Life Cycle Assessment (LCA) of the LignoLoc® wooden nail

Summary of the full LCA report

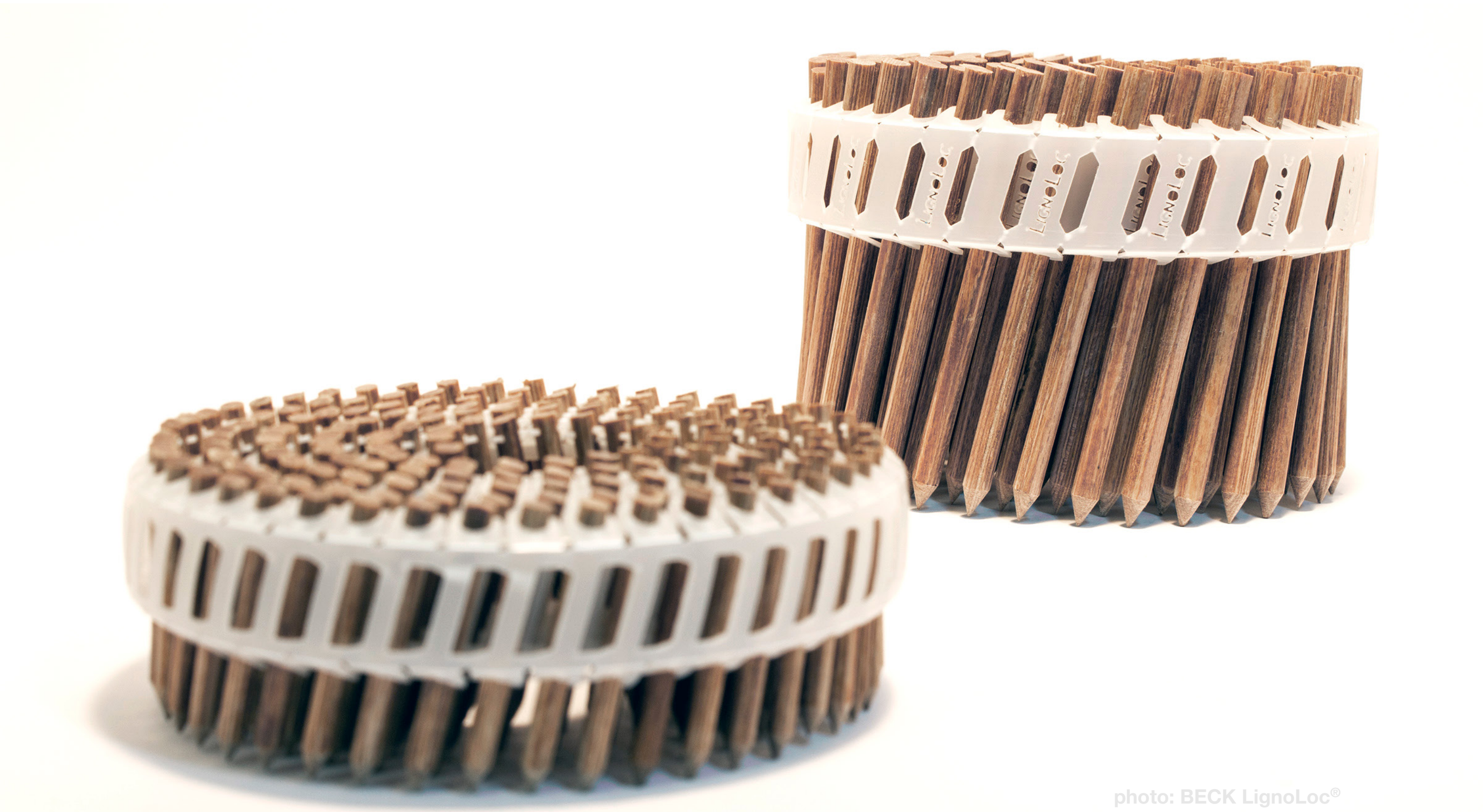

photo: BECK LignoLoc®

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Goal and scope in a nutshell

The methodology of the sustainability assessment is based on ISO 14040/14044.

Goal

Assessment of the envionmental impacts of a LignoLoc® wooden nail and comparison with an existing product with similar properties (smaller steel nail).

