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The Legend of the Circular Tire: Creating a Vision for a more Resource Productive Tire Business Ecosystem

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Abstract: While the topic of circular economy (CE) has become more popular, tires are one example in which the market appears to be going in a more linear, less circular direction. In fact, the prevalence of tire retreading has decreased in Europe over the past decade. This paper presents a vision for a more circular tire business ecosystem and show that while there are resource and environmental gains to be had, achieving them will require significant changes to the system including both implementation of technical solutions and new ways of working. Moreover, these changes require efforts that may not seem motivated given the magnitude of gains considered in context with vehicle-level priorities. The case illustrates the conflict between norms of product longevity, achieving circularity and a circular economy tomorrow and those of achieving measurable improvements of environmental performance based on rules governing the linear economy today.

Introduction

Product lifetimes are known to be results of not only product design, technical specifications and material durability, but based on how the product is used and the system in which it operates (van Nes 2010, Chapman 2010). While the realized product lifetime of a product can be influenced (or increased) by addressing individual aspects of the product, i.e. material composition, aesthetics, reparability, and ease of use, understanding and addressing the product system with all its complexities could yield even more substantial improvements (Rai & Terpenny 2008; Diener et al 2019). As difficult as this may be, such an approach is supported by theories of systems science which suggest that 'engineering' approaches, which often take a mechanical view of systems, are severely limited in their success in changing complex systems (Checkland 2010), in which actions of and interactions between people and organizations, not mechanical workings, govern outcomes (Ingelstam 2002).

A systems-view could be especially relevant for products that are mere components of other products, potentially not prioritized as such, and that are potentially controlled by not one actor, but multiple actors during their lifetime (Diener et al 2019). This is exactly the type of situation described in this paper in which we describe a component that seems to be going towards less longevity.

While the topic of circular economy (CE) has become more popular, tires are one example in which the market appears to be going in a more linear, less circular direction. The prevalence of tire retreading has decreased in Europe over the past decade (EY 2016). Besides a lingering question of retreaded tire quality and safety, the availability of low-cost tires appears to have displaced some of the market for retreaded tires. It was hypothesized that monitoring, collecting and utilizing key tire health metrics (e.g. pressure, temperature, vibration) could reinvigorate tire retreading and reuse in a tire ecosystem. To assess the tire system and possibilities, we studied a truck tire business ecosystem, collaborated with actors in it and used multi-disciplinary approach to understand the system and resulting tire longevity. In doing so, we (1) develop a vision for a circular tire business ecosystem, (2) provide suggestions of how it could be achieved with data cultivation and sharing and (3) assess the magnitude of potential environmental impact reductions and resource benefits in the tire ecosystem. The works provide guidance specific to the system studied while the study itself provides an example of how combining a variety of assessments of a complex system can facilitate system-level learning and ultimately, to understanding how to achieve increased product longevity and how difficult that may be.

Method

Researchers studied an incumbent business ecosystem[1] of a long-haul truck tire, including key actors: a truck manufacturer, truck fleet operator, truck tire retreading company, and tire material recyclers. To study these actors and the ecosystem as a whole, we first assess the environmental impact of a product (tire) and create a list of opportunities to reduce it. We then assess information sharing as a key enabler to achieving better resource productivity. We utilize many methods including: interviews and collaboration with key actors in the business ecosystem, and life cycle assessment to estimate the magnitude of possible improvements. Tests of sensor technology on truck tires were also conducted, although they are not explained here.

Quantifying magnitude of potential benefits: Life cycle assessment and complementary assessments

For this study, we focused on the gains that can be made with the types of tires that are currently used in the system studied, the ones that fulfil the function demanded by the users. The functional unit is thus km of use of tire type demanded by users in the system in Sweden. Tires are used on a heavy-duty truck with diesel or electric drivetrain, which is assumed to have an energy efficiency that is between two and three times that of a diesel engine. After a tire is used it can either be recycled or retreaded and reused. According to the tire retreading company in the project, a tire core, or "casing", can be retreaded up to three times. Questions addressed are the following: To what extent can the environmental impact be reduced by: (1) retreading tires up to three times?, (2) using sensors ensuring optimal tire pressure and temperature.

