Life Cycle Assessment of Protection Products for ETICS

Pedro Emanuel Frazão Pedroso
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1. Introduction

The construction sector is one of the main contributors for the consumption of raw materials and global emissions of greenhouse gases. This sector is responsible for the consumption of: ≈40% of all stone, gravel and sand extracted; ≈25% of all fell wood and ≈16% of all water consumed. Besides that, it is also responsible for about 19% of global emissions of greenhouse gases [1]. This is only at the production and construction phases; if maintenance and end-of-life phases are also considered, the construction sector is responsible for ≈40% of energy produced, ≈30% of raw materials extracted, ≈25% of the production of solid waste, ≈25% of the use of potable water, ≈12% of land use and ≈33% of the emissions of greenhouse gases [2].

Thus, there are numerous ways to intervene and minimize those impacts: from the construction phase, minimizing the use of raw materials; to the use phase, where the energy consumption can be minimized by adopting passive systems to maintain comfort in the buildings; and to the improvement and expansion of the buildings life cycle, and reuse/recycling of materials in the end-of-life phase.

This dissertation focuses on the life cycle of protection products for ETICS (External Thermal Insulation Composite Systems) by considering the finishing layer of ETICS and extra protection products such as water-repellents, biocides, multifunctional and anti-*graffiti*. These products are first sully described and them studied in terms of their environmental impacts using two indicators: Abiotic Depletion Potential (fossil fuels) or ADP(ff); and Global Warming Potential for a 100-year horizon or GWP100a. Besides the environmental study, an economic assessment is also presented in the form of a Present Value Life Cycle Cost (PVLCC).

2. State of the art

The LCA methodology consists in a way to quantify and assess the environmental performance of products and/or services. It allows to compare different products, manufactured in different factories, in different countries, in distinct conditions. It also facilitates the assessment of the processes of manufacture of a product, and allows the environmental optimization of processes, helping the adoption of more efficient manufacture processes. This methodology is normalized by the Institute of Standardization and Normalization (ISO) in the form of the standards ISO14040:2006, ISO14044:2006 and ISO15643:2010-2017 (for the building sector).

The quality of a LCA study depends massively on the data that is possible to collect the production floor, or in databases where generic information of many products is available [3,4].

The Environmental Product Declarations are voluntary type III environmental declarations normalized by ISO 14025:2006 (generic) and EN 15804:2012+A2:2019 (building materials). These documents have the objective of presenting, in a standardized way, all the relevant environmental information of the product they represents.

The ETICS are a system that protects the facades of a building from the outside. Its main purpose is to improve the thermal qualities of a given building, both new or under renovation/reconstruction. It consists in a few overlapping layers, being the last one a finishing layer that protects the inner ones from the weather. With the need to improve the comfort inside the houses, ETICS have the ability to keep constant temperatures throughout the year, in various weather conditions, while reducing the consumption of energy. This solution has gained ground in the last 15 years in Portugal, having passed from 200.000 m^2 in 2006 to 2.400.00 m^2 in 2010 [5,6].

Thus, the study of the service life of this solution, considering the various protection products that exist in the market, is of great importance. This dissertation considers only this last layer, which is, usually, a plastic coating, and, sometimes, a current paint [7,8]. The water-repellent products are, probably, one of the older forms of protection, being water the main agent of degradation of construction [9,10]. This type of protection can be divided in two, according to the medium in which the active ingredient is diluted: water or solvent. The need to diminish the environmental and the health impacts that the solvent based products have in both the environment and animals (including humans) has accelerated the ongoing transition from solvent to water based products.

Another division of the water-repellent products relies on their form of action: film formers and penetrating products. The last can be divided in pore-blockers and impregnating solutions [11–14]. From these, the impregnating solutions are the most common in the market, and are based mostly in silicone resins, like silanes and siloxanes [12,14,15]. These products form an apparent contact angle (APA) of at least 90º, resulting in an added difficulty for the water to adhere to the surfaces [16].

The microorganisms tend to adhere and form colonies in the pores of cement-based mortars, resulting in changes in pH that affect the cement and subsequent layers of protection, and producing stains on the façades that reduce the aesthetic appeal of the building and result in the need for maintenance of these surfaces [17,18]. A problem that the biocidal products have is their toxic nature to animals, which makes this category of product highly regulated by the European Union (EU), namely by ECHA (European Chemicals Agency) [19].

