A condom’s footprint - life cycle assessment of a natural rubber condom

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Abstract

Purpose Worldwide, billions of condoms are used each year, and many brands popped up that are working on sustainable solutions. However, none has published an analysis of a condom’s life using a standardized and quantitative approach such as the life cycle assessment (LCA). This study presents the first LCA of a natural rubber condom from einhorn products GmbH. It has been conducted to identify environmental hotspots, future research needs along the entire life of a condom and to open up a discussion among interested stakeholder.

Methods The assessed environmental impacts are climate change, water depletion, eutrophication, ecotoxicity, acidification, human toxicity, and photochemical oxidant formation. The data were obtained by intensive literature research and consultation of customers and suppliers.

Results and discussion The hotspot assessment showed that, on average, more than 90% of impacts are contributed by the production and downstream phases. Activities contributing most are energy consumption and packaging material used during condom production, production of tissue paper used to discard condoms, international transport, and business travels. The upstream life cycle phases do show minor contributions to most of the categories except for ecotoxicity, where the plantation activities are responsible for around 50% of the emissions. However, the impact of plantation might be underestimated because of missing analysis of biodiversity and especially for countries where rubber is responsible for deforestation the contribution of the plantation could increase.

Conclusions The results highlight the importance of the condom’s production, packaging, and the end-of-life stage. Future research should address the sensitivity of the results regarding further impact categories and should verify assumptions made and fill data gaps within the inventory.

Keywords Condom · Natural rubber · Footprint · Life cycle assessment · LCA · Environmental impact · Hotspot

1 Introduction

Condoms are an important tool of the safer sex concept as they are used not only for contraception but also to protect against sexually transmitted infections (STIs), such as HIV/AIDS (ISO 4074 2015). Around 241 million condoms are being sold annually in Germany (BZgA 2015), while several billions are sold globally. Top global condom vendors are, for example, Church & Dwight, Ansell, and Reckitt Benckiser (Research and Markets 2017). They are mainly made from natural rubber while other materials are lamb skins or synthetic rubber, such as polyisoprene or polyurethane (Marfatia et al. 2015).

It is known that natural rubber plantations can pose high risks to the local environment, such as deforestation and loss of biodiversity, loss of soil productivity, water quality, and quantity, to name but a few (Ahrends et al. 2015; Chen et al. 2016; Haustermann and Knoke 2018). Biodiversity risks are increased as these plantations are mainly located in South East Asia (FAO 2016). At the level of latex processing and condom production, energy, water and a diverse amount of chemical substances are consumed in order to change the raw material properties making
it suitable for rubber products. For example, tetramethylthiuram disulfide (Thiram) is used to process natural rubber for products like gloves and condoms. It is classified as endocrine disruptor (causing hormonal effects) and listed as substance of very high concern under the SIN list (ChemSec 2018).

Offering more sustainable condoms has been a goal for a variety of international brands (e.g., einhorn products, Sustain, Glyde, Fair Squared) focusing on a range of issues from fight against HIV, ban of harmful substances, and vegan condoms all the way to fair trade and transparency. However, to the authors’ knowledge, only one descriptive study from Dresen et al. (1993) is focusing on environmental impact of condoms and its supply chain. An analysis of a condom’s life using a standardized and quantitative approach towards environmental sustainability has not been conducted or published, so far. Hence, this study is meant to dare a first step into this knowledge gap.

2 Methods

This chapter first outlines the assessment framework employed for the LCA. Afterwards, the inventory data used for the assessment are described for each life cycle stage.

2.1 Goal and scope

The goal of this study is to examine the environmental hotspots1 of a condom’s life cycle and to identify data gaps. Hence, an environmental LCA for a male condom has been conducted. Table 1 highlights the functional unit and reference flow used for the assessment. The condom studied is from the company einhorn products GmbH (einhorn). Its life is shown in Fig. 1 highlighting the foreground phases of natural rubber plantation, latex processing, condom production, einhorn’s office (i.e., corporative activities, such as research and development), and end-of-life. Included background processes are given in dashed boxes. The timeframe assessed is one year from June 2015 (start of the online shop of einhorn) to May 2016.

2.2 Impact assessment and methods

The following midpoint impact categories are assessed: climate change, terrestrial acidification, terrestrial ecotoxicity, water depletion, freshwater eutrophication, human toxicity, and photochemical oxidant formation (ReCipe (hierarchist) (v.1.1, 2014) (Goedkoop et al. 2013)). The choice of impact categories is based on Jawjit et al. (2015, p. 86) who assessed environmental impacts of natural rubber processing and used

1 In this study, the term “hotspot” refers to the major contributors to the environmental impact (UNEP/SETAC 2009, p. 60) most of the impact categories employed here. Added are ecotoxicity and water depletion.

