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Integrating neglected ecological impacts of road transport into corporate management

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ABSTRACT

Companies producing consumer goods are showing a greater interest in integrating the concept of 'environmental footprinting' into their management. Usually, one component of a footprint is road transport. While land use and greenhouse gas emissions are accounted for in life cycle assessment the focus often is on the latter. The additional impact by roads and vehicles – particularly regarding biological diversity – is seldom considered. One reason for this deficit is that findings from road ecology are not sufficiently quantifiable to integrate in life cycle or footprinting analyses. In this article, approaches for quantifying direct land use, degradation of adjunct area, and fragmentation are introduced. Methodologically, this is achieved through a literature analysis and the use of case studies. Four equations are presented that allow measuring spatial impacts of transport processes. Results can be used for more complete impact mitigation and reporting in the context of LCA.

1. Introduction

Companies at different stages of value chains are interested in knowing the environmental impact of their products because they seek to meet consumer interests. In spite of discrete regulatory or monetary incentives like the European Emissions Trading Scheme (EU-ETS), the demands of end customers and other stakeholders are usually the strongest drivers behind a company's environmental management efforts (Christini et al., 2011). In addition, changes in the moral dimension concerning humans' relations to other life forms and to future human beings (Krebs, 2008; Nussbaum, 2006; Becker, 2010), scientific research, and governmental initiatives like the CBD increase the pressure on companies to extend their activities in the field of ecosystem service conservation (Chapin et al., 2000; Sala et al., 2000; MA, 2005; CBD, 2010a,b, 2011). Due to being spatially demanding as well as resource and emission intensive, mobility, and here particularly road traffic, is one of the substantial causes of ecosystem degradation (Lindenmayer, 2006; Andel et al., 2010). Changes in economic organization – particularly in global trade and specialization – and the resulting support of mobility by the state in order to assist national competitiveness are significant drivers of increments in road infrastructure and traffic volumes in the European Union member states in the last 20 years (EU, 2013). While the reduction of greenhouse gas emissions by route optimization, mode choice, driver training or adjusted warehouse management in the field of transport are in the focus of life cycle assessment (LCA), spatial ecological impacts are often neglected (Dekker et al., 2012; Murphy and Poist, 2000).

The ecological impact of roads and traffic and options to avoid and to mitigate these impacts are investigated in the research field of 'road ecology'. To date, studies of different species groups like mammals, birds, or amphibians as well as studies of different road types like forest roads or highways have confirmed the differing but overall significantly negative impact of roads and traffic on biodiversity (Benítez-López et al., 2010; Eigenbrod et al., 2009; Charry and Jones, 2009; Fahrig and Rytwinski, 2009). This knowledge has not reached the attention of corporate environmental management, inter alia because it has not been expressed in a way where it could be used in LCA. Hence, the objective of this article is to present quantitative methods to integrate the three significant, neglected impacts of direct land use, degradation of adjunct areas, and fragmentation into LCA and corporate environmental management.

To this end, ecological findings are analyzed in a literature study in order to construct indicators that allow calculating the share of impact of an individual user. This article is structured as follows: in the first section, the most significant spatial, ecological effects of road transport are described. Next, four approaches of quantification of the impacts of land use and fragmentation are introduced. Finally, the formulae are applied to a case study. The formulae

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serve the purpose and procedure of LCA and can aid organizations to understand, quantify, and ultimately reduce the impact of road transport on biodiversity.

2. Review: Analysis of the ecological impacts of roads and traffic

In this section, the impacts of land use, degradation of habitat, habitat fragmentation and road mortality are described. Quantitative results of studies constitute the basis for the development of the indicators. The before mentioned effects are focused upon because they are underrepresented in corporate environmental management and because their severity of impact on individuals, species and ecosystems is high (cp. Friedrich, 2014).

2.1. Land use and degradation of habitat

The soil and habitat functions of natural area can be either lost completely where surfaces are sealed; or be lost partially in areas adjunct to roads. These areas are often affected by additional artificial construction and by diffusing effects, such as noise or substance emissions. In the literature, the zone over which significant ecological effects extend outward from a road is called 'road-effect zone' (Forman and Deblinger, 2000). Beside material emissions from vehicles, such as nitrogen oxide, particulate matter, ozone, carbon monoxide, carbon dioxide, sulfur dioxide, non-methane hydrocarbons, rubber, or litter, and from the road, such as salt or dust, intangible emissions like vibration, heat, noise, and light occur (Friedrich and Geldermann, 2013). Furthermore, a road and the physical modification of the landscape can produce changes in local climate because winds, temperature, and moisture can change. In addition, hydrologic systems can be altered and corresponding downstream effects can occur because roads may block water flows, increase the risk of flooding, or contribute to erosion and sedimentation (Forman et al., 2003).