Functional Unit

1 nail (dimensions on p.3) of similar functionality, i.e. providing mechanical properties similar to the LignoLoc® wooden nail:

- Characteristic withdrawal parameter = 8.46 N/mm^2
- Characteristic pull-through parameter = 5.16 N/mm^2
- Characteristic yield moment = 1455 Nmm
- Characteristic tensile capacity = 155.5 N/mm^2
- Characteristic shear resistance = 361.8 N

System boundaries

Cradle-to-grave excluding use phase.

End-of-Life

- Wooden nail: Assumption of 100% incineration.
- Steel nail: Assumption of recycling with a recycling rate of 85%.

Approach

Attributional environmental impact assessment based on mass and economic allocation. Differences between mass and economic allocation were marginal.

Data sources – wooden nail

- Primary data for the processing of raw material (wood, phenolic resin) into the final, packed and collated wooden nail.
- Literature data for the forest management.
- Own calculations for the end-of-life incineration.

Data sources – steel nail

- Primary data for processing the steel wire rod to the final nail (both galvanized and non-galvanized).
- Literature data for raw material extraction to steel wire rod and for the end-of-life recycling.

The comparison of the nails has not been reviewed externally. This is considered reasonable due to the fact that all investigated nails are manufactured by the same company.

Introduction

In 2017, the BECK Fastener Group (Austria) and DR. HANS KORTE Innovationsberatung Holz & Fasern (Germany) introduced the world's first collated wooden nail under the name LignoLoc®, which can substitute classic steel nails in a multitude of applications. This novelty allows for solutions and applications entirely made of wood, which provides substantial advantages for example in light weight, optics and recycling. LignoLoc® wooden nail has been tried and tested and enjoys high demand from several industries. The nova-Institute has investigated how the new nail compares ecologically, and the results are promising! Below you will find a summary of the life cycle assessment.

Figure 1: LignoLoc® in wooden matrix

Key Information

LignoLoc® wooden nail	Functionally similar steel nail from BECK
• Length: 50 mm • Diameter: 3.7 mm • Composition: 78% beech wood, 22% phenolic resin • Density 1,300 kg/m^3 • Weight: 0.664 g	• Length: 50 mm • Diameter: 2.8 mm • Density: 7,850 kg/m^3 • Weight: 2.5 g • Weight (galvanized): 2.7g
Assumptions	**Assumptions**
• 170 nails in a 15° PP coil • Beech wood density 700 kg/m^3 • Thermal energy covered by waste wood incineration on site	• Wire rod production in China • Wire rod ship transport China – Rotterdam = 20,000 km • Wire rod truck transport Rotterdam – Austria = 1,000 km

The LignoLoc® wooden nail is manufactured from sustainably sourced, PEFC-certified beech wood and compacted with phenolic resin. With a pneumatic nailer the nail can be shot into wood with high speed, where friction heat on the surface causes welding between nail and the surrounding wood. As a result, twice the pull-out strength in comparison to steel nails of same dimension can be achieved.

To better understand the environmental performance of the nail, a life cycle assessment (LCA) was conducted. The LCA consists of a goal and scope definition, life cycle inventory, life cycle impact assessment and interpretation of the results.

Goal and Scope

The main goals of the LCA were to evaluate the environmental impacts of LignoLoc® wooden nail and compare it to a steel nail with similar functionality.

The functional unit for the comparison was one LignoLoc® wooden nail, which was compared to a functionally similar steel nail by BECK as defined in the box above.

A full life cycle (cradle-to-grave) consists of raw material extraction, production, packaging and distribution, usage, and end-of-life. For the LignoLoc® wooden nail, the following life cycle as shown in Figure 2 was identified:

- **Raw material acquisition** of beech wood (sustainably managed forests Germany) and of phenolic resin (German production).
- **Production and packaging** of the wooden nail over several process steps in Germany and Austria.
- Because potential applications of nails are diverse, the **use phase** of the nail was only investigated exemplarily for the particular case of fastening wooden pallets, and left out of calculations and diagrams for the nails from cradle-to-grave.
- At **end-of-life**, wood can usually either be left to rot and decompose, recycled into usable product or incinerated for energy generation. Because end-of-life options depend on (unknown) usage and the resin compacted nail does not decompose as easily, the study assumed a scenario in which 100% of the nails get incinerated for energy generation at their end of life.