A single score value has been used to screen for sensitivity of assumptions made. This is not the classical way doing a sensitivity analysis, but it made the screening for potential points of importance faster because many of the inventory data were set up newly. The single score is derived from the endpoint categories “damage to human health,” “damage to ecosystems,” and “damage to resources” (incl. normalization and weighting (40% human health, 40% ecosystems, 20% resources)); hence, it should be noted that more than the five midpoint indicators listed above are combined to calculate this single score (Goedkoop et al. 2013). Results of the sensitivity analysis are summarized in Section 3.3.

The identification of hotspot life cycle stages (compare Section 3.4) is based on equal weighting of all impact categories. This approach was favored instead of the single-score methodology (as used for sensitivity analysis), because it was easier to understand for decision makers in the company einhorn although it means that two different weighting methodologies have been used in the study (see Section 3.3). In a first step, an average has been calculated from the contribution of a life cycle stage to all impact categories applied. In a second step, a color scheme has been applied to categorize life cycle stages to highest (contribution over 40%), high (contribution 10–20%), medium (contribution 5–10%), and minor (contribution less than 5%) impacts. This approach follows one of the suggestions given by the Life Cycle Initiative (UNEP 2017).

Open LCA (v.1.5) has been employed using Ecoinvent (v.3.2. APOS) for background processes. Decision on type of data used is related to whether the process unit is within foreground or background. For foreground phases, the most specifically available data form has been used (mainly gate-to-gate company data), while for background units, mainly generic data were employed. Data for all foreground phases are partly gathered by questionnaire (condom production and corporative activities) and consultation. Further, foreground data are collected via desktop research. With regard to consistency allocation procedures are in line with Ecoinvent data quality guidelines (Weidema et al. 2013).

2.3 Inventory

This chapter provides an overview of inventory data used. The Electronic Supplementary Material provides an overview of activities included, data limitations, assumptions, and allocations made. The allocated datasets are freely available on einhorn’s website (www.einhorn.my/science) and will be updated regularly.
Table 1 Study overview

| Product studied     | Condom incl. packaging system |
|---------------------|-------------------------------|
| Functional unit     | Contraception and protection against sexual transmitted infections during one act of sexual intercourse. |
| Reference flow      | One condom⁴                   |

⁴ Assumption: The possibility that more than one condom is used during sexual intercourse (e.g., due to wrong application or material malfunction of the first condom) is neglected here.

2.3.1 Natural rubber plantation

The raw material for the product system studied is field latex² harvested from the rubber tree (Hevea brasiliensis). Latex is a white, milky suspension (also called “latex milk”) consisting of rubber and non-rubber particles in water (Sethuraj and Mathew 1992; Petsri et al. 2013). It contains a dry rubber content (DRC) of about 35% (± 15%), 4–5% of non-rubber particles, and about 60% water (Sethuraj and Mathew 1992; MRB 2009). Natural rubber itself consists mainly out of polyisoprene (C₅H₈) with a carbon content of 88% per kilogram of dry rubber (Petsri et al. 2013). Latex is literally tapped from the rubber tree by cutting the bark, which is why the harvesting process is referred to as “tapping.” The main activities in a natural rubber plantation are preparing the land, establishing and maintaining the plantation, and harvesting.

The latter has been used mostly to reflect the plantation cycle of 25 years (Petsri et al. 2013), while the other methods were used to assess the status quo of the plantation under consideration. For example, the average yield for plantations in Kedah (i.e., in 1025 kg/(ha x year) (MRB 2009)) has been used here to reflect local conditions over the whole plantation cycle, while the current yield of the plantation represents around 60% of the average value.

The compiled activity data³ (see Table 2) are based on an annual mean over the plantation cycle of 25 years. Afterwards, the land is prepared for a new plantation or other uses. Harvesting activities are included for 19 years only because harvesting starts when the trees become adult. Maintenance activities are accounted for the whole plantation cycle.