Studies have found outward effects with significant impact extending from about 15 to 200 m for material emissions, which can repress plant germination and can also change competitive relations and hence, plant composition (Reck and Kaule, 1992; Forman et al., 2003). Vibrations and noise extend between 200 and 800 m, affecting tortoise, anuran species, or breeding-birds and their breeding success (Eigenbrod et al., 2009; Boarman and Sazaki, 2006; Reijnen and Foppen, 1994; Reijnen et al., 1997). Impact can occur for up to 2000 to 5000 m for distinct mammalian species that are extremely sensitive to noise, such as female moose (Shanley and Pyare, 2011; Benítez-López et al., 2010). A non-species-specific study found that 33% of the significant impacts lie within the first 100 m, while only 8% of the impact occurs further than 500 m away from a road (Biglin and Dupigny-Giroux, 2006). For its reach and immediacy of impact, noise usually is the spatially most relevant impact (McClure et al., 2013; Parris and Schneider, 2008). Affecting various ends of communication, hunting or protection of most animal species, such as avian, mammalian, and amphibian species, several studies found a sound pressure threshold of negative impact of noise at 55 dB(A) (Dooling and Popper, 2007; Helldin et al., 2013; Reijnen et al., 1996). For a highway with 50,000 vehicles per day, Forman and Deblinger (2000) estimated the affected zone to average 600 m in width. The extension of a road-effect zone predominantly depends on traffic volume and on the topography of a landscape (Shanley and Pyare, 2011; Charry and Jones, 2009). Next, the impact of road mortality is referred to because besides often being the problem first perceived by humans and of most devastating impact at the level of an individual it can amount to be one reason of fragmentation.

2.2. Habitat fragmentation

Landscape fragmentation is the result of transforming large habitat patches into smaller, more isolated fragments of habitat (EEA, 2011). The phenomenon consists of two slightly different effects: the subdivision of populations, and the barrier effect, meaning that animals and plants are unable to move freely within a landscape. A road can represent a barrier in three principal ways:

(1) Animals can be deterred from approaching a road because of noise, light, or changes in habitat. When they do come to a road, they can be deterred from crossing because of physical obstacles like fences, median barriers, or even the road surface, which may display uninviting conditions for being dry or for being without shelter; or because of the presence of fast moving vehicles, which increase levels of noise and stress. This applies to life on the ground, in the air, and in streams.

(2) Animals that attempt to cross a road may die. Death predominantly is the result of collision with vehicles, but can also be attributed to attack by predators. While collisions are a problem of its own, they are also closely related to fragmentation because collisions occur due to a need for movement and can be frequent enough directly to threaten entire populations and species or to reduce genetic exchange. While road width and vehicle speed influence the degree of risk, various studies identify traffic volume as the dominant factor in unsuccessful crossings (Jaeger et al., 2005a; Charry and Jones, 2009). Studies specifically investigating traffic volumes suggest that roadkill rates increase as traffic increases up to a level of about 3000 vehicles per day. For traffic levels between 3000 and 10,000 vehicles, the rate remains high or may begin to drop and will drop further for levels above 10,000 vehicles as the density of vehicles and noise deters animals from crossings (Charry and Jones, 2009; Forman and Sperling, 2011). This is positive only in part because it means that the effect of the road to be a barrier becomes more substantial.

(3) Spores, insects, and other life forms that do not actively cross a road but are carried over by host animals, can no longer disperse if one of the before mentioned aspects applies to their host.

The barrier effect is problematic because it impedes an individual animal's access to resources like food, resting places, or seasonal habitats, or mates (Bertiller et al., 2007). Consequences from denied access to mates can be inbreeding and decreased variability of genomes (Fischer and Matthies, 1998; Riley et al., 2006). The risk of genetic differentiation and extinction due to the barrier effect is significantly higher in species with low dispersal abilities (Keller et al., 2004), in specialist species that require niche habitats (Fahrig, 2003) and in mammals with large habitat demands (Yahner, 1998; Herrmann et al., 2007). The effect of genetic subdivision is particularly dangerous because the time lag between the occurrence of an impact and the full ecological consequences can take decades and to date are sparely understood (Tilman et al., 1994; Jaeger et al., 2005b). More information needs to be generated by applying molecular or genetic approaches to a higher degree (Balkenhol and Waits, 2009). This type of investigation is particularly needed to study the effectiveness of wildlife crossing structures, which seem to become an increasingly popular strategy of mitigation (Corlatti et al., 2009; Van der Grift et al., 2013).

While fragmentation so far usually is cumulatively measured for larger landscapes, which yields too generic to be used for the measurement of individual vehicle impact, here a study that determined and weighted over 10,000 locations of fragmenting conflict in Germany for species of four different habitats was employed (BMU, 2010; Hänel and Reck, 2011). In the next section, being based upon the information referred to above, four methods of