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Environmental Product Declarations and Effects of Scope of Consideration on Results of Life Cycle Assessments: Sample Analyses for the Case of Pavement Design Using Geogrid

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Abstract

An Environmental Product Declaration (EPD) is defined as a declaration that "quantifies environmental information on the life cycle of a product to enable comparisons between products fulfilling the same function." The use of EPDs to assess environmental impacts is growing rapidly, including in the construction industry.

When conducting Life Cycle Assessments (LCAs) for construction projects, alternative design approaches often involve the substitution of products from different categories to achieve the desired result. In this scenario, an analysis which simply compares the EPDs of the alternative products may yield flawed results, because the differing design approaches will have effects which extend beyond the products themselves. To capture a true comparison of the environmental impacts, the scope of consideration for the LCAs must extend beyond the EPDs and account for all impacts resulting from each design approach.

This paper will demonstrate the importance of adopting a proper scope of consideration for LCAs using the example of a flexible pavement with alternative designs using a conventional approach and a mechanically stabilized aggregate layer for enhanced performance. Sample analyses will be presented showing the effects of the scope of consideration, and the sensitivity of the results to the variables considered. The objective of the study is to highlight key considerations for accurate LCAs, the importance of establishing standard factors and approaches, and the necessity of a comprehensive approach.

Keywords: Environmental Product Declaration, Life Cycle Assessment, sustainability, resilience, pavement

1. Introduction

An assessment of environmental impact is becoming a more common design criterion in a growing number of jurisdictions around the world. In an effort to standardize and streamline such assessments, processes have been developed to systematically determine and report the environmental impacts of the production and use of many products and materials. One of the tools created for this purpose is the Environmental Product Declaration (EPD). An EPD is defined as a declaration that "quantifies environmental information on the life cycle of a product to enable comparisons between products fulfilling the same function." (ISO, 2006) The use of EPDs to assess environmental impacts such as Global Warming Potential (GWP) is growing rapidly, including in the construction industry.

When conducting Life Cycle Assessments (LCAs) for construction projects, the objective of reducing environmental impact may require the consideration of multiple designs. Alternative design approaches often involve the substitution of products from different categories to achieve the desired result. In this scenario, an analysis which simply compares the EPDs of the alternative products may yield flawed results, because the differing design approaches will have effects which extend beyond the products themselves. To capture a true comparison of the environmental impacts, the scope of consideration for the LCAs must extend beyond the EPDs and account for all impacts resulting from each design approach.

This paper will demonstrate the importance of adopting a proper scope of consideration for LCAs using the example of a flexible pavement with alternative designs using a conventional approach and a mechanically stabilized aggregate layer for enhanced performance. The pavement section alternatives will be evaluated using the 1993 empirical methodology of the American Association of State Highway and Transportation Officials (AASHTO). The analysis presented here considers hypothetical examples for the purpose of illustrating how design decisions can impact environmental assessments.

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LCAs, the importance of establishing standard factors and approaches, and the necessity of a comprehensive approach.

2. Pavement Design Background

2.1 Design Methodology Used in Analysis

For this analysis, the design methodology used is the 1993 empirical design formula published by the American Association of State Highway and Transportation Officials (AASHTO) (AASHTO, 1993). For the enhanced design using mechanical stabilization of the aggregate layer, additional guidance provided by AASHTO in Publication R 50-09 (AASHTO, 2009) is also followed. A comprehensive explanation of the proper design of both conventional pavements and pavements incorporating a mechanically stabilized aggregate layer is complex, and is beyond the scope of this paper. The concepts illustrated here regarding the importance of adopting an appropriate scope of consideration for sustainability analyses are independent of both the design method used and the structure to be built. Methodology is noted simply to assure the reader that the examples chosen are realistic.

2.2 Quantification and Application of Geogrid Stabilization Benefit

In the AASHTO 1993 empirical design formula (Equation 1 below), the predicted pavement life is a function of the structural number (SN), serviceability limits, and reliability. Pavement life using a geogrid is calculated from an enhanced SN based on the increased stiffness of the mechanically stabilized layer (MSL). The “a” value of the geogrid stabilized MSL is the key component of the enhanced SN value (Equation 2) that is calculated for the pavement section.