The considered plantation is located in the region of Kedah (Malaysia) and has an area of 80 ha with about 450 trees per hectare. The plantation started its current plantation cycle in 1994. Half of the present rubber trees were planted in 1996. Prior to 1994, the area has been used as rubber plantation at least once (information from field survey)⁴. Based on this, the land preparation for the given plantation was mainly felling the natural rubber trees prior plantation. Felling by sawing machine is commonly used in Malaysia (MRB 2009). After felling the trees, roots are pulled out of the ground, and the remaining biomass is incinerated (Petsri et al. 2013). Greenhouse gas emissions (CO₂, CH₄, N₂O) from biomass incineration have been included based on emission factors from IPCC 2006 methodology provided by Petsri et al. (2013). Not included here is land preparation, such as terracing, road construction, and the like, because it can be assumed that infrastructure already existed from previous usage (for further information, see MRB (2009)).

The included activities for plantation maintenance cover consumption of fertilizer, fungicides, pesticides, and herbicides and their water consumption. Direct emissions from agrochemical application are calculated in compliance with Ecoinvent database (Nemecek and Schnetzer 2011; Nemecek et al. 2016). However, heavy metal emissions from agrochemicals have not been included due to missing data on soil erosion and heavy metal uptake of rubber trees. Furthermore, not included are packaging of agrochemicals and their application and water consumption for cleaning the site. Additional irrigation is not applied at the given plantation. All assumptions and limitations are listed in the Electronic Supplementary Material. These points can be marked as future research question.

Harvesting is done manually; hence, it is a very labor-intensive process. The bark is cut in a certain manner until latex is oozing out and drips for 2 to 3 h. It will be collected in cups and transported to a collection point. Due to lack of data, only the application of preservatives and stimulation is included. Ammonia is a common preservative in Malaysia (alternatives are, e.g., sodium sulfite or formalin) to stop the coagulation process, depending on the time between tapping and further processing (Webster and Baulkwill 1989; Sethuraj and...
Mathew 1992; MRB 2009). Next to that, the rubber trees can be stimulated in order to increase their yield. The active ingredient of a common Malaysian stimulant is ethylene gas that is applied to the tree’s bark and evaporates to the air (MRB 2009). However, no further information about that process has been found, which is why ethylene gas emissions are not included. The same accounts for possible ammonia volatilization during the collection process. Tools, such as the tapping knife and headlight, organic litter, consumed river water for cleaning, as well as the transport of harvested latex and by-products to the collection point and the plantation building itself have not been included due to lack of data. They should be included in the next iteration of the dataset.

By-products of field latex are field coagula, rubber wood, and seeds. Field coagulum is latex that already coagulated in the field (e.g., cup lumps or tree laces) and can be used to produce block rubber. Rubber seeds can be used for propagation or oil production while rubber wood is sold to furniture industry, for example (MRB 2009).

Economic allocation has been applied to represent the contributions of fresh latex only (using prices as given within Table 2, cp. column for original data). Mass allocation has been rejected as the co-product rubber wood holds close to 80% of produced wet mass (cp. Table 3). For carbon sequestration, allocation is based on carbon content of the products. This means that only the carbon content of latex itself has been considered. From a life cycle perspective, it becomes clear that biogenic carbon bound in products and by-products (latex, wood, and seeds) of the plantation is released as emissions from incineration processes employed at end-of-life treatment for instance. Therefore, only the biogenic carbon bound in latex has been included as only its life cycle is assessed (i.e., 88% of dry matter). Both allocation procedures are in compliance with Ecoinvent database (Jungbluth et al. 2007; Weidema et al. 2013).

2.3.2 Latex processing

The dry rubber content of the fresh latex needs to be concentrated to 60% to be used for condom production (MRB 2009). Basic activities are precipitation of magnesium content, centrifuging the latex, and additional chemical preservation. Skim block rubber is produced as a by-product. The fresh latex is processed by a company located in Kedah, Malaysia. Because of missing site-specific data, the activities considered within the study at hand are based on literature. The accuracy of these data (see Table 4) in comparison to on-site data is important for future research. The implementation of the literature data, its limitations, and adjustments are explained in the subsequent texts.

Two different studies analyzing 4 and 10 processing sites in Thailand (Chaiprapat et al. 2015; Jawjit et al. 2015) were found to be most comprehensive and best meet the system boundary considered here (i.e., using centrifugation and skim rubber block production as by-product). However, both studies do not give information on dry rubber content which will influence the output in terms of concentrated latex. In addition, the studies do relate to high ammonia content while for the condom low ammonium content is needed for the processed latex. Hence, the amount of fresh latex needed to produce concentrated latex has been calculated based on Webster and Baulkwill (1989). This resulted in 2.17 kg fresh latex (35% DRC) needed to produce 1 kg of concentrated latex (60% DRC) and 0.056 kg of skim block rubber.

