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EXECUTIVE SUMMARY OF THE THESIS

Environmental Impact of EPAL Pallets: A Comparative LCA of Standard Pallet Exchange and the Nolpal System.

TESI MAGISTRALE IN MATERIALS ENGINEERING AND NANOTECHNOLOGY – INGEGNERIA DEI MATERIALI E DELLE NANOTECNOLOGIE

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1. Introduction

Since their invention, pallets have occupied a crucial role in industrial applications. Driven by global industrial expansion, their production and usage are projected to grow by over 4% annually through 2028, according to data from Freedonia World Pallets [1]. Nevertheless, this growth entails rising environmental impacts and costs at every stage of the life cycle, particularly from transport emissions between producers and customers.

To reduce these impacts, it is necessary to adopt new, more sustainable management systems of pallets worldwide. A possible solution that addresses this challenge is the management system proposed by the Italian company Nolpal. Nolpal introduces a disruptive nationwide EPAL pallet rental service based on an open pooling system: under this framework, clients lease pallets for distribution, while Nolpal assumes full responsibility for the pallet return process. By leveraging a nationwide network of hubs strategically located near major industrial centers, Nolpal facilitates localized return and repair.

The aim of this thesis is to analyse and compare the environmental impacts of two management strategies: the standard exchange approach and the Nolpal alternative. This evaluation is performed using openLCA software, which models the environmental footprint of pallets from raw material collection to final disposal, generating comparative data on emissions, energy consumption, and costs.

2. Literature review

In response to the need for a new management system to substantially reduce environmental impacts, companies and researchers have begun studying new possibilities at each stage of the pallet life cycle, focusing especially on the transport and use stages of the supply chain.

In their study, Roy et al. [2] presented the current different management systems, underlining the differences, both in costs and impacts, between the standard direct exchange with the rising prevalence of rental/pooling systems.

In this sense, Bengtsson and Logie [3] compared the management systems of pallets made of different materials (hardwood, softwood, plastic and cardboard). The results showed that pooling system is the best option in terms of environmental impacts, especially in the case of wooden pallets.

Chhugani et al. [4] compared transport emissions and energy consumption across different heavy-duty vehicles, providing important information for the LCA assessment of the transport and use stages of pallets.

When it comes to the impact assessment of the full life cycle of pallets, Ipina et al. [5] and Khan et al. [6] presented the most recent studies on the topic. Using an LCA study, they analyzed the impacts across all stages, from the collection of raw materials to the end-of-life of pallets. Results showed that the transport stage is the most detrimental, underscoring once again the need to find new solutions for pallet management.

While numerous studies have been conducted on this topic and many alternatives have been proposed, none represents a definitive solution to the challenge, which remains open to further improvements and possibilities.

3. Case study

Among the various management strategies in the pallet industry, three main systems can be found:

- Single-use system;
- Buy/sell system;
- Pooled system.

The single-use strategy is designed to last only one trip, after which the pallet is typically disposed of via landfill or incineration; this falls outside the scope of our study, since EPAL pallets are designed to last for several trips. The buy/sell system is surely the most common one for long-lasting pallets: in this scenario, the producer sells the pallet to the customer, who can use it and, eventually, resell it.

The last management strategy is the closed-loop or pooling one, which relies on leasing pallets; this is the case of companies like Nolpal, which are heavily focused on increasing the adoption rate of pallet rental systems among transport and logistics firms, shifting the industry away from traditional purchasing models. This transition not only yields an overall reduction in costs but also substantially reduces environmental pollution by lowering greenhouse gas emissions from transport vehicles.

Founded in 2011, Nolpal is an innovative enterprise focused on new management systems for EPAL pallets. The company's key innovation lies in introducing and scaling rental strategies across Italy. Operating through a network of strategically located hubs at major transportation nodes, the company serves as a critical enabler of sustainable logistics. On the one hand, it guarantees high nationwide availability of certified pallets; on the other, it significantly optimizes reverse logistics flows. This strategic positioning minimizes transport distances, allowing companies to achieve significant cost savings by reducing expenditures on empty pallet repositioning, warehousing, inventory management, and structural reconditioning. Such an approach represents a major advancement over the standard management strategy, which traditionally burdens producers with the costs of purchasing their own EPAL pallets, managing their repair, and dealing with storage constraints.
The improvements introduced by Nolpal extend beyond operational management. Given the vast volume of assets handled, the company has integrated an advanced electronic tracking system to monitor the entire lifecycle of its pallets. The implementation of digital vouchers streamlines transaction records, facilitates seamless exchange processes, and enforces strict accountability among supply chain actors. Consequently, this transition from traditional paperwork to a digital framework drastically reduces process lead times while maximizing overall management efficiency [7].