Graffiti are, historically, words, scribblings or drawings made on surfaces in an unauthorized way, through carving or any other mean [20]. Nowadays, *graffiti* are a form of vandalism that consists on drawings made essentially with aerosol paints on any surface, in an indiscriminate way, without any sort of concern about the historical value of the buildings or definitive alterations of the surfaces on which the paint is applied [21–23].

The anti-*graffiti* products can be divided in three categories: sacrificial; semi-permanent and permanent. This categorization takes into consideration the amount of cleaning cycles the protection endures: Sacrificial products are removed with every cleaning cycle, with the *graffiti*, and consist, usually, of a type of wax with hydrophobic and oleophobic properties [21,23,24]; Permanent products resist to a few cleaning cycles (usually more than 10), and have a service life of about 10 years. They mainly consist of epoxy resins, polyurethane, acrylic-siloxane or fluorocarbon copolymers [25,26]; Semi-permanent products can be: a mixture of both permanent and sacrificial products, forming a two-layer system with a permanent base that is coated with a sacrificial one; or a single layer product that has a service life of more than one, but less than three to five, cleaning cycles [21,23,25].

Multifunctional products are defined by their ability to protect a surface from more than one aggressive agent. In this category, this work also considers the self-cleaning products because this ability is linked to the hydrophobicity of the surface [27,28].

The multifunctional products can be categorized as film forming, superhydrophobic or photocatalytic: Film forming products are paints without pigment that can be applied on top of other finishing layers, and that can have hydrophobic, biocidal and even self-cleaning properties; Superhydrophobic products consist of formulations based in silicon resins with improved hydrophobic abilities that facilitate the forming of water beads that roll through the surface, biomimicking the *lotus effect* [27–29]; Photocatalytic products are based in formulations of titanium dioxide (TiO_2) which has the ability to form a hydrophilic surface when exposed to UV radiation and becomes slightly hydrophobic when ceases to receive UV radiation. This mechanism allows TiO_2 to decompose pollutants, when exposed to UV radiation, by the creation of super oxides and hydroperoxide radicals [30–34]. When the surface ceases to receive UV radiation, it becomes hydrophobic, and the water film that was formed with the radiation can drain and drive all the pollutants off the surface [32,35–37].

3. Environmental LCA of protection products

The environmental LCA is a data intensive analysis. So, this work focuses, on a first approach, on gathering as much data as possible from protection products available in the Portuguese market, followed by its organization, so it can be compared in a meaningful way. The referred data was collected from Safety Data Sheets (SDS) and Technical Data Sheets (TDS) for all products considered, as well as from European Technical Assessments (ETA) for the products present in certified ETICS solutions. This data consists in all information about products' consumption rates, dilutions, components, quantities, densities, and all parameters with influence in either the yield or composition of each and every product.

With these products organized in the different categories, with all the meaningful information gathered, it was possible to verify that the quantity and quality of the information was extremely variable. So, an Information Quality Level (IQL) was developed. This index has into consideration the amount of information, both in the identification of the components and in their proportions in each product, and quality of that information. This index attributes a value on the interval [0, 5], being 0 equal to "no information" and 5 to "complete information".

This step was followed by the normalization of the data gathered. This means that the data was collected in different units, with different presentation formats that vary from producer to producer, and, even within the same producer, vary from product to product (e.g. from different units in the consumption rate to various dilutions and number of coats to apply). All these characteristics were consolidated into a whole consumption rate in kilograms per square meter [kg/m^2].

After the collection of all available data, mainly about the components and their proportions, the next step was the attribution of existing production processes to each component to calculate the impacts in the ADP(ff) and GWP100a indicators. The first stage to do so is the choice of the software and of the environmental impact assessment method, which, in this case, are the SimaPro software and the "CML-IA Baseline V3.05" [38,39], respectively. The processes needed are available in various databases in the SimaPro software.