Energy and water consumption are derived from the above-mentioned studies. Their average amounts have been related to the input of fresh latex calculated previously. Furthermore, the average amount of DAP (diammonium (hydrogen) phosphate; regulating magnesium content prior to concentration) from both studies has been added. The wastewater equals the sum of water input and the difference of water in fresh and concentrated latex and rubber and solids lost during the process (rainwater and evaporation are excluded).

Concentrated latex needed for condom production is the low ammonium one (LA-type), containing less than 0.3% of preserving ammonia (ISO 2010). The so-called LA-TZ preservative system is used here. It has been the most popular in the past (Webster and Baulkwill 1989; Sethuraj and Mathew 1992), although it contains TMTD which is known to form nitrosamines that can remain in the final products and is classified as endocrine disruptor according to the SIN list.
Limitations of the data given here are missing NH$_3$ volatilization emissions from deammonification, missing data for wastewater treatment (except electricity), emitted hydrogen sulfide and methane specific to latex-processing sites, and missing information about black and pond rubber production. As the fate of added chemicals is not completely clear, an unspecified mass of 0.01 kg per kilogram of concentrated latex is added to the output side in order to keep the mass balance. This can be marked as further research question.

The used data are allocated according to economic value, because there is no major difference between economic and physical allocation and it is consistent with allocation methodology used in Ecoinvent (Weidema et al. 2013) and other processes within the studied system.

### Table 2 Natural rubber plantation, activity data (annual average over 25 years plantation cycle), not allocated

| Activity                                      | Unit       | Inventory data [unit/(ha * year)] | Original data                                                                                                                                                                                                 |
|-----------------------------------------------|------------|----------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| **Input**                                     |            |                                  |                                                                                                                                                                                                              |
| Harvesting wood                               |            |                                  |                                                                                                                                                                                                              |
| Power sawing                                  | Machine hour | 2.34                             | 125 l gasoline per hectare (Petsri et al. 2013), Ecoinvent dataset for power sawing: 2.13 l gasoline per machine hour (Magnusson et al. 2000)          |
| Biomass residues after harvest, to be incinerated | tonne     | 1.74                             | 43.54 kg/ha after plantation cycle (Petsri et al. 2013)                                                                                                                                                |
| **Plantation maintenance & harvesting latex**  |            |                                  |                                                                                                                                                                                                              |
| N fertilizer                                  | kg         | 34.75                            | Fertilizer application according to field survey (including immature (first 6 years) and mature phases (19 years))                                                                                   |
| P fertilizer                                  | kg         | 31.07                            | Average application in Malaysia between 2006 and 2013 (FAO 2016); herbicide = glyphosate, fungicides = triazole                                                                                      |
| K fertilizer                                  | kg         | 41.84                            |                                                                                                                                                                                                              |
| Mg fertilizer                                 | kg         | 2.64                             |                                                                                                                                                                                                              |
| Insecticides                                  | kg         | 0.34                             | Average application in Malaysia between 2006 and 2013 (FAO 2016); herbicide = glyphosate, fungicides = triazole                                                                                      |
| Herbicides                                    | kg         | 5.21                             | 100 liter/kg active ingredient (excl. fungicides), informed guess (MRB 2009; Petsri et al. 2013)                                                                                                           |
| Fungicides & bactericides                     | kg         | 1.23                             | 0.3% of latex weight (wet mass), average value (Webster and Baulkwill 1989; Sethuraj and Mathew 1992; MRB 2009)                                                                                          |
| Water (for plant protection)                  | m$^3$      | 0.56                             | 0.75 g/tree, 2 times a year (application possible 2–12 times year, but only done irregularly at plantation), applied during mature phase (i.e., 19 years) (MRB 2009)          |
| Ammonia (preservation)                        | kg         | 6.68                             | 0.3% of latex weight (wet mass), average value (Webster and Baulkwill 1989; Sethuraj and Mathew 1992; MRB 2009)                                                                                          |
| Ethephon (stimulation)                        | kg         | 0.51                             | 0.3% of latex weight (wet mass), average value (Webster and Baulkwill 1989; Sethuraj and Mathew 1992; MRB 2009)                                                                                          |
| **Output**                                    |            |                                  |                                                                                                                                                                                                              |
| Products                                      |            |                                  |                                                                                                                                                                                                              |
| Fresh latex (60% wet mass)                    | kg         | 2225.71                          | 1025 kg/(ha * year), average yield for soil in Kedah, harvested only during mature phase (i.e., 19 years) (MRB 2009), price (average 2014–2016): 4.61 MYR/kg (dry mass) (MRB 2016) |
| Field coagulum (50% wet mass)                 | kg         | 445.14                           | 20% of fresh latex production (MRB 2009), price (average 2014–2016): 2.11 MYR/kg (wet mass) (MRB 2016)                                                                                                 |
| Timber, felled (50% wet mass)                 | kg         | 10,749.84                        | 600 kg/tree (dry) after plantation cycle (Petsri et al. 2013), 448 trees/ha (field survey), price: 0.15 MYR/kg (wet mass) (MTIB 2016)                                                                      |
| Rubber seeds (50% wet mass)                   | kg         | 114.00                           | 300 kg/ha (Ng et al. 2013), 50% harvested during mature phase (i.e., 19 years), price: 1 MYR/kg (wet mass) (Ng et al. 2013)                                                                               |
Table 3: Physical and economic allocation factors at rubber plantation

