Laser texturing vs. hydrophobic coatings in wind turbines | Series of LCA studies - part 2

26 August 2025, 11:04

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In our recent comparative life cycle assessment (LCA) study, the environmental impact of femtosecond laser texturing was evaluated against a conventional hydrophobic coating system used for wind turbine blades.

Tackling ice accumulation in wind turbines

Wind turbines are critical to the transition toward renewable energy, but their operation is not without its own set of challenges. One significant issue is ice formation on turbine blades, which reduces aerodynamic efficiency, increases mechanical load, and can cause costly downtime. Traditionally, this issue is addressed using hydrophobic coatings, along with other mechanisms designed to repel water, prevent ice adhesion and melt the ice after its formation. These coatings are often silicone-based and require a primer for effective adhesion. Their application involves several steps, including surface cleaning, coating with spray guns, curing, and post-application maintenance.

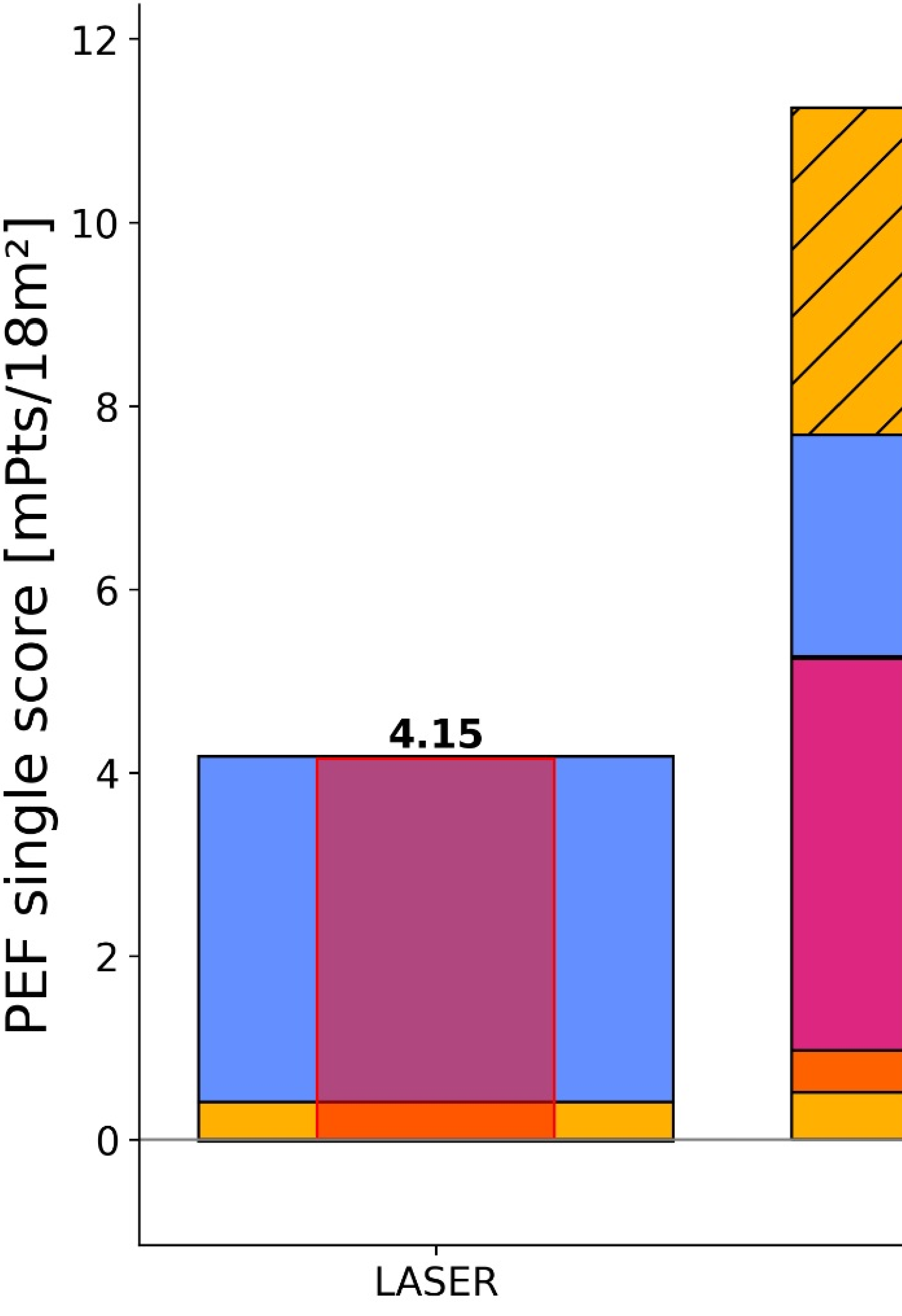
Comparing two surface treatments

The study focused on treating an 18 m^2 surface area. The laser-based treatment included phases such as surface pre-cleaning, laser texturing using a polygon scanner, air filtration to capture particulate matter, and end-of-life waste management. In contrast, the coating process included the production and transport of primers and coatings, spray application, solvent use, VOC emissions during curing, and the disposal of used filters and chemical containers.

Key environmental findings

Key environmental hotspots identified in the LCA included climate change potential, non-renewable energy sources, resource depletion, among others. For the laser process, the majority of the impact stemmed from electricity use and the production of laser equipment. The polygon scanner had its efficiency estimated in 2.6 m^2/h and required approximately 100 kWh for the full 18 m^2 treatment. However, the lack of chemical use, the absence of VOCs, and the minimal waste generation significantly offset this energy requirement. In fact, 90.7% of the laser's environmental impact was associated with the application phase, primarily electricity use and laser equipment production, while end-of-life waste was negligible.

In comparison, the conventional coating process had a higher total environmental impact, driven largely by the production and application of the coating itself. The VOC emissions alone contributed significantly to climate change and air quality degradation. Additionally, the coating required multiple materials, including solvents and filters, each contributing to cumulative energy use and waste generation. According to the LCA, the single score impact of the coating process was more than double that of the laser process (11.25 mPts vs. 4.15 mPts), indicating a clear advantage for laser texturing in terms of overall environmental burden.