The next challenge this dissertation encountered was in the attribution of those processes to every component of the products studied. The problem is that not all chemicals and components in the SDS are represented in the database. Therefore, it was the necessary to choose reasonably similar processes by searching for different nomenclatures for each component or, in the worst-case scenario, attributing processes from the same chemical family. For this research, ECHA [19] (for searching the different

CAS - unique number of a given chemical, attributed by the Chemical Abstracts Service) and PubChem [40] databases were used both of which have various nomenclatures for every chemical substance listed, including commercial names.

After this attribution of processes to every single component, the impacts of those processes in the ADP(ff) and GWP100a categories were collected. These impacts, however, are presented in a declared unit – kilogram [kg] – that is not meaningful in the context of this work. As so, the definition of the functional unit is an absolute requirement. The objective of this work is to quantify the environmental and economic impacts in the service life of protection solutions for a ETICS covered wall. So, the functional unit considered is the manufacture of each material to coat a square meter [m^2] of wall. This unit allows the modelling of various protection solutions, providing the grounds for presenting results per square meter of any and all combinations of protection products.

Thus, knowing the consumption rates, the environmental impacts in the declared unit of the components, the proportions of the components in each product, and having defined the functional unit as [m^2], it was possible to: first, calculate the environmental impacts for the products in the declared unit, using the proportions and the impacts gathered for every component in the SimaPro software; and, then, using the density of the products and their whole consumption rate, it was possible to transform the impacts from the declared unit to the functional unit, reaching values of [MJ/m^2] for ADP(ff) and [kg eq CO_2/m^2] for GWP100a.

3.1. Presentation and discussion of results

The products are divided in various categories and, for each category, a representative average product is presented. These representative products are named "Zab", where "Z" means that it is a representative product, created from averaging the characteristics of all the products from the category it represents, and "ab" represents a two digit number that is unique to every single product.

3.1.1. Hydrophobic protection

The hydrophobic products are extensively present in the market and can be divided in two categories: water-based and solvent-based. A third category is also considered, the 100% active ingredient one, but will be later included in the water-based products. The environmental impacts from these two categories are very different, with the solvent-based products presenting impacts in ADP(ff) and GWP100a much higher than the water-based ones. In Table 1, the environmental impacts of the representative products are presented.

Table 1 - Environmental impacts of the representative average hydrophobic products

Product	ADP(ff)	GWP100a
	[MJ/m^2]	[kg eq CO_2/m^2]
Z01[HF]	4.168	0.384
Z02[HF]	29.946	1.067
Z10[HF]	14.510	1.480
Z03[HF]	17.244	0.819

The products listed in Table 1 represent the following categories:

- Z01[HF] – water-based hydrophobic products;
- Z02[HF] – solvent-based hydrophobic products;
- Z10[HF] – 100% active ingredient products;
- Z03[HF] – average from all hydrophobic products.

In the next step, the impact of the different components was determined, allowing the construction of Table 2 that presents the most relevant components of the water-based hydrophobic products studied in terms of environmental impact and of their proportion in the final product.

As easily observed, water is the main component in kilogram per kilogram of product, however, its environmental impact is irrelevant, being, in average, 0.1%. On the contrary, silicone-based products, that constitute the active ingredient in hydrophobic emulsions, despite representing about 10% in average of the components of each product, are responsible for, in average, more than 85% of environmental impacts in ADP(ff) and GWP100a.

Table 2 - Average contribution of the most relevant components per water-based hydrophobic product

Components		ADP(ff)	GWP100a
Description	**Average %**	[MJ/kg]	[kg eq CO_2/kg]
Silane	8.37%	90.2%	90.4%
Siloxane	9.03%	86.5%	86.0%
Silicone	11.67%	97.9%	98.5%
Water	90.26%	0.1%	0.1%

In the case of the solvent-based products, the number of relevant components is higher, not only because there are different types of solvents, but also because there are more active ingredients soluble in solvent than in water. In Table 3, the components with their average proportion in the final products, and their relative impacts, are presented.