Functionally similar steel nails were identified together with BECK, who produce these steel nails themselves. Their steel nails are formed out of wire rod, a key product of the steel industry. Because the origin of the wire rod and whether the nail has been galvanized or not make larger differences, we investigated several steel nail variants (wire rod from Europe or Asia, galvanized or ungalvanized). The inventory data for the wire rod production was provided by the World Steel Association, primary data for further processing until the final nail was provided by BECK.

For this study, environmental impact categories investigated were global warming potential (GWP100), abiotic depletion potential for elements (ADP elements), fossil fuels (ADP fossil fuels) and cumulative energy demand (CED).

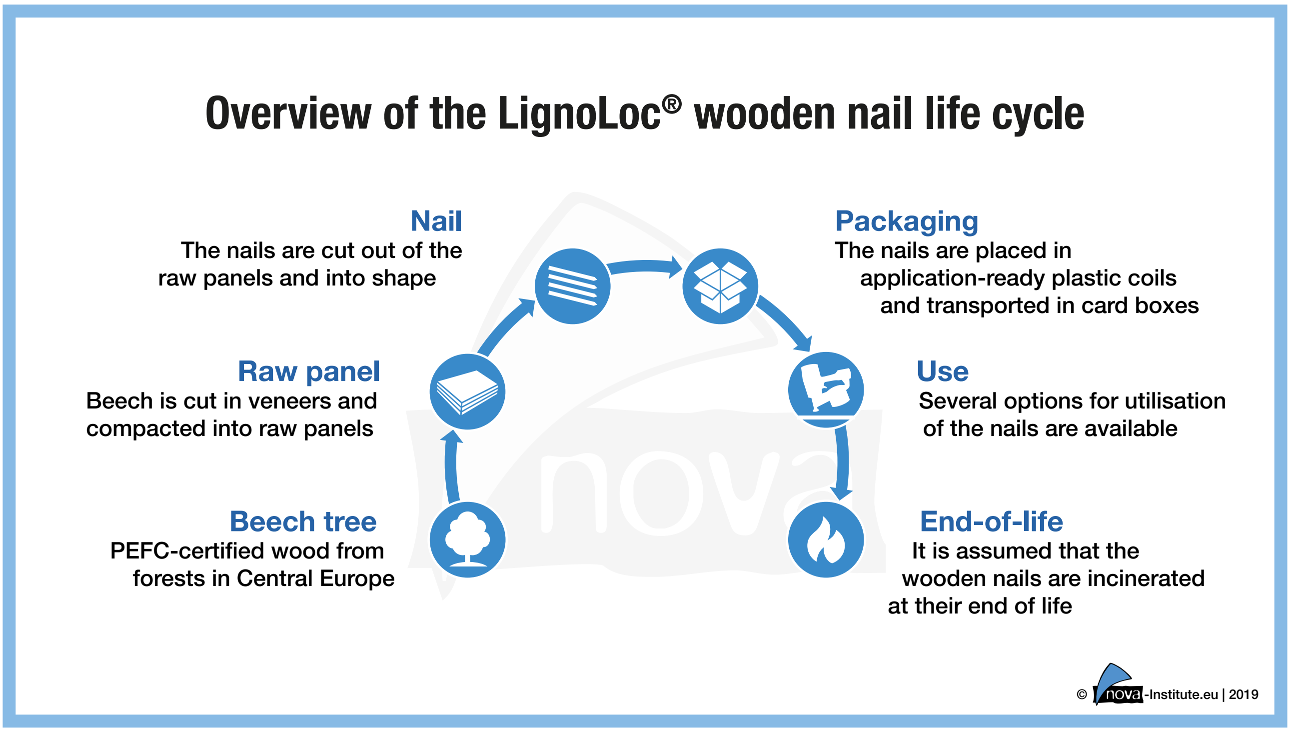

Figure 2: Overview of the LignoLoc® wooden nail life cycle

Results – Cradle-to-gate production

The main environmental hotspots during wooden nail production (cradle-to-gate), i.e. raw material extraction and manufacturing up to the final nail, are the phenolic resin production and the high energy and electricity demand for compacting the beech wood. In combination, they make up the lion's share of the global warming potential (~77%) and the abiotic depletion of fossil fuels (~75%). The packaging of the nails is responsible for half of the abiotic depletion of elements, largely due to the cardboard boxes used. The raw material extraction of beech wood has the highest share of the cumulative energy demand, illustrating the amount of (renewable) energy stored within in the wood.