The “a” value is representative of aggregate quality and degree of enhanced confinement achieved with a particular geogrid. Calibration and validation of this “a” value must be performed with an extensive catalogue of pavement structures (layer thicknesses & material types), subgrade conditions, and performance data. Algorithms that are based on the “a” value calibrations have been created and incorporated into the design methodology. The software used for this analysis is Tensar+ (Tensar, 2022), which follows this methodology. The program automatically assigns the proper calibrated “a” value to the MSL for the user-defined input conditions, and uses the assigned layer coefficient in the AASHTO design analysis.

$$\log_{10}(W_{18}) = Z_R S_o + 9.36\log_{10}(SN+1) - 0.20 + \frac{\log_{10}\left[\frac{\Delta PSI}{4.2-1.5}\right]}{0.40+\frac{1094}{(SN+1)^{5.19}}} + 2.32\log_{10} M_R - 8.07 \quad \text{(Equation 1)}$$

Where:

W_{18} = predicted number of 80 kN (18,000 lb.) Equivalent Single Axle Loads (ESALs)

Z_R = standard normal deviate

S_0 = combined standard error of the traffic prediction and performance prediction

ΔPSI = difference between the design initial serviceability index and the design terminal serviceability index

M_R = subgrade resilient modulus in pounds per square inch

$SN = a_1D_1 + a_2D_2m_2 + a_3D_3m_3$ (Equation 2)

Where:

a_i = layer coefficients representative of surface, and aggregate base courses

D_i = actual thickness (in inches) of surface, and aggregate base courses

m_i = drainage coefficient for aggregate base course

Layer coefficients presented in the AASHTO 1993 Design Manual for pavement materials are empirically derived correlations to material properties. As such, the layer coefficient is a measure of the relative ability of the material to function as a structural component within the pavement. The use of enhanced layer coefficients for MSLs is consistent with this approach. It is important to note that the new increased layer coefficient is not a reflection of the aggregate material alone, but is adjusted to account for the improved long-term performance due to inclusion of the geogrid, yielding a stiffened composite of aggregate and geogrid. In addition, current AASHTO correlations for the resilient modulus of a granular base layer and its layer coefficient are not valid for a composite material that consists of granular aggregate material and a stabilization geogrid.

Because of increased contact forces and stresses around the geogrid resulting from efficient aggregate confinement, stiffness compared to the unbound aggregate increases significantly and improves overall pavement performance. This increase in, *and retention of*, stiffness results in a reduction in the amount of rutting and increased fatigue life of the pavement.

As illustrated in the example below, the performance benefit from the incorporation of the MSL may be used by the designer to achieve multiple objectives. Before sustainability became a design consideration, the performance benefit would typically be used to either reduce the cost of the pavement, extend its design life, or some combination of the two. With the addition of Life Cycle Analyses on sustainability criteria, this design approach also provides the opportunity to optimize the design based on carbon footprint, if the analysis is properly conducted.

3. Example Demonstrating the Effects of Scope of Consideration for Alternative Pavement Designs

To demonstrate the effects of the scope of consideration on the results of a sustainability Life Cycle Assessment (LCA), the example of a typical asphalt pavement with a width of ten (10) meters and a length of one (1) kilometer (km) is considered. Figure 1 shows the pavement section to be evaluated.

Figure 1: Asphalt Pavement Section.

As discussed in Section 2, the pavement designer might decide to add a geogrid to the pavement section to stabilize the aggregate layer and thereby increase the traffic capacity of the pavement. If the designer is required to evaluate the GWP of the project, he or she would likely consult the EPD for the geogrid. If all other factors are held constant, the scope of consideration for the analysis would include only the geogrid, and its addition would result in an increase in GWP due to emissions from its production and transportation to the project site.

Restricting the scope of consideration to the product alone is a valid approach when the evaluation consists only of deciding between interchangeable products. Most EPDs are written to support this case, especially those for consumer products. But an accurate analysis for engineering and construction decisions may be significantly more complex, because design changes usually involve multiple materials and products. A pavement design using an MSL instead of a conventional unbound aggregate layer is one such case.

To accurately evaluate the GWP of a conventional pavement design as compared to a design using an MSL, it is necessary to compare the entire structure for each alternative. Each of the materials used in the pavement structure has an environmental impact, and each contributes to the traffic capacity of the structure. The designer must therefore match the scope of consideration for the LCA to the scope of the design.