| Product         | Physical (based on wet mass) | Economic (prices given in Table 2) |
|-----------------|-----------------------------|-----------------------------------|
| Latex           | 0.16                        | 0.57                              |
| Rubber wood     | 0.79                        | 0.26                              |
| Field coagulum  | 0.03                        | 0.15                              |
| Rubber seeds    | 0.01                        | 0.02                              |

Table 5 lists the allocation factors highlighting that the difference between both is marginal.

2.3.3 Condom production

After concentration, the latex is ready to be used for the production of condoms. The processes involved are preparing the latex compound (with chemicals), dipping, vulcanization, stripping and cleaning, testing, and packaging. The condom production of the condoms takes place at Richter Rubber Technology (RRT) in Malaysia. RRT is producing condoms as well as machines to manufacture and test condoms (solely, the first is assessed here). The annual production volume in 2015 has been 554 million condoms which is more than twice as much as the annual amount of condoms sold in Germany (BZgA 2015, p. 22). Only a small share is produced for einhorn, but most condoms at RRT are produced with similar ingredients and technology as provided here.

Only very limited literature data have been available supposedly because the mixture of chemicals added to the concentrated latex is often a business secret. Hence, the data have been derived from a questionnaire to RRT and consultation. Gate-to-gate information on used ingredients, energy and water consumption, and amount of waste and wastewater have been gathered and compiled in Table 6. For business confidentiality reasons, the ingredients had to be aggregated. We hope to provide a more detailed and transparent analysis of the ingredients in future studies. Capital goods, such as machinery and production building, are not included in the dataset.

2.3.4 Corporate activities

After the transportation of condoms from Malaysia to Germany, the condoms are stored at einhorn’s office in Berlin (Germany) before being retailed. The activities here are dedicated to product development, sales, logistics, communication, and “fairstainability.”

Although it is not consistent with other phases of the life cycle, the scope of assessed activities of this phase has been broadened towards office activities (energy and water consumption) and transports, such as commuting and business travels. Prior phases only include production activities while the mentioned points have been neglected. However, for einhorn, they do represent major issues in order to decrease their environmental impact, which is why they are included here. Note that all activities are directly associated with the condom, because no other product existed during the assessed timeframe. The information has been gathered by consultation and a questionnaire.

Around 1.5 Mio condoms have been sold in one year (since the start of online retailing in June 2015). For simplification, it is assumed that there is no additional stock at the office. The office is a co-working space, i.e., four to five different companies share the office area of 238 m². einhorn holds a share of 27% of it (equals 64.26 m²). This has been used to allocate the different office activities as no information on economic activities of all companies was available. Furthermore, information on municipal waste streams was not available too (Table 7).

2.3.5 Logistics

The raw material extraction is done at a natural rubber plantation in the region of Kedah (Malaysia). The tapped field latex is transported to the latex-processing site (to concentrate the rubber content) and then send to condom manufacturing where the condoms are produced, tested, and packed. Afterwards, the condoms are mainly transported to Germany by ship while a minor share has been transported by plane during the assessed time period. Further road transport is done by trucks. The condoms are stored at einhorn’s office in Germany and are sold via web shops and grocery stores.

After usage, the condoms and packaging materials enter the end-of-life treatment. Table 8 summarizes the phases, companies involved, the transport distance from the previous phase, and details for goods transported. Note that for interpretation the logistic stages of intercontinental transport (i.e., transport from Malaysia to Germany) and retailing are outlined as separate life cycle stages because of their importance. However, they are summarized here for a better overview.