Table 3 - Average contribution of the most relevant components per solvent-based hydrophobic product

Components		ADP(ff)	GWP100a	Components		ADP(ff)	GWP100a
Description	**Average %**	[MJ/kg]	[kg eq CO_2/kg]	**Description**	**Average %**	[MJ/kg]	[kg eq CO_2/kg]
Silane	10.6%	10.1%	26.5%	**Solvent**	51.4%	61.5%	41.0%
Siloxane	8.3%	19.6%	48.8%	**Ethanol**	75.0%	69.4%	77.6%
Silicone	21.4%	25.0%	38.8%	**White spirits**	76.3%	69.5%	26.9%
Acrylic Resin	43.0%	44.3%	70.0%	**Naphtha**	86.7%	82.5%	45.2%
Hydro-oil	3.4%	5.8%	22.2%	**Kerosene**	60.0%	47.5%	12.7%

In this case, the environmental impacts contribution is more balanced between the active ingredients and the solvent base.

3.1.2. Biocidal products

The biocidal products are available in market in the form of additives that should be added to paints to give them the biocidal properties. Table 4 presents the representative average products for the biocidal additives.

Table 4 - Environmental impacts of the representative average biocidal additives

Product	ADP(ff)	GWP100a
	[MJ/m^2]	[kg eq CO_2/m^2]
Z04[BC]_A	0.171	0.013
Z04[BC]_B	0.509	0.040

There are two Z04[BC] products because the average of the impacts was calculated in different ways. In the first one, the average environmental impact was calculated using the final values of the four additives considered, directly, considering an average paint consumption rate of 1,04 l/m^2. For Z04[BC]_B, the value for the environmental impacts was calculated for the same four products, but first in the declared unit and then transformed to the functional unit considering the consumption rate of the paint in which they will be incorporated. The Z04[BC]_A should be used for a representation without a specific paint to add the biocide, and Z04[BC]_B should be considered when it is needed to add the representative average biocide to a specific paint, so that the impacts of the biocidal additive consider the specific properties of the paint (this will be important in the subsequent sections).

In Table 5, the average environmental impacts are presented in relation to their proportion in each product. In this case, as in the water-based hydrophobic products, the water, despite representing, in average, more than 80% of the product, has an environmental impact inferior to 0,5%. On the contrary, the biocidal agents, despite being incorporated in low percentages in the final product, represent higher environmental impacts, like DCOIT, that in average represents about 2.5% of the proportion of the product, but is responsible for more than 68% of the impacts in ADP(ff) and GWP100a.

Table 5 - Average component proportion in biocidal additives related to the average environmental impacts

Components		ADP(ff)	GWP100a	Components		ADP(ff)	GWP100a
Description	**Average %**	[MJ/kg]	[kg eq CO_2/kg]	**Description**	**Average %**	[MJ/kg]	[kg eq CO_2/kg]
IPBC	0.7%	37.0%	40.0%	**Zinc oxide**	2.9%	26.1%	26.6%
DCOIT	2.5%	75.2%	68.3%	**Propane-2-Ol**	2.5%	99.7%	99.3%
Terbutrine	1.0%	65.0%	64.4%	**Diuron ISO**	10.0%	82.3%	82.3%
Water	81.9%	0.4%	0.5%				

3.1.3. Anti-*graffiti*

In the case of the anti-*graffiti* products, the number of products in the Portuguese market is very small, and the information disclosed by the producers is quite low. Therefore, the number of products with a IQL equal or superior to three is only of five, three of which are permanent, one being sacrificial and the last semi-permanent, as presented in Table 6.

Table 6 - Commercial and representative average anti-*graffiti* products

Product	ADP(ff)	GWP100a	Type	Service life		IQL
	[MJ/m^2]	[kg eq CO_2/m^2]		Years	Cleaning cycles	
C01[AG]	0.497	0.051	Semi-permanent	NA	1	3
C02[AG]	4.453	3.961	Permanent	5	NA	4
F03[AG]	12.264	1.112	Permanent	NA	<7	4
L04[AG]	42.091	1.149	Permanent	NA	>20	3
Q08[AG]	8.076	0.116	Sacrificial	5	1	4
Z06[AG]	19.603	2.074	Permanent	NA	NA	NA
Z07[AG]	13.476	1.278	NA	NA	NA	NA

Z06[AG] represents the average of the three permanent products and Z07[AG] represents the average of all anti-*graffiti* products, regardless of the type.