In this case, the designer has multiple options for making use of the performance benefit provided by the geogrid in the MSL design. The following analysis demonstrates how these options affect the environmental impact of the design as a whole in terms of embodied carbon emissions.

For this analysis, a simplified calculation of embodied CO_2 equivalent ($kgCO_2e$) for the pavement structure at the completion of construction is used in lieu of a full evaluation of GWP or a more detailed LCA. For the geogrid, the Product and Construction Process Stages (A1 – A5) from the EPD are used.

A more detailed analysis would require numerous additional inputs (e.g., traffic data) which would result in complexity beyond the scope of this analysis. Nonetheless, the analysis presented demonstrates the premise which is considered here. A qualitative discussion of factors impacting a more detailed analysis is presented below.

Based on typical values and assumptions as presented in Table 1, the embodied CO_2 equivalent is calculated as the sum of

- The embodied carbon within the construction materials at their respective "factory gates"
- Emissions related to delivery of materials to the site
- Completion of construction of the pavement

The distances to the project site from the aggregate quarry, the asphalt plant, and the geogrid manufacturing plant are all assumed to be 50 km. The analysis was conducted using Tensar Plus software, supplemented by additional references to estimate the embodied carbon of the asphalt cement concrete portion of the pavement. The embodied carbon of each design component will vary somewhat depending on the specifics of the project location and material sources. The values here are assumed to be typical. A precise LCA for any project would require more detailed evaluation of each of the material and energy inputs.

Table 1: Unit Values for Embodied Carbon, $kgCO_2e$.

Item	Value	Units
Aggregate	0.00438	$kgCO_2e/kg$
Asphalt Cement Concrete	0.062	$kgCO_2e/kg$
Stabilization Geogrid	0.66385	$kgCO_2e/m^2$
Material Compaction	5.35	$kgCO_2/m^3$
Transport by Road	62	gCO_2/tonne-km

Table 2 summarizes the design parameters used for the determination of the traffic capacities of the pavement sections.

Table 2: Pavement Design Parameters for Evaluated Sections.

AASHTO 1993 Design Parameter	Value
Asphalt Layer Coefficient	0.42
Unbound Aggregate Layer Coefficient	0.14
Initial Serviceability	4.2
Terminal Serviceability	2.0
Aggregate Drainage Factor	1.0
Reliability	95%
Standard Deviation	0.49

The calculated traffic capacity of the conventional pavement section as shown in Figure 1, using AASHTO 1993 methodology, is 513,300 Equivalent Single Axle Loads (ESALs). The embodied carbon of the structure using the assumptions above is 228,280 kgCO_2e.

Two design alternative pavement sections using an MSL illustrate how embodied carbon values are affected by the entire pavement structure, instead of just the addition of a geogrid. These alternatives are shown in Figure 2.

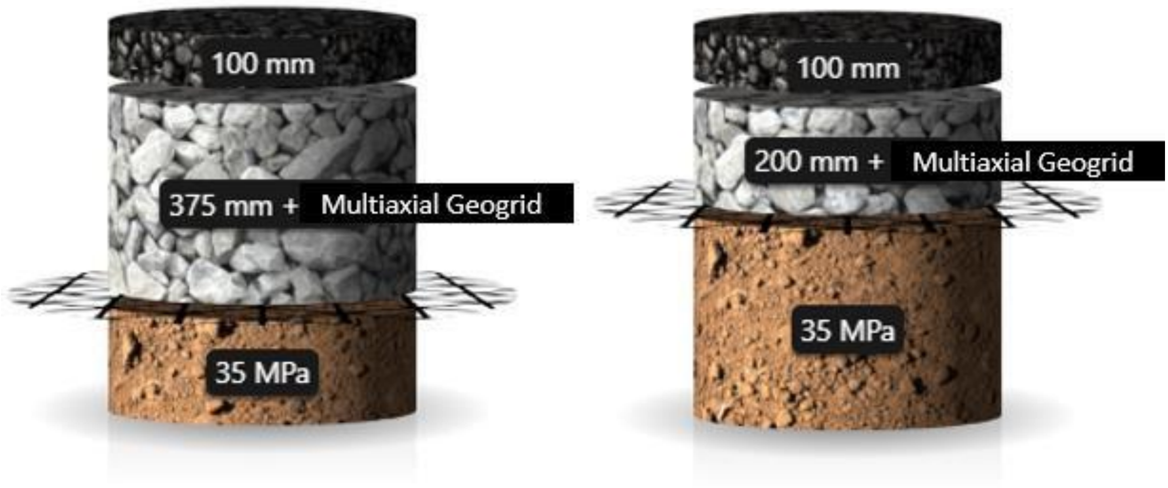

Figure 2: Alternative Pavement Sections Using an MSL.