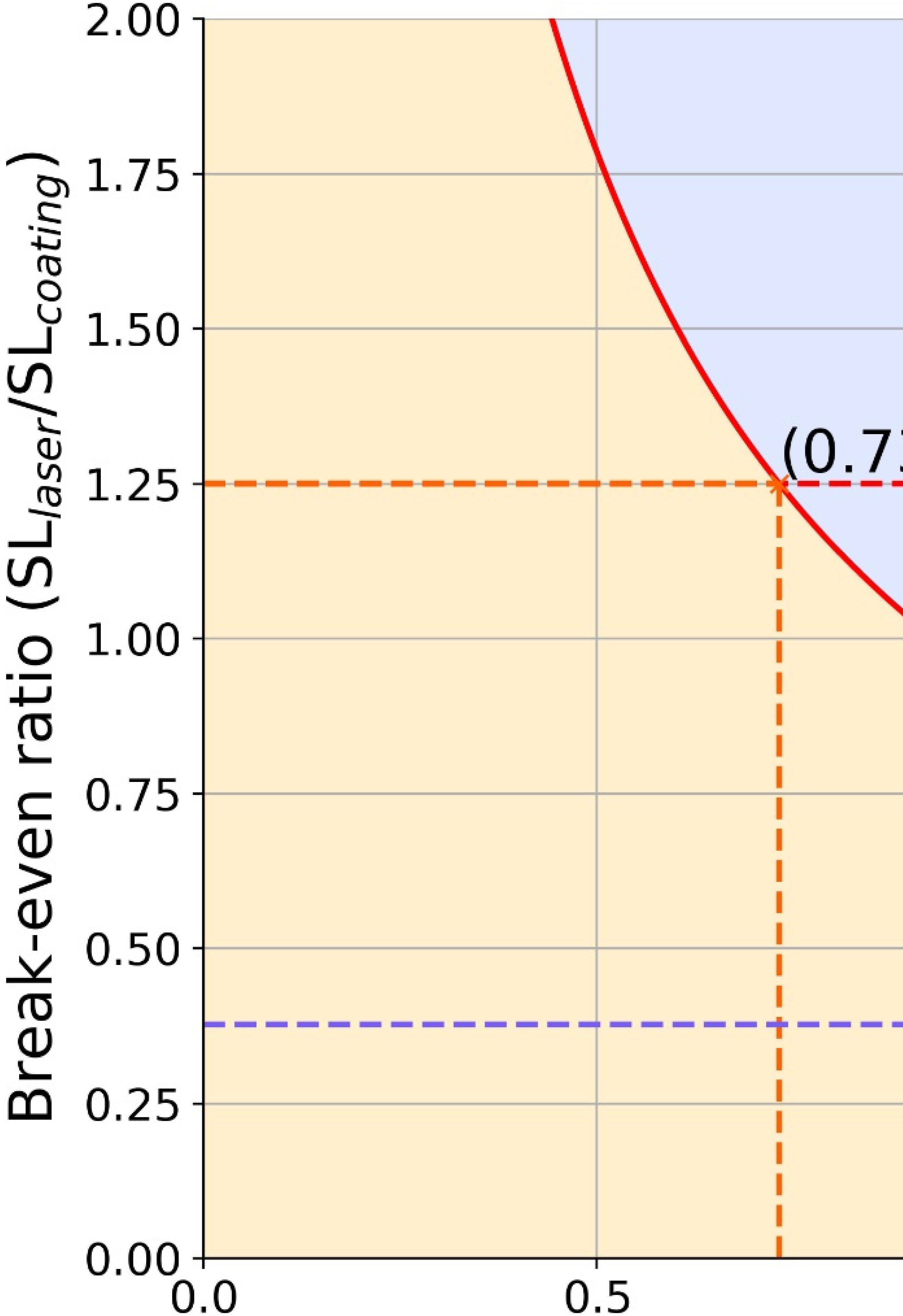


PEF single score [mPts/18m²]
12
10
8
6
4
2
0
4.15
LASER

Figure 1. Absolute and relative Product Environmental Footprint (PEF) single score (mPts/18m²) comparing femtosecond laser and a epoxy coating.

The role of service life and efficiency

Another key finding from the study was the importance of service life (SL) and efficiency in determining the break-even point between the two technologies. The laser treatment was assumed to last 1.25 times longer than the coating. Even if this ratio were reduced, the laser process still outperformed the coating in most environmental categories, provided the laser efficiency remained above a threshold value. For instance, with an efficiency of 2.63 m^2/h, the laser reached environmental parity with the coating at an SL ratio of just 0.38. This means that even if the laser-modified surface lasted less than half as long as expected, it would still offer a lower environmental impact compared to the coating.



Break-even ratio (SL$_{laser}$/SL$_{coating}$)
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
0.0
0.5

Figure 2. Break-even of single score Product Environmental Footprint (PEF) single score demonstrating the effect of service life of both surface treatment in the environmental impact.

Conclusion

Femtosecond laser surface texturing represents a paradigm shift in sustainable surface engineering. The LCA evidence supports the notion that laser texturing not only meets but exceeds environmental expectations, making it a compelling choice for industries striving to improve both performance and sustainability.

Discover the FEMTOFUNC project

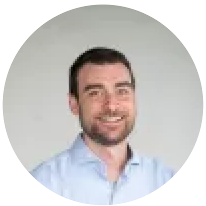
This case study is part of the broader FEMTOFUNC research on biomimetic surface functionality.

Discover the FEMTOFUNC project

Series of LCA studies on the application of femtosecond lasers

In a series of 4 parts, we briefly describe our findings and show the extent to which a femtosecond laser outperforms coatings in terms of ecological footprint:
Part 1: femtosecond laser texturing as a sustainable surface solution
Part 3: laser vs. antibacterial coatings on door handles
Part 4: laser texturing vs. hard chromium coatings in bearings

Authors



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