In these products, there is not a common ground in terms of active ingredients, as it is observable in Table 7 where the main components of all anti-*graffiti* products are presented. These main components are those that either represent a high proportion of the formulation of the product or are responsible for a large part of its environmental impacts. In this case, it is important to take into consideration the IQL, that is between 3 and 4 for all products. As this is a relative mean of measuring the quality of information, and the full information of these products is not disclosed (for any of them), it is difficult to accept these results with a reasonable margin of safety. The best results are the ones of the permanent products, both due to their IQL index and for the fact that three products are accounted for, therefore some error is eliminated in averaging these three products into Z06[AG]. The sacrificial product, Q08[AG], being a wax, its formulation of 40% ME wax and 60% water is reasonable and will be considered in the next steps of this study. The semi-permanent product, given its IQL of 3 and its lower-than-expected environmental impacts, will not be considered any further.

In the Table 7 are represented a permanent product (F03[AG]) and a sacrificial one (Q08[AG]), with their most impactful ingredients in both percentage of weight in the finished product, and in environmental impacts.

Table 7 - Main components of the anti-*graffiti* products

Product	Components		SimaPro process	ADP(ff)	GWP100a
	Description	%		%	%
F03[AG]	Silsesquioxanes	25.0%	Polydimethylsiloxane {GLO}	86.7%	93.2%
	Water	61.7%	Tap water {RER}	0.0%	0.0%
Q08[AG]	Wax ME	40.0%	Paraffin {GLO}	100.0%	99.9%
	Water	60.0%	Tap water {RER}	0.2%	0.0%
Only the SimaPro process prefix is presented, but all processes are followed by "| market for | Cut-off, S"					

3.1.4. Multifunctional products

The multifunctional products, as the anti-*graffiti* ones, are a small category, with only a few products in market. However, in this case, the small number of products can be attributed to the relatively recent developments of these products, especially in biomimicking the *lotus effect* (which requires nanotechnology developments, that are recent, to create the nano-structures needed to create the super-hydrophobicity that provides the self-cleaning ability), and to the photocatalytic products, which are also very reliant on nanotechnology. In Table 8, all studied multifunctional products are presented.

Table 8 - Commercial and representative average multifunctional products

Product	ADP(ff)	GWP100a	IQL	Type
	[MJ/m^2]	[kg eq CO_2/m^2]		
D20[MF]	17.203	0.614	3	Super-hydrophobic oleophobic
F04[MF]	6.464	0.432	4	Photocatalyst
F05[MF]	6.815	0.422	4	Photocatalyst
H03[MF]	8.949	0.499	4	Film
Z08[MF]	6.639	0.427	-	Photocatalyst

Z08[MF] represents the average between F04[MF] and F05[MF], both of which are photocatalytic products with a TiO_2 base. The film product represents a water-based transparent paint with no pigment added ,which is self-cleaning, hydrophobic and has some biocidal ability. The D20[MF] product is closer to a pure self-cleaning product, however, as discussed, this capability of self-cleaning has the secondary effects of hydrophobicity and of hindering the growth of microorganisms. In Table 9 the main components of every product considered in this study are presented.

Table 9 - Main components of representative multifunctional products

Product	Components		SimaPro process	ADP(fl	GWP100
	Description	%		%	%
D20[MF	Silane	20.0%	Dimethyldichlirosilane {GLO}	20.8%	59.7%
	Solvent	77.0%	Solvent, organic {GLO}	74.8%	33.1%
F04[MF	Ethil silicate	10.0%	Tetraethyl orthosilicate {GLO}	32.3%	27.8%
	Titanium dioxide	20.0%	Titanium dioxide {RER}	46.2%	60.7%
	water	60.0%	Tap water {RER}	0.0%	0.0%
H03[MF	Methil methacrylate	1.9%	Methyl methacrylate {RER}	13.8%	16.3%
	Acrilic resin	9.8%	Methyl acrylate {GLO}	39.4%	32.7%
	Water	78.7%	Tap water {RER}	0.0%	0.0%
Only the SimaPro process prefix is shown above, but all of them are followed by "| market for | Cut-off, C					

As in other products already presented, water-based products, such as the photocatalytic ones, have lower environmental impacts, being the photocatalytic agent (TiO_2) the main contributor to the environmental impacts. In the film product (H03[MF]), the main part of the environmental impact result from two components that represent about 12% of the formulation but that are responsible for more than 40% of both ADP(ff) and GWP100a impacts. In the super-hydrophobic product (D20[MF]), being solvent-based, the environmental impacts of the silane and solvent parts are directly proportional to their proportion on the product.