[1] An economic community produces goods and services of value for customers, who themselves are members of the ecosystem (Moore 1996).

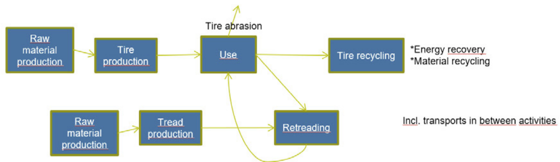

Figure 1. The simplified tire life cycle as modelled.

Data collection was performed during 2018 and 2019. Generally, the LCA is using primary data for the processes which are represented by a partner in the project (e.g. retreading), and secondary data for remaining processes (e.g. tyre production). Modelling of the product system was made in the LCA software GaBi.

Environmental impact measures from LCA were complemented with three other assessments: (1) a qualitative overview of toxicological aspects of the tire life cycle, (2) material per service unit-MIPS (Schmidt-Bleek 1998), calculating the amount of tire material use per amount of function delivered by a tire for different treading outcomes, and (3) economic circularity (Linder et al 2017), measuring how much value of virgin tires is retained when retreaded, using new and retreaded tire pricing among other statistics from project partners to determine percentage value retained.

Describing the business ecosystem and identifying possibilities of data cultivation and sharing

The process of investigating the needs of information and information sharing consisted of an initial set of onsite interviews with the participating companies regarding their current way of working with sourcing of tires, selling tires and tire related services, as functional sales, maintenance and repairs, retreading, collecting and end of life treatment. These interviews formed the input for making a functional analysis (lie et al., 2011), listing tire related data functions described as needed. The functional analysis was presented during a workshop with the participating companies where they prioritized the list of functions.

Based on prioritized functions, images of the current value flows were developed depicting the amount of tire material, information, money, immaterial values in the current tire system (den Ouden 2011). As well as for desirable, future value flows for amore circular business ecosystem. To isolate and explore how the tire related health data could be shared among the actors, a further visualization was made based on the so-called living lab methodology (Ståhlbröst & Holst 2013). This methodology provided a clear visual representation of the various data flows over a tire's various life cycle phases and with touch points between the actors and tire related data in a "Metro map" (based on the analogy of the London subway map), which was further used as a mediating object to explore actors' actual willingness and capabilities to share, receive and use the tire-related data.

Results from individual works

First, opportunities identified from LCA are presented focused primarily on the potential magnitude of assessed "inefficiencies" in the system. Next, opportunities related to achieving these gains via data cultivation and utilization are presented.

Potential environmental impact reductions and resource productivity gains

The use phase of a tire is where the environmental impact is highest for most environmental impact categories including toxicity; the energy required to overcome a tire's rolling resistance as well as its weight and wind resistance is substantial, and this requires a lot of fuel combustion for internal combustion engine vehicles (ICEVs) or electricity for electric vehicles (EVs). As such, the biggest influence one can have on tire function's environmental burden is by choosing a light tire with low rolling resistance (Of course, this choice can conflict with other basic requirements such as safety and tire longevity, which has an influence on overall operation and standstill cost). Nonetheless, retreading can result in some reduction to a tire's lifecycle environmental impact, from 1% (CO2-eq) for trucks with combustion engines to 25% for trucks with electric drivetrains with low carbon electricity (Sweden). Depending on existing tire maintenance procedures, large CO2-eq reductions (up to around 15%) could also be gained by maintaining optimal tire pressure, which has a large impact on fuel efficiency. These results (summarized in the Table) are rather similar for other environmental impact categories.

Action	**Potential CO_2-eq reductions in total life cycle**
Tire monitoring implemented	Up to 15%, less than 1% for already thorough maintenance, to 15% for "bad" tire maintenance
Retreading 1-3 times (for use in electric truck, low carbon electricity)	Up to 25%
Retreading 1-3 times (for use in diesel truck)	<=1%

Table 1. Comparing tire life cycle improvement opportunities.