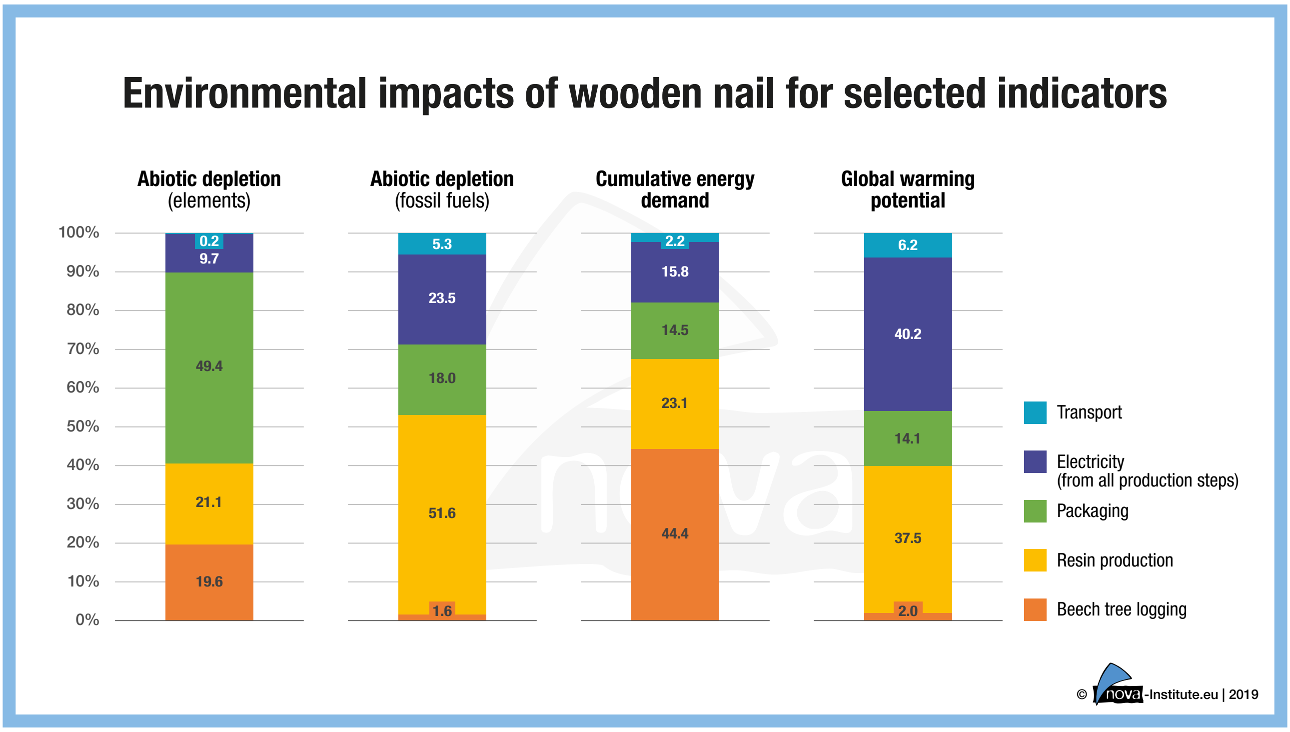

Figure 3: Hot spot analysis of the environmental impacts of the LignoLoc® wooden nail production (cradle-to-gate)

Cradle-to-grave comparison

A cradle-to-grave comparison of LignoLoc® wooden nail with the different steel nails was conducted, but the use phase was excluded. As nails can be used in a multitude of applications, it is not feasible to identify their average use. It was assumed that all wooden nails get incinerated at their end-of-life – adding an environmental burden for incineration emissions, but also a credit for substituting thermal energy. The life cycle of the steel nail comprises of the raw material extraction, the production of wire rod in EU or Asia, the forming and packaging of the nail at BECK and recycling with a recovery rate of 85% at the end-of-life. We investigated wire rods from Asia and Europe and also the impacts of an optional galvanization with Zinc.

The cradle-to-grave results can be seen in Figure 3 and are briefly discussed in the following:

ADP elements: The wooden nail has a lower impact, but only by a small margin compared to an ungalvanized steel nail from BECK. Galvanized steel nails have much higher impacts due to the use of zinc.

ADP fossil fuels: The steel nail made of wire rod from Europe has the lowest impact in this category, but only by a small margin in comparison to the wooden nail and the steel nail from Asia. Galvanization increases the impacts.