4. Life cycle assessment

The aim of this study is to analyze the environmental impacts of the Nolpal management system and, simultaneously, compare the results with those obtained from the standard direct exchange system. The chosen approach is cradle-to-grave, allowing the study of impacts from all stages of pallets' life cycle. Data for this analysis have been derived from different sources; it is possible to distinguish between:

- **Primary data**: obtained directly from studies conducted by Nolpal and referred to a six-month period of transports and logistic operations.
- **Secondary data**: derived from literature and used to perform the analysis of the production stage and the End-of-Life treatments.

$$= \frac{75000\ \text{kg of product delivered}}{\text{RSL}\left(\text{number of}\ \frac{\text{trips}}{\text{pallet}}\right) \text{x load bearing capacity} \left(\frac{\text{kg}}{\text{trip}}\right)}$$

The FU is defined as "The delivery of 75000 kg of product using wooden pallets". The number of pallets required to fulfil the selected FU has been calculated using the load carrying capacity and reference service life (RSL) of the pallet analysed, defined as the estimated number of trips a pallet can perform before reaching the end-of-life phase [8].
Assuming a maximum load capacity of 1500 kg per trip, the total transport requirement is calculated at 50 trips. Since a single EPAL pallet has an estimated lifespan of 25 trips, two pallets are needed to transport the total product volume.
In the absence of specific data regarding the vehicle class used in pallet logistics, the transportation phase has been modeled assuming diesel-fueled EURO 6 trucks. The study is geographically limited to Italy and accounts for the distribution of Nolpal points.
The boundaries of the assessment are shown in Figure 1.

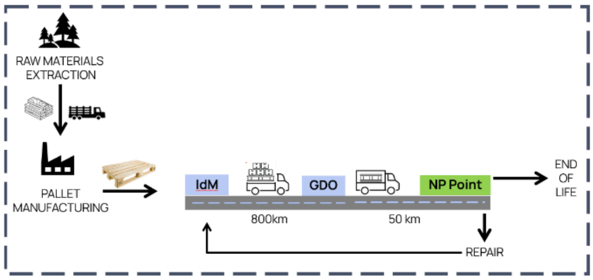

Figure 1: System boundaries

Regarding the production stage, it is divided into three steps:

- **Saw**: wood logs are cut into green lumber.
- **Dry**: green lumber is dried obtaining rough dry lumber.
- **Plane**: the elaboration of lumber to obtain wooden boards for pallets.

As shown in Figure 2, in addition to these steps, a boiler process has been integrated into the system. This stage repurposes sawing by-products to generate the industrial heat required for the drying and planing phases, as well as for the phytosanitary treatments conducted during pallet assembly [9]. The production stage begins with 1343 kg of logs, including bark, which undergo the three processes described above to ultimately yield the "planed dry lumber" required for EPAL pallet assembly. All consumption data, including electrical and thermal energy, have been sourced from previous LCA studies based on pallet manufacturing. [10].

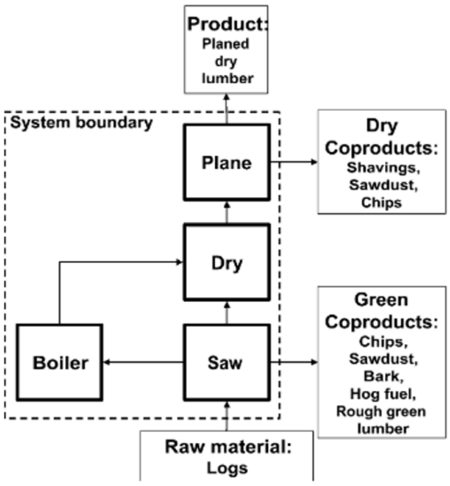

Figure 2: System boundaries for the production stage.

After the production stage and the pallet assembly, the transport and use phase has been modeled for the two possible scenarios. To perform the comparative analysis, all transport distances have been fixed:

- **800 km**: average distance between the trademark industry and the retailer.
- **50 km**: average distance between the retailer and the nearest Nolpal point.

1. Direct exchange without Nolpal

To respect the selected functional unit, a total of 50 delivery trips is required. Given that an EPAL pallet has an average lifespan of 25 trips, two pallets (each weighing 25 kg) are required. The transport modeling considered two distinct phases per trip: a loaded delivery and a recollection of pallets. Consequently, the transport performance has been evaluated at 1000 t*km for loaded pallets and 1000 t*km for empty returns, calculated as 25 kg × 800 km × 25 trips × 2 pallets. Additionally, pallet repair operations, typically required twice per lifecycle, have been accounted for by including two 150 km round trips for each pallet to reach a standard repair facility.

