

Digital product passport concept for an aluminum bike frame: A case study to enhance circularity and sustainability

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EXTENDED ABSTRACT

Cycling poses an active mobility mode that offers low-cost as well as low to zero emissions compared to other mobility modes (e.g., passenger cars). Bicycles with aluminium frames are associated with increased energy consumption during their life cycle and corresponding environmental impacts. The transition to circular and sustainable value chains requires transparent data access across all lifecycle stages for all stakeholders along this value chain. In this context, Digital Product Passports (DPPs) offer a structured approach to improving sustainability and circularity by facilitating data-driven decision-making. While the implementation of DPPs in the bicycle industry remains at an early stage, their application holds significant potential to advance sustainability and circularity. This study addresses this gap by proposing the first structured DPP framework for aluminium bicycle frames. It also outlines use cases in the context of sustainable product management, demonstrating how the framework enhances sustainability and circularity across the bicycle's life cycle. The development of the DPP framework is based on a structured stakeholder mapping and a systematic literature review. In addition, two expert interviews were conducted to gather further insights and validate and supplement the results. The resulting DPP concept comprises 62 data points organized into four categories: (1) bike frame specifications, (2) diagnostics and maintenance, (3) sustainability and circularity, and (4) value chain actors. These data points provide insights into material traceability, lifecycle

impacts, and product repairability, supporting sustainable product management. The concept also details the specific data requirements of the affected stakeholders, such as engineers, consumers, and recyclers. Furthermore, four use cases illustrating how stakeholders can leverage the DPP to enhance circularity and sustainability in bicycle production and disposal were derived. Hereby, for each lifecycle stage, one stakeholder group was selected. During the early stage, engineers have to opt for the optimal manufacturing process, which includes decisions such as implementing production methods and materials that ensure both performance and sustainability. At the Beginning of Life, raw material suppliers, who can choose between sourcing virgin or recycled materials, are essential stakeholders. Therefore, data regarding the origin of the material and its recyclability have to be provided by the suppliers. In the Middle of Life, consumers can either repair a bicycle or purchase a new one, which leads to a need for modularity and availability of repair options. Lastly, in the End of Life stage, waste management companies are responsible for handling discarded frames. To optimize this process, information such as disassembly guidelines and alloy compositions is required. This study contributes in three ways. First, it introduces a DPP concept for aluminum bicycle frames to enhance value chain circularity and sustainability. Second, it suggests a concept that improves data transparency and facilitates data-driven decision-making, serving as a foundation for future DPP development. Third, the study provides actionable insights for stakeholders to support the adoption of DPPs to accelerate the transition to a circular economy.