3.1.5. ETICS finishing layers

In this category, the finishing layers described in the ETA of each ETICS are considered. However, only a few of the certified systems have TDS and SDS available and, among these, only a few provided relevant information in those documents. Adding to that, one specific manufacturer provides solutions with paints that are not mentioned in their certification document. However, that information was considered, but is presented in a different way: finishing layers in ETA have a "[AE]" suffix, while the paints do not present in ETA are presented with the "[TT]" suffix. In Table 10 it is possible to assess the environmental impacts evaluated.

Table 10 - Commercial finishing layers considered in this study, with two control products

Product	ADP(ff)	GWP100a	IQL
	[MJ/m^2]	[kg eq CO_2/m^2]	
H04[TT]	8.265	0.625	5
H05[TT]	11.603	1.064	4
H06[TT]	7.910	0.606	5
A05[AE]	40.811	3.971	3
A06[AE]	40.811	3.971	3
A07[AE]	5.528	0.260	3
H07[AE]	27.232	2.053	5
K01[AE]	104.139	10.143	3
K02[AE]	104.139	10.143	3
K03[AE]	10.829	0.505	3
X01	32.66	1.98	EPD
X08	10.54	0.38	EPD

In this case, it was possible to verify the accuracy of the calculations and approximations needed to reach meaningful results. That verification was made by comparing the results achieved (with the calculation methods used in this work) with the results of the products X01 and X08. These products are paints, not available in the Portuguese market (so they were not considered in this study) but whose manufacturer has a EPD available for consultation, and that document has the values presented above. for ADP(ff) and GWP100a. Their role here is of control products, since EPD is a verified document and these values can be used as a comparation to assess if the values calculated in this work plausible.

The product A05[AE] was considered despite 70.3% of unknow components. This is related to the project in which this dissertation is developing its work. However, the unknown part is, most probably, some kind of filler, like crushed limestone with high volume and low environmental impacts (as observable in the product K01[AE]).

The products with the component copolymer were considered siloxanes because the process for polydimethylsiloxane is one of the more environmental impactful active ingredients, so it was a conservative choice the apply this process.

Table 11 - Main components of some ETICS finishing layers considered in this work

Product	Components		SimaPro Process	ADP(ff)	GWP100a
	Description	%		%	%
H04[TT]	Terbutrin	2.4%	Triazine-compound, unspecified {GLO}	11.5%	10.3%
	Titanium dioxide	24.2%	Titanium dioxide {RER}	53.4%	62.1%
	Water	46.8%	Tap water {RER}	0.0%	0.0%
A05[AE]	Copolymer	10.0%	Polydimethylsiloxane {GLO}	99.2%	99.5%
	Unknown	70.3%	Unknown	0.0%	0.0%
H07[AE]	Terbutrin	2.5%	Triazine-compound, unspecified {GLO}	26.5%	23.8%
	Titanium dioxide	10.0%	Titanium dioxide {RER}	49.2%	57.5%
	Water	27.5%	Tap water {RER}	0.0%	0.0%
K01[AE]	Copolymer	20.0%	Polydimethylsiloxane {GLO}	99.6%	99.7%
	-	65.6%	Limestone, crushed, washed {CH}	0.1%	0.0%
All processes presented above are followed by"| market for | Cut-Off, S"					

4. Economic and environmental analysis – case-studies

In this part of this work, the solutions studied from an environmental point of view for a singular application will be studied for an average service life of an ETICS.

It was determined, based on the ETAG 004 [7] and on other literature [41,42], that an reasonable average value for the service life of an ETICS solution is 30 years [41]. The next challenge is the determination of the service life of each protection product and of their effect in the service life and maintenance of ETICS. As this information does not exist, a “worst case scenario approach” was considered. This means that, from now on, the service life values indicated by the manufacturers will be considered for all products and, after that interval of time, a new coating will be necessary. These values are presented in Table 12 for the products that will be considered in the case-studies.