2. Direct exchange with Nolpal

In this scenario, while the initial departure of the loaded carriers from the manufacturer spans the same 800 km, the reverse logistics flow is drastically optimized. After the goods are unloaded at the retailer, the truck carrying the empty pallets is not driven back to the original starting point. Instead, the pallets are delivered to the nearest Nolpal hub, located an average of 50 km away. Furthermore, since pallet reconditioning and maintenance are performed directly at Nolpal facilities, the additional 150 km round trips to external repairers are eliminated entirely.

To conclude the assessment, several end-of-life treatments are assumed and modeled for both scenarios presented. The treatments involved in this study are incineration, landfilling and composting.

5. Results

The assessments have been carried out using the openLCA software, alongside the Ecoinvent 3.11 database, in compliance with the ISO standards 14040 [11] and 14044 [12]. The EF 3.1 characterization method has been used.

After a comprehensive screening across all 25 analysed impact categories, the focus has been shifted directly to the Climate Change indicator to evaluate the environmental implications of these baseline data. This targeted analysis enables a clearer understanding of the drivers of the carbon footprint and the potential mitigation strategies offered by alternative logistics models.

1. Scenario A, without Nolpal

The results of the analysis, presented in Table 1, demonstrate that the transport and use phase represents the most significant contributor to the overall environmental impact, far exceeding both the production and repair stages.

Table 1: Share of impacts without Nolpal system

NO NOLPAL SCENARIO	Production	Transport and use	Repair
Percentage of incidence	5,30%	92,13%	2,56%

This trend confirms the importance of providing solutions that reduce the impacts of pallet logistics, underlining the need of alternatives proposed by companies like Nolpal as well.
Within the Climate Change category, the results, shown in Figure 3, demonstrate that the fossil sub-indicator is the primary driver of the overall score. This dominant weight directly reflects the LCA outcome, as it is strictly driven by fossil-derived emissions from diesel fuel combustion during the transport phase.

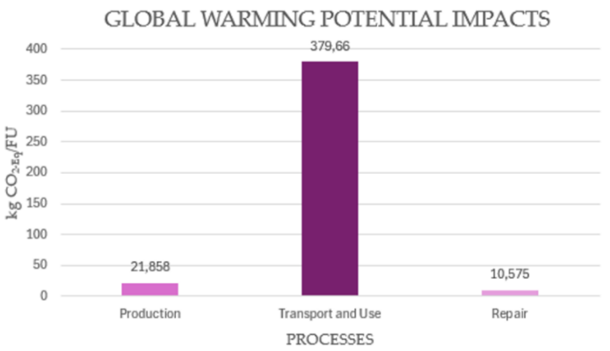

Figure 3: Life cycle stages contributions to climate change without Nolpal

2. Scenario B, Nolpal implementation
Following the baseline scenario assessment, the analysis is extended to evaluate the implementation of the Nolpal pooling alternative. While the overall environmental burden is significantly mitigated, the distribution of impacts across life cycle stages follows a trend similar to that of the standard exchange system. As detailed in Table 2, the transport and use phase remains the predominant contributor, accounting for 88.26% of the total climate change impact.
Nevertheless, the emissions for the use phase in the Nolpal scenario drop to 201.69 kg $CO_{2\text{-}Eq}$ per functional unit.

Table 2: Share of impacts with Nolpal system

NOLPAL SCENARIO	Production	Transport and use	Repair
Percentage of incidence	9,57%	88,26%	2,17%

3. Comparison of the scenarios
As shown in Figure 4, the comparisons highlight a reduction in environmental impacts for the Nolpal alternative. This reduction is due to the reduction in transport distances both for usage and repair of pallets. As previously stated, the scenario involving the implementation of Nolpal method allows a reduction from 379.66 kg $CO_{2\text{-}Eq}$ to 201.69 $CO_{2\text{-}Eq}$, meaning that the emissions of greenhouse gases are reduced by more than 53%. These results in climate change, but also in the others impact categories, confirm that Nolpal provides a system that is, ecologically speaking, significantly better than the standard systems.

