Do ETICS sufficiently contribute to meet political objectives? In 4th European ETICS Forum. Warsaw.

Passer, A., Lasvouxs, S., Allacker, K., De Lathauwer, D., Spirinckx, C., Wittstock, B., … Wallbaum, H. (2015). Environmental product declarations entering the building sector: Critical reflections based on 5 to 10 years experience in different European countries. The International Journal of Life Cycle Assessment, 20(9), 1199–1212. https://doi.org/10.1007/s11367-015-0926-3

Petrovic, B., Myhren, J. A., Zhang, X., Wallhagen, M., & Eriksson, O. (2019). Life cycle assessment of building materials for a single-family house in Sweden. Energy Procedia, 158, 3547–3552. https://doi.org/10.1016/j.egypro.2019.01.913

Sierra-Pérez, J., Boschmonart-Rives, J., & Gabarrell, X. (2016). Environmental assessment of façade-building systems and thermal insulation materials for different climatic conditions. Journal of Cleaner Production, 113, 102–113. https://doi.org/10.1016/j.jclepro.2015.11.090