Measures focused solely on tire material and economic value (and not demands of energy during use) are more convincing. Approximately 55% of tire material sent to retreading is reused in retreaded tires. Retreading increases the material per service unit from 1 material unit per 1 service unit to around 0.6 material units per 1 service unit for multiple retreadings. From an economic perspective of the tires themselves, the circularity metric shows roughly that currently 30% of the value of tires is recirculated when retreaded in today's system. This is based on assessed value (price) of retreaded tires, which are sold for less than new. This is estimated to be able to be increased to over 50% for three retreadings.

A vision of how a more resource productive tire business ecosystem could be facilitated with data cultivation and utilization

Embedded sensors can help monitor tire pressure, which is critical to vehicle efficiency and tire wear and can identify damage due to jolts and impacts, improper air pressure, and increased heat, can provide the tire service providers, haulers, retreading companies, vehicle manufacturers and recyclers with valuable information for preserving economic value. There is also a potential for generating valuable information for other actors, e.g. road authorities and actors involved in road maintenance. The information is naturally valuable to individual actors as well as the ecosystem as a whole as it can be used to inform: (1) maintenance or tire change-out, (2) estimates of remaining tire lifetime, (3) retreading activities, and (4) assessments for fitness for reuse and repurposing. The data can hypothetically be shared among actors in the ecosystem but sharing such valuable information is not a natural function of the current system, a limitation that could be resolved with incentives and alternative business models. For example, data can be shared via alternative pricing, sold as an extra service or can be contained as part of a function-based or circular business model (Linder & Williander, 2015; Altmann & Linder 2019). Potential solutions are to be considered with the possibility (and likelihood) that tensions will arise between individual firms, who each have their own ideas and interests in commercializing the data (Altmann & Linder (2019). Figure 2 (on the next page) provides an illustration of the tire business ecosystem and key data nodes.

Synthesis: Vision for a circular tire ecosystem and key lessons learned

Putting lessons learned from separate assessments together provides lessons learned about the business ecosystem. With this new knowledge, a vision of a circular tire business ecosystem was created (Figure 3, next page).
The vision builds on the following findings:
1) The theoretical mileage of a heavy tire casings is rarely realized for applications in most developed countries.
2) There are unrealized environmental and economic values in a tire system. Hypothetically, there is economic value in monitoring tire condition and use for reasons of reducing risks for premature tire casing disposal, fuel efficiency, and to avoid costly vehicle stand-still by tire failures. Tire use data that can be collected during use can also be valuable for facilitating reuse, for example by informing retreading (or remarketing) processes. In addition, retreaded tires are less expensive than replacing with new (conventional) tires. Use of sensor-generated data can facilitate the potential to help realize something closer to the theoretical lifetime.
3) Retreading increases the material per service unit from 1 material unit per 1 service unit to around 0.6 material units per 1 service unit for multiple retreadings. Currently, 30% of the value of tires is recirculated when retreaded in today's system. Multiple retreadings could allow the system to achieve over 50% economic value circulated.
4) Tires are already repurposed and reused in different positions (e.g. drive vs roll) for long-haul trucks. In fact, for certain applications, retreaded tires are apparently considered to be "better than new". Thus, comparing these tires with new tires used in other positions may not be a sound approach as the function delivered is not the same. This represents one of many complexities in determining a single tire's share of the burden for a truck and trailer that could have 18 up to 46 tires.
5) Repurposing of tire casings from long-haul trucks to short-distance vehicles such as forklifts is allegedly suitable.
6) Electrification of the vehicle fleet will make the potential environmental improvements of retreading more significant as the ratio of use phase to production phases will be less.
7) Retreaded tires must be of similar quality and rolling resistance as new tires (for that same application). From a resource and environmental perspective, this is especially important for ICEV cases.
8) Today's main end of life treatments of disposed tires are granulation and incineration in cement production. While recycling outcomes such as use in cement kilns do offset use of fossil fuels in those applications (and are calculated that way in LCA), they are a result of today's fossil-based economy and result in environmental impacts themselves. The vision presented here suggests a delay to end-of-life treatment, and ultimately, a reduction to tire material throughput.
9) Even without vehicle and production emissions, toxicity via tire road particle emissions during use –which have been identified to have adverse effects on humans and other organisms – will still exist with tires as they are designed today. The vision presented here does not address this issue.