Used retailing options are online retailing and traditional retailers, such as supermarkets and grocery stores. LCA results of retailing systems are prone to high uncertainties based on the chosen assumptions that need to be made for different retailing channels (cp. van Loon et al. 2014). Hence, we rather tried to set up a first indication of how important the retailing phase is in the condom’s life and then tried to understand it completely. The model presented here is very limited and needs to be detailed further in future work. Van Loon et al. (2014) indicate which aspects could be integrated further.

Figure 2 illustrates the retail model used, distances, additional packaging, and shares each retail channel holds. For traditional retailing, only the distance to the average consumer’s location is used (380.7 km. based on a customer...
survey from einhorn). In addition, the traditional retailing requires the customer to buy the condom in a store, which is why a shopping trip is considered. According to the Federal Ministry for Transport and Digital Infrastructure (BMVI), a daily distance of 8.13 km per person is covered in Germany for shopping purposes with 83.1% of it done by motorized transport (car or motorcycle) (BMVI 2015). Half the way is used here to transport the condom back home. Conservatively, it is considered that all customers take the car for the shopping trip. For other online retailers, the average distance has been calculated based on consultation with einhorn (488.9 km), and the transport to the customer (380.7 km) is considered in addition. For purchasing via einhorn's online shop, only the distance to the customer is considered. The transport processes are based on the vehicle fleet of Deutsche Post DHL (DHL 2015). After consumption, a transport distance of municipal waste

Table 4  Latex processing, activity data, not allocated

| Activity                                                | Unit     | Inventory data | Original data                                                                 |
|---------------------------------------------------------|----------|----------------|-------------------------------------------------------------------------------|
| Input                                                   |          |                |                                                                               |
| Fresh latex (35% DRC)                                   | tonne    | 2.17           | Based on composition of fresh latex, concentrated latex and skim block rubber as given within (Webster and Baulkwill 1989) |
| Water                                                   | m³       | 5.09           | 2.35 m³/tonne fresh latex input (Chaiprapat et al. 2015; Jawjit et al. 2015)  |
| Electricity                                             | kWh      | 93.44          | 43.13 kWh/tonne fresh latex input (Chaiprapat et al. 2015; Jawjit et al. 2015) |
| DAP (for magnesium precipitation)                       | kg       | 2.17           | 0.1% of fresh latex weight (Chaiprapat et al. 2015; Jawjit et al. 2015)        |
| Preservative system                                      |          |                |                                                                               |
| Ammonia                                                 | kg       | 4.33           | LA-TZ preservative system: 0.2% ammonia. 0.013% tetramethylthiuram disulfide (TMTD). 0.013% zinc oxide and 0.05% lauric acid (by weight of fresh latex) (Webster and Baulkwill 1989; Sethuraj and Mathew 1992) |
| tmtd                                                    | kg       | 0.28           |                                                                               |
| ZnO                                                     | kg       | 0.28           |                                                                               |
| Lauric acid                                             | kg       | 1.08           |                                                                               |
| By-product processing                                   |          |                |                                                                               |
| Sulfuric acid (coagulant)                               | kg       | 4.33           | 0.2% of fresh latex weight (Chaiprapat et al. 2015; Jawjit et al. 2015)        |
| LPG (for drying)                                        | MJ       | 156.66         | 1.64 kg LPG/tonne fresh latex input (Chaiprapat et al. 2015). Conversion factor of 0.02265 kg/MJ as given by the employed Ecoinvent dataset “heat production, propane, at industrial furnace > 100 kW.” |
| Output                                                  |          |                |                                                                               |
| Products & waste                                        |          |                |                                                                               |
| Concentrated latex (39% wet mass)                       | tonne    | 1.00           | Calculated based on composition of fresh latex, concentrated latex and skim block rubber as given within (Webster and Baulkwill 1989), price (2014–2016 average): 4.24 MYR/kg (MRB 2016) |
| Skim block rubber (0% wet mass)                         | tonne    | 0.06           | Calculated based on composition of fresh latex, concentrated latex and skim block rubber as given within (Webster and Baulkwill 1989). Price (2014–2016 average): 5.29 MYR/kg (MRB 2016) |
| Wastewater                                              | m³       | 6.20           | Sum of water input difference of water in fresh and concentrated latex, rubber, and solids lost during the process (rainwater and evaporation are excluded) |
| Unspecified mass                                         | tonne    | 0.01           | Mass balance for chemicals not analyzed (i.e., fate unclear)                   |
collection of 5 km is considered, based on the dataset for Switzerland in Ecoinvent (Doka 2007).