Table 12 - Relevant data for the products considered in the case-studies

Type	Product	Cost	Service life	ADP(ff)	GWP100a
		[€/m^2]	[years]	[MJ/m^2]	[kg eq CO_2/m^2]
ETICS finishing layer	A05[AE]	8.87	10	40.81	3.97
	A06[AE]	9.11	10	40.81	3.97
	ZA0[AE]	8.99	10	40.81	3.97
Biocide	A03[BC]	48.49*	5	3.72*	0.24*
Water-repellent	A01[HF]	3.14	5	2.51	0.25
Multifunctional	F04[MF]	5.00	10	6.46	0.43
Anti-*graffiti*	F03[AG]	5.00	5	12.26	1.11
*** - Values for a ZA0[AE] consumption rate of 1.3 l/m^2**					

The ZA0[AE] product represents the average of A05[AE] and A06[AE]. In terms of economic assessments, a LCC will be considered, specifically: a fixed cost approach, in which the inflation rate is not considered; an actualization of values from the future to the present having in consideration a secure investment rate [43,44] in this case, certificates of the Portuguese treasury with an average rate of 1,38% [45]. The maintenance plans are shown with the planned interventions in 5-year increments until the end of life (EoL) of the ETICS. The solutions S01_2 (Min) and S01_2 (Max) are border solutions and represent the best and worst case scenarios, respectively. The solution S01_1 is the one to compare to S02 and S03.

In the Table 13, all the considered solutions are presented. In each year is defined the amount of product to apply, per square meter.

Table 13 - Maintenance solutions considered

Solution	Product	Year 0	5	10	15	20	25	30
		%	%	%	%	%	%	
S01_1	ZA0[AE]	100%	0%	50%	0%	50%	0%	EoL
S01_2 (Min)	ZA0[AE]	100%	0%	25%	0%	25%	0%	EoL
S01_2 (Max)	ZA0[AE]	100%	0%	100%	0%	100%	0%	EoL
S02	ZA0[AE]	95%	0%	0%	0%	0%	0%	EoL
	A03[BC]	5%	0%	0%	0%	0%	0%	
	A01[HF]	100%	100%	100%	100%	100%	100%	
S03	ZA0[AE]	100%	0%	0%	0%	0%	0%	EoL
	F04[MF]	100%	0%	100%	0%	100%	0%	
S04	ZA0[AE]	100%	0%	0%	0%	0%	0%	EoL
	F03[AG]	100%	100%	100%	100%	100%	100%	

In Table 14, the results for the LCA and LCC are presented. These results consider the maintenance plans from and the environmental impacts calculated before, and the LCC achieved with the calculations methods already described.

Table 14 - Results for the environmental LCA and LCC

Solution	PVLCC	ADP(ff)	GWP100a
	[€/m^2]	[MJ/m^2]	[kg eq CO_2/m^2]
S01_2 (Min)	12.66 €	61.22	5.96
S01_2 (Max)	23.66 €	122.43	11.91
S01_1	16.33 €	81.62	7.94
S02	26.95 €	53.99	5.27
S03	22.15 €	60.20	5.27
S04	34.44 €	114.40	10.64

Despite reaching values that can be considered reasonable, as so the maintenance interventions, a final decision is still not obvious. So, in order to facilitate a possible decision, a multicriteria analysis is needed.

This multicriteria analysis only compares the various solutions between themselves, with the exception of S04, which is the anti-*graffiti* one, and that ,obviously, does not compete with the other solutions in regards to function.

The multicriteria analysis consists in the attribution of weights to the environmental indicators vs the economic indicator. It is considered that the environmental indicators always have the same weight, because, throughout this work, it was observed that ADP(ff) and GWP100a have some level of correlation. Therefore, for bad environmental solutions, both go up, and, in good environmental solutions, both decrease. Thus, it is considered here that the environmental weight is a function of the economical weight, and that the ADP(ff) weight is equal to the GWP100a weight, and both are equal to half of the environmental weight. First, the values reached in Table 14 are normalized into Table 15.