Conclusions

Assessments of the tire business ecosystem and its resource productivity reveal inefficiencies in the physical system and therefore, room for improvement. These potentials may be numerous but achieving them requires not just technical enhancements or interventions but changes in traditional use and reuse patterns, and modifying established data and value sharing practices in the business ecosystem. These types of changes imply changes both internal and external to all organizations involved. Given the complexity of the system including its actors and their individual interests (as illustrated for this study), it can be concluded that such engagement may not seem motivated given the magnitude of gains, especially when considered in context with higher-level (vehicle and fleet-level) priorities and when carbon reductions are in-

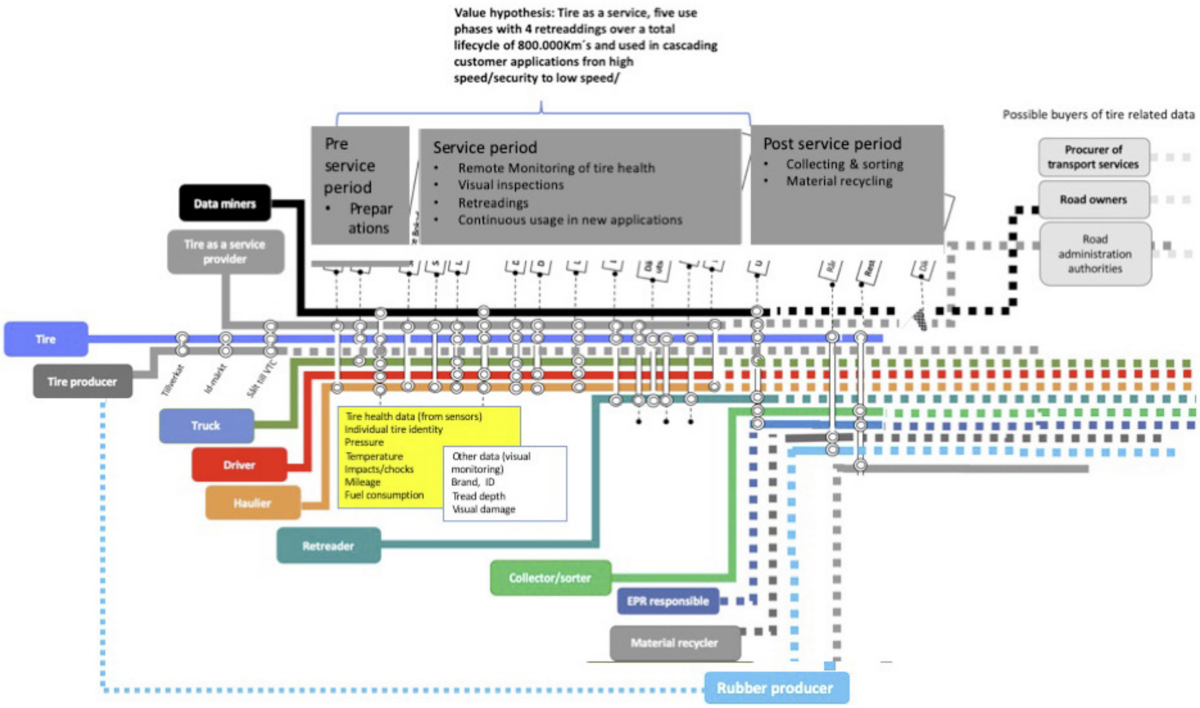

Figure 2. This map from the project illustrates the opportunities but also the complexity of the tire business ecosystem and possible difficulties of making change. Ultimately, identifying and visualizing key data and who values it helps determine what potentials there are for actors in the business ecosystem to share or monetize this data and lead to increased productivity for the business ecosystem as a whole.