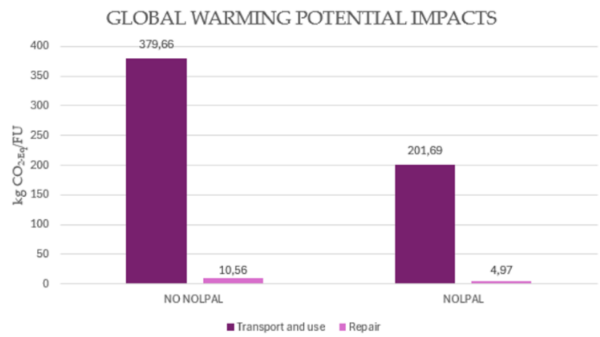

Figure 4: Comparative analysis of the Global Warming Potential for the use and repair phases across both scenarios

4. End-of-Life treatments
To achieve a comprehensive cradle-to-grave assessment, the end-of-life stage has been fully integrated into the overall life cycle model. Specifically, three distinct EoL scenarios are modeled for the pallets: landfilling, incineration, and composting. As illustrated in Figure 5, the results reflect the cumulative Climate Change impacts of the entire life cycle, combining the production, use, repair, and respective EoL phases.

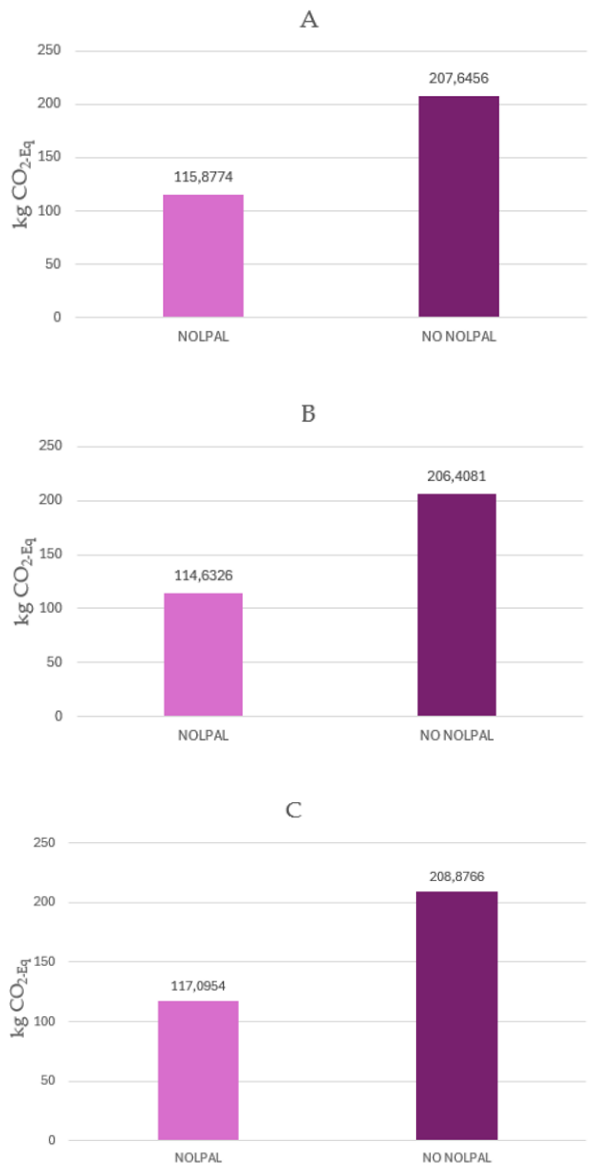

Figure 5: Climate change results for EoL scenarios: A-Landfilling; B-Incineration; C-Composting

The data demonstrates that, regardless of the chosen disposal method, the Nolpal pooling system consistently maintains its structural environmental advantage, preserving the 53% reduction in total greenhouse gas emissions compared to the standard exchange system.

This analysis excludes the recycling pathway due to a lack of representative data. Nevertheless, integrating recycling metrics will be a key improvement to enhance the assessment's completeness. Furthermore, new circular economy strategies could be adopted to decouple economic growth from resource consumption: industrial Symbiosis could be a strategic operational model, where waste streams from one enterprise serve as valuable feedstocks for another.

Conclusions

As global industrialization continues to expand, traditional pallet management systems are becoming economically and logistically unsustainable. For these reasons, the Nolpal company occupies a prominent position within the current logistics landscape, as the first enterprise in Italy to operationalize a comprehensive, decentralized pooling model. Nolpal is a great example that shows how targeted structural optimization can decouple industry and supply chain growth from rising emissions. The strategic deployment of a network of regional Nolpal points represents a comprehensive reconfiguration of the conventional pooling system.
It is important to acknowledge several limitations encountered during the assessment of this case study, notably gaps in the available data that necessitated explicit assumptions to finalize the analysis.
Nevertheless, the comparison between the standard pallet management system and the Nolpal alternative here highlights two key findings. Firstly, transportation and the operational use phase should be prioritized for structural interventions to achieve immediate reductions in greenhouse gas emissions. Secondly, subsequent studies should incorporate advanced end-of-life solutions, with particular emphasis on strategies such as industrial symbiosis, to close material loops.

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