GWP 100: The wooden nail has the lowest GWP. BECK steel nails with wire rod from Europe and Asia have roughly 50% higher GWP or 100% higher GWP when galvanized

CED: The wooden nail has the highest CED of the compared nails, with the other nails having between 50-70% of the energy demand of the wooden nail. Again, the galvanized steel nails have a higher impact compared to their ungalvanized counterparts.

Comparing the LignoLoc® wooden nail to the BECK steel nail with wire rod from Asia, the environmental impacts amount to

- ADP (elements) = 10% of steel nail
- ADP (fossil fuels) = 94% of steel nail
- GWP 100 = 69% of steel nail
- CED = 179% of steel nail

Impact category	LignoLoc® wooden nail	BECK steel nail with wire rod from Asia	Galvanized BECK steel nail with wire rod from Asia	BECK steel nail with wire rod from Europe	Galvanized BECK steel nail with wire rod from Europe
ADP (elements) in µg SB eq	0.29	2.89	1,190	0.09	1,190
ADP (fossil fuels) in KJ	51.3	54.7	67.8	47.5	60.6
CED in KJ	127.0	71.1	87.0	63.7	79.5
GWP 100 in g CO_2 eq	2.97	4.29	5.49	4.38	5.58

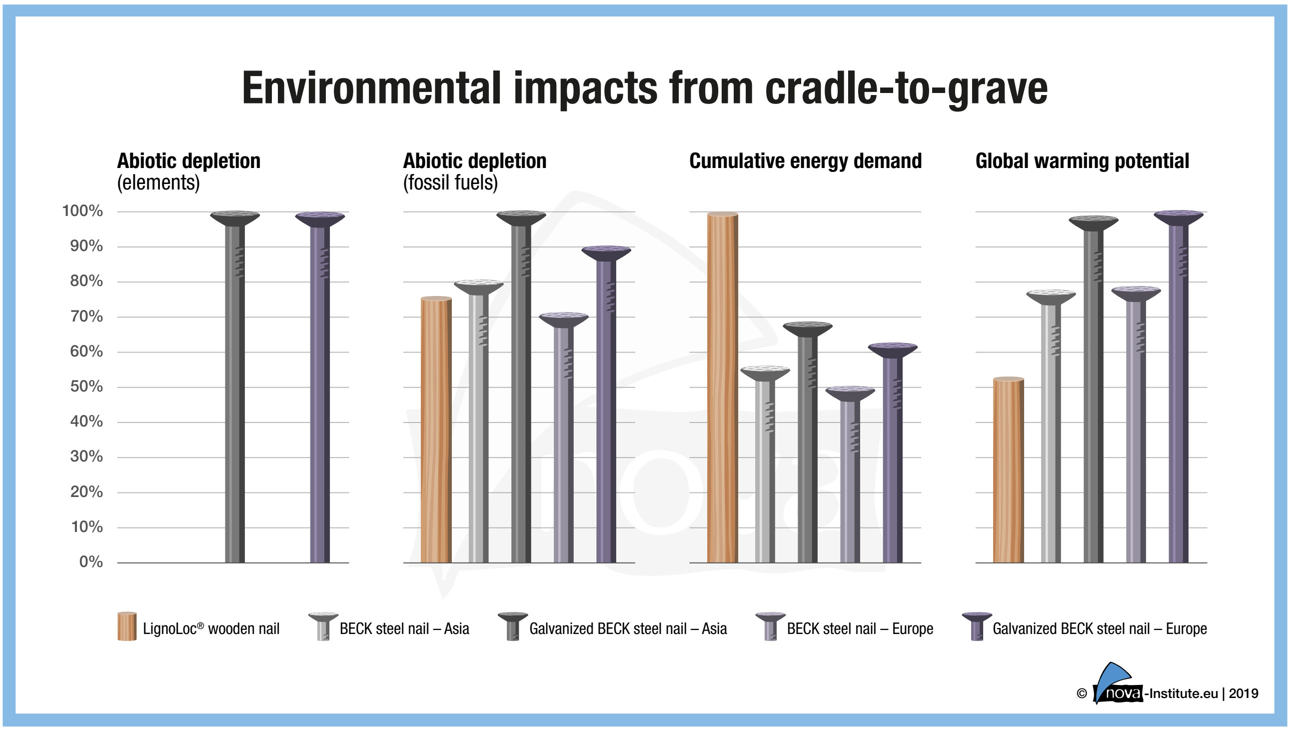

Figure 4: Environmental impacts of the LignoLoc® wooden nail in comparison to functionally similar steel nail variants from cradle-to-grave excluding use phase.