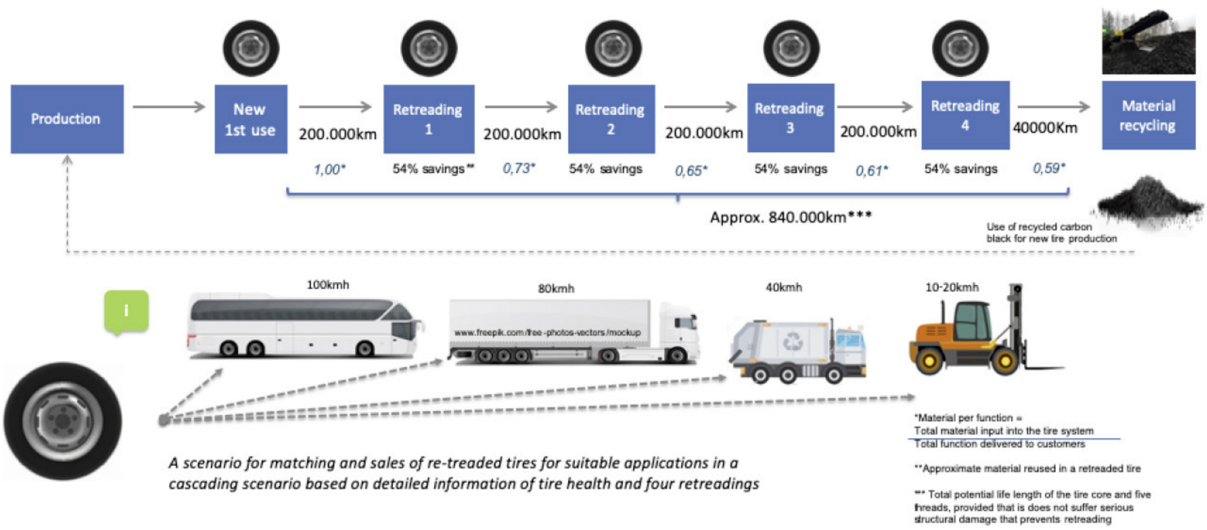

Figure 3. Depicting increased resource productivity via tire life extension and cascading use. Material per function delivered is reduced for every retreading and reuse as approximately 55% (including discards) of tire material is saved after each use. Tires could be used in a planned cascade in which the function delivered is not less but slightly different for each application. Considering material efficiency gains and the costs of new tires for each of these applications, there are potentially huge gains to be had for the system. However, risk for individual actors builds up and can dissuade later reuses. A circular business ecosystem in which data about tire use and health is monitored and collected could help mitigate this risk and result in greater economic and environmental productivity.

focus. For example, the tire's rolling resistance during use is the most determinant factor in the tire's resulting life cycle impact (for most impact categories). Does a 1-25% reduction in tire GHG impact of tires justify the efforts needed to achieve three retreadings in the tire business ecosystem? This question can be posed in context in which choosing an ultra-low resistance tire that has a shorter longevity could potentially achieve a larger reduction, without the efforts to realize three retreadings and without the fear of increased rolling resistance and perceived risk. Of course, this is not an either-or proposition – both actions could be taken – and other measures such as potential improvements in tire material efficiency and economic circularity are quite large (greater than 30%) and suggest there is great improvement to be had.

Moreover, all measured resource and environmental gains are assessed in a tire business ecosystem that is entrenched in a fossil-based world. Tires are made partially from fossil-based material, are used in fossil-based transportation system, and recycled as substitutes for other fossil fuel (oil) use (e.g. cement kilns).

Nonetheless, cases like this illustrate the conflicts that exist between striving according to norms of product longevity, achieving circularity and a circular economy tomorrow and those norms focused on achieving measurable improvements of environmental performance based on rules governing the linear economy today.

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