Table 15 - Normalized results for the solutions

Solution	PVLCC	ADP(ff)	GWP100a	Sum	Normalization
S01_2 (Min)	1.00	0.89	0.90	2.79	0.93
S01_1	0.74	0.60	0.60	1.94	0.65
S01_2 (Máx)	0.23	0.00	0.00	0.23	0.08
S02	0.00	1.00	1.00	2.00	0.67
S03	0.34	0.91	1.00	2.24	0.75

With the normalized results, it was then possible to attribute weights to the three indicators considered in this study, and see how the variation of the weights of the environmental and economic parts influence the best solution, as observed in Table 16. S01_2 solutions were ignored as these are not "real" but border solutions, best and worst-case scenarios. Therefore, the average S01_1 solution was considered, but the other two were valuable to define the spectrum of possibilities in which the values vary. Therefore, three products remain and, all of them, for some combinations of weights, are the best solution. S01_1 is the best solution in terms of cost effectiveness, from the point where cost is all that matters to a 50%-50% split between the weight of the economic and environmental indicators. The S03 solution is never the worst solution, and it is the best one when the PVLCC weight is in the [0,2; 0,4] interval and the environmental weight is in the [0,6; 0,8] interval. However, this solution is close to the first one in the [0,0; 0,5] interval, regarding the PVLCC weight. The S02 solution is the worst in terms of cost, but the best environmentally, being the best solution when the weight of the environmental indicator reaches the interval [0,9; 1,0].

Table 16 - Effect of the variation of the economic weight vs the environmental weight

Weight PVLCC	1.00	0.90	0.80	0.70	0.60	0.50	0.40	0.30	0.20	0.10	0.00
Weight ADP(ff)	0.00	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
Weight GWP100a	0.00	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
S01_2 (Min)	1.00	0.99	0.98	0.97	0.96	0.95	0.94	0.93	0.92	0.91	0.90
S01_2 (Max)	0.23	0.21	0.18	0.16	0.14	0.11	0.09	0.07	0.05	0.02	0.00
S01_1	0.74	0.73	0.71	0.70	0.68	0.67	0.66	0.64	0.63	0.61	0.60
S02	0.00	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
S03	0.34	0.40	0.46	0.52	0.58	0.65	0.71	0.77	0.83	0.89	0.95
Colour code	(green)	Best solution (without S01_2)					(blue)	Average solution (without S01_2)			
	(orange)	Worst solution (without S01_2)					(grey)	Limit solutions (S01_2)			

5. Conclusions

The quality of information is critical in any work of this kind, so developments in the Information Quality Level are fundamental to find better and more pragmatic ways to sift information to reach meaningful results. This work tried to establish a ground base with a pragmatic set of rules/advices to categorize information but the highly variable formats of information, the inconstant quantities of information that are presented by the manufacturers, and the unprecise way in which information is presented are, in themselves, challenges to studies of this type. Even though, in this study, sometimes the IQL had to be re-engineered so that the sift was not so tight that hardly any product could satisfy its requirements, nor so wide that products with barely any information would be considered.

The biocidal products, despite of their potential toxicity, have a very small impact on the ADP(ff) and GWP100a environmental indicators. There are two reasons for this result: first, these substances are highly regulated by ECHA, which controls the amount of biocidal ingredients that can be incorporated; second, the biocidal additives are used in small proportions, that vary from 1,25% to 10%. So, biocidal products need to be studied in terms of their impact on the environment using other categories, particularly in terms of the toxicity of their leaching.

The multifunctional products, despite being present in the market, are still a relatively new class of products, so lacks variety of solutions and long-term studies that consider the exposure to the elements, their durability in harsh conditions, and other factors that contribute to their success or demise as a protection product in the building sector.

The environmental impacts of the anti-*graffiti* products are highly dependent on the number of cleaning cycles that are expected. Applying a sacrificial product in an area prone to vandalism will result in very high environmental and economic impacts because the protection layer must be reapplied after each cleaning cycle. In these products, the service life is important, but the recurrence of cleaning cycles is probably more important as a decision factor.

In terms of choice of an optimal solution, the requirements of the owner are what defines the best solution. The variation of the weight of the economic indicator vs. the environmental indicator showed three different "best" solutions for different combinations of weights, with only three solutions to choose from. If more solutions were studied, most likely, more "best" solutions would have been encountered. So, the definition of objectives is pivotal on getting the best possible solution for the challenges at hand. Thus, defining the right indicators, and the weight of each, is of the most importance in translating this work to real life scenarios. After that, better information is necessary: manufacturers have to disclose more information about the components of their products; or, more likely, the manufacturers have to start providing EPD with all the relevant environmental information that is needed for an informed and pragmatic decision.

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