Connected to different retailing options are additional tertiary packaging that are added to the condom if condoms are send directly to the customer (i.e., for all online purchases). The newly added packaging is mainly used by einhorn and contains up to seven bags of condoms. It is a folding boxboard with the mass of 133.04 g (i.e., 2.7 g per condom). For simplification, it is assumed that other online retailers are using the same packaging. As the new packaging is added, the former one is discarded for online retailing. For transport to traditional retailing, the former tertiary packaging is reused, but finally also discarded in groceries and supermarkets.

### Table 5: Physical and economic allocation factors at latex concentration

| Product                     | Physical (based on wet mass) | Economic (prices given in Table 4) |
|-----------------------------|------------------------------|------------------------------------|
| Concentrated latex          | 0.95                         | 0.94                               |
| Skim block rubber: at gate  | 0.05                         | 0.06                               |

### Table 6: Condom production, activity data

| Activity                      | Unit Inventory data (unit/condom) | Original data                                         |
|-------------------------------|-----------------------------------|-------------------------------------------------------|
| Input                         |                                   |                                                       |
| Tap water                     | ml                                | 39.71                                                 |
| Electricity                   | Wh                                | 6.81                                                  |
| Ingredients                   |                                   |                                                       |
| Concentrated latex            | g                                 | 2.88                                                  |
| Ingredients                   | g                                 | 1.42                                                  |
| Lubricant (silicone oil)      | g                                 | 0.38                                                  |
| Packaging                     |                                   |                                                       |
| Primary packaging             | g                                 | 0.89                                                  |
| Secondary packaging           | g                                 | 2.84 g/bag (containing 7 condoms) + rejection rate, composition: 68 wt% paper / 32 wt% polyethylene |
| Transport packaging           | g                                 | 0.85                                                  |
| Output                        |                                   |                                                       |
| Product & waste               |                                   |                                                       |
| Condom. packed                | g                                 | 3.87                                                  |
| Prim. packaging (rejected)    | g                                 | 0.004                                                 |
| Sec. packaging (rejected)     | g                                 | 0.008                                                 |
| Condom waste (rejected)       | g                                 | 0.022                                                 |
| Wastewater                    | ml                                | 128.68                                                |

#### 2.3.6 End-of-life

After usage, the condoms and the packaging materials enter the end-of-life phase. As only German consumption is analyzed, this accounts for end-of-life actions too. Used condoms and discarded packaging material are the relevant waste streams under consideration.

Important choices regarding end-of-life options are made by the consumer. An online customer survey provided insights of where and how condoms are discarded. Over 87% of einhorn’s customer state that they discard used condoms into residual waste bins, followed by flushing down the toilet, using the yellow or organic. In addition, the surveys showed that close to 50% of consumers use toilet paper to discard the condom while the other half only knots the condom and discards it (einhorn 2016). The assessment in the study at hand is based on a simplified disposal route of condoms: Only the residual waste stream is assessed because it holds the highest share among the options. In addition, waste management companies, such as Berliner Stadtreinigung (BSR), advise to discard condoms into residual waste bins leading to incineration of the condom (BSR 2016). To reflect the discarding behavior, the impact of additionally used toilet tissue paper has been allocated to half of the condoms, as well. It has been assumed that three papers of three-ply toilet paper with a basic weight of 20 g/m² and an area of 12 ×
12 cm are used (Tillmann 2012). The toilet paper enters the residual waste stream and is incinerated with the used condom.

Analyzing the relevant German waste streams for the used packaging material shows that the majority of aluminum, plastic, and paper packaging not collected separately end up in energy-recovery plants (waste incineration or substitute fuels) (UBA 2015). Datasets for incineration have been available in Ecoinvent for polyethylene and paper but not for aluminum where only a general municipal solid waste incineration in Germany is used instead. Tertiary packaging is made from boxboard, which is collected separately in Germany. Between 2008 and 2013, over 88% (and here mainly separately collected) waste paper and board has been recycled leading to waste paper usage in new paper production of over 70% (UBA 2015).