Results – Pallet use case scenario

For versatile products, like nails, a clear use phase definition is hardly feasible. Instead, we investigated the theoretical use case scenario of nails in a pallet by focusing on the European EPAL pallets system. Replacing steel nails with functionally similar LignoLoc® wooden nails would reduce the weight of a standard EPAL1 pallet by approximately 425 g. Although the seemingly small difference, in a system of 500 million pallets in Europe alone and with average annual transport distances of 80,000 km per truck, the greenhouse gas emissions savings due to reduced transport loads can add up to significant amounts.

Interpretation

Altogether, under the stated assumptions and for cradle-to-grave excluding the use phase, the LignoLoc® wooden nail has a lower global warming potential, a lower abiotic depletion of elements, a similar abiotic depletion of fossil fuels and a higher cumulative energy demand when compared to functionally similar steel nails from BECK.

The highest environmental impacts are caused by the compaction of the beech wood with the phenolic resin, where the production of the phenolic resin itself and the long press times and heat requirements to compact the wood are the two main contributing factors.

The GWP100 as well as the ADP (fossil fuels) directly relate to this: The phenolic resin and its production as well as the energy-intensive raw panel production process account for three quarters of the impacts in these categories.

The ADP (elements) of the wooden nail is comparably low and largely caused by the packaging in cardboxes. Especially when compared to galvanized steel nails there is a larger difference, because the element Zinc is used for galvanization.

The CED is to a larger extent covered by the renewable beech tree growth, because the inherent biogenic energy for thermal energy generation to press the compacted wood. Still, the high CED indicates that the production process of the LignoLoc® wooden nail requires a larger amount of energy than that of a comparable steel nail.

Depending on the use case, the wooden nail can offer additional environmental benefits, as has been investigated for the use in pallets. Here, the lighter wooden nails lead to a reduced transport weight, which, looking at the number of circulating pallets, can have a huge impact.

Conclusions and Recommendations

In conclusion, the results indicate lower environmental impacts for the LignoLoc® wooden nail than for a comparable BECK steel nail. The wooden nail shows lower global warming potential with additional benefits for binding CO_2 during its lifetime. It has a lower abiotic depletion of elements, in particular when the steel nail is galvanized with zinc. The abiotic depletion of fossil fuels is on a similar level. The cumulative energy demand is higher, but this is in a large part caused by the inherent sunlight energy stored in the beech wood.

The LignoLoc® wooden nail is a novel type of fastener that is mostly made from renewable resources but there is still further room for improvement:

One main recommendation is the investigation of alternative resins, e.g. with lower thermal energy demand or of bio-based origin, because the phenolic resin used is contributing to a large extent to the environmental impacts of the wooden nail.

Improvements could also be achieved by reducing the amount of cut-off material, if technologically feasible. Because of the high environmental impact of the raw panel production, increasing the amount of panel that is converted into wooden nails could lead to large benefits for the LCA results.

A methodological recommendation: The cut-off material is incinerated to provide thermal energy for the production process of raw panel and wooden nail, and currently it is assumed that 100% of the cut-offs are nessesary to cover the energy requirements. Determining the actual thermal energy demands of these processes could result in energy surplus from the incineration of the cut-offs, meaning that they generate more energy than required for the production process. This surplus could then substitute energy of other processes (outside of the LCA scope), leading to a credit and improving the LCA results.

Finally, it seems likely that further potentially advantageous use cases besides the pallet system can be identified. Despite the above-mentioned lower weight, wooden nails can provide additional environmental advantages when compared to steel nails: They help to reduce tool wear in post-processing wooden components and do not act as thermal bridges, improving insulation properties and energy efficiency, particularly in buildings and construction. Therefore, the construction sector, e.g. cross-laminated timbers, seems like a potentially interesting use case for the LignoLoc® wooden nail.

nova-Institute

nova-Institut GmbH was founded as a private and independent institute in 1994 and is located in the chemical park Knapsack in Hürth. For over 20 years, the nova-Institute has been researching and providing consultancy worldwide on how food, biomass for industry and bio-based products can be sustainably provided. To this end, the nova-Institute has carried out numerous sustainability assessments for public authorities and industry and participated in several European research projects.

Christopher vom Berg has been an expert in the nova sustainability team for two years and Michael Carus is founder and managing director of the nova-Institute.

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