The first alternative section uses the same aggregate thickness as the conventional design, but with a geogrid added to create an MSL. As discussed above, this results in a very small increase (2.9%) in the embodied carbon of the pavement structure, to 234,918 kgCO_2e. However it also increases the traffic capacity of the pavement more than sevenfold, to 3,817,300 ESALs.

The second alternative section uses a reduced aggregate thickness in the MSL, taking full advantage of the performance enhancement provided by the geogrid. This section delivers traffic capacity of 597,000 ESALs, which is roughly equal to the conventional section. But because of the significant reduction in aggregate required, the embodied carbon of this design is much lower than that of the conventional section. Using the same assumptions as before, the embodied carbon is reduced to 196,758 kgCO_2e (13.9% reduction).

Traffic capacities and embodied carbon values for each of the pavement sections are summarized in Table 3.

Table 3: Calculated Traffic Capacities and Embodied Carbon for Evaluated Pavement Sections.

Pavement Section	Calculated Traffic Capacity (ESALs)	Embodied Carbon (kgCO_2e)
Conventional Design, 100mm / 375 mm	513,300	228,280
MSL Design, 100 mm / 375 mm	3,817,300	234,918
MSL Design, 100 mm / 200 mm	597,000	196,758

4. Conclusions

The analysis of alternate pavement sections clearly demonstrates the importance of using the appropriate scope of consideration when evaluating environmental impacts. If the alternatives with equivalent traffic capacity are evaluated solely based on the embodied carbon reflected on the EPD for the geogrid added to the design, the result would be an inaccurate comparison. Even if the environmental impacts of the entire project are correctly calculated separately, the failure to consider design alternatives on an equivalent basis will yield results which are not optimized.

The pavement section using an MSL design without a reduction in aggregate thickness demonstrates an additional aspect to be considered beyond the limited analysis presented here: depending on the density of the traffic loading for the road, the increase in traffic capacity will translate into an extension of the time period between maintenance events, which will result in additional environmental benefit. A more complete LCA for the project, with a cradle-to-grave system boundary, should take this into account.

It should also be noted that the specific case of a flexible pavement section with a geogrid stabilized aggregate layer includes materials whose GWP and other impacts varies across the complete life cycle of the project. For example, asphalt cement concrete and aggregate base material are likely to be at least partially recycled at the end of the project's life, while geogrid is more likely to be left in place or disposed of in a landfill. This factor would be extremely unlikely to change the design decision to use an MSL, due to the large difference between the GWP of the geogrid and that of the conventional materials, but a comprehensive LCA would quantify such considerations and allow a more precise analysis.

It should also be noted that civil engineering design and construction are categorically different from most areas where the analysis of GWP and other environmental impacts are applied, in that the consequences of a failure are potentially catastrophic. The incorporation of environmental analysis in design must include the proper understanding and assessment of the relative risks involved. The first responsibility in civil engineering and construction must be to the safety and well-being of the public who will be directly affected by the project. Consideration of more diffuse risks with lower levels of certainty must come on top of, not in lieu of, good engineering and construction practice.

When comparing the environmental impacts of alternative designs, the scope of consideration for the analysis should match the scope of the designs: in other words, the designer should conduct the environmental analysis such that the material and energy inputs encompass all the parameters which are included in the design analysis. There are many instances where the same design objective may be achieved using completely different approaches. Matching the scope of consideration for environmental impacts to the design scope is necessary to ensure that all the complexities of the designs are fully captured.

The principle demonstrated here is broadly applicable to the analysis of alternative designs, materials, and products in all types of construction. As processes for the assessment of environmental impacts continue to evolve, it will be critical for both the engineering community and governing agencies to ensure that these analyses are conducted in a technically sound manner, including an appropriate scope of consideration.

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