### Results

This section shows the results of the conducted life cycle assessment. Trying to identify phases and activities that do contribute most to the environmental impact, first a short overview of contributions by each life cycle stage to the overall results is provided. Subsequently, the activities’ contributions within each stage are

| Table 7 | Correlative activities, allocated |
|---------|----------------------------------|
| **Activity** | **Unit** | **Inventory data (unit/year)** | **Original data** |
| Input | Tap water | liter | 150.00 | Water bill from 2013 |
| | Electricity | kWh | 1056.24 | Energy bill from 2014/15; green energy mix (not included here) |
| | Heating (light fuel oil) | kWh | 9767.52 | Average consumption in Berlin: 152 kWh/m² (Heizspiegel 2014) |
| Commuting | Public transport | km | 21,840.00 | Average distance 7 km (one way), 6 employees, 260 work days |
| | Bycicle | km | 3640.00 | See previous texts, 1 employee |
| Business travel | Plain | km | 37,870.00 | |
| | Train | km | 8370.00 | |
| | Car | km | 856.00 | |
| Output | Condoms ready for retail | unit | 1,500,000.00 | |
| | Wastewater | liter | 323.150 | |

| Table 8 | Foreground phases, companies, and transportation distances |
|---------|--------------------------------------------------------------|
| **Phase** | **Company** | **Location** | **Transport distance from previous phase**<sup>a</sup> (km) | **Transported good**<sup>b</sup> (g/condom) |
| Rubber plantation | Kai Sik Plantation | Malaysia, Kedah | – | – |
| | Lee Latex | – | 7.8 | 6.28 (fresh latex) |
| | – | – | 34.5 | 3.67 (concentrated latex) |
| Condom production | Richter Rubber | Malaysia, Kedah | 63.0 (truck to airport) | 1.73 (condom) |
| Planning & storage | einhorn | Germany, Berlin | + 10,700 (plane to Berlin) | 0.89 (primary) |
| | | | + 14.2 (truck to office) | 0.41 (secondary) |
| | | | + 45.5 (truck to harbor) | 0.85 (tertiary 1) |
| | | | + 16,500 (shipping to Hamburg) | |
| | | | + 294.0 (truck to Berlin) | |
| Retail | diverse | Germany | Retailing/Einhorn webshop: 380.7<sup>b</sup> + shopping trip 4 km (by car) | 1.7 (condom) |
| | | | E-tailing: 488.9 + 380.7 | 0.89 (primary) |
| | | | | 0.41 (secondary) |
| | | | | 0.85 (tertiary 1: 69.9%) |
| | | | | 2.72 (tertiary 2: 30.1%) |
| End-of-life | – | Germany (diverse) | 5 km (waste collection) | – |

<sup>a</sup> Based on google.de/maps
<sup>b</sup> Average distance from Berlin to state capital weighted according to share of online customers per state (einhorn 2016)
<sup>c</sup> Primary, primary packaging; secondary, secondary packaging; tertiary 1, transport packaging from Malaysia to Germany; tertiary 2, transport packaging to customer
outlined. Afterwards, the sensitivity analysis and hotspot assessment are presented.

3.1 Contribution of life cycle stages

The contribution of the life cycle stages to the environmental impact of condom is displayed in Fig. 3. It can be concluded that the system’s impact is mainly driven by the production of the condom and the downstream phases while rubber plantation and processing only play a minor role, except for terrestrial ecotoxicity.

The contribution of the natural rubber plantation towards the environmental impact categories stays under 1% except for terrestrial ecotoxicity, where it is responsible for more than 50% of the emissions. The contribution of the latex processing stage is also rather small compared to other downstream phases (range between 0.6% and 2.75%). As Fig. 3 indicates, the manufacturing of condoms is the biggest source of emissions in the condom’s life. Between 36.9 and 52.5% of the emitted emissions within the selected impact categories (except terrestrial ecotoxicity) stemmed from the manufacturing process and its upstream activities (excl. supply of latex). Terrestrial ecotoxicity is the only impact category that the condom production does not dominate (22.1%). Further, the road transportation of the packed condom from the production site in Malaysia to einhorn’s office in Germany does contribute to the environmental impact within a range of about 1.4 to 19.3%, with highest contributions to climate change (7.1%), terrestrial acidification (15.2%), and photochemical oxidation (19.3%). The stage of planning and storage contributes between 6.2 and 22.6% to the selected impact categories. Except for terrestrial acidification, it is responsible for more than 10% of the environmental impacts. The share of retailing on the condom’s footprint ranges from about 7.2 to 1.50%; hence, it is relatively constant. The impact of the end-of-life stage is rather high ranging between 10.1 and 39.2%. Based on these numbers, it can already be concluded that the condom’s environmental impact (based on the assessed impact categories) is dominated by condom production and downstream phases. The only exemption is terrestrial ecotoxicity where the rubber plantation is contributing most emissions. The next section will detail which activities are the strongest contributors to each phase’s impact.

3.2 Activity contribution

3.2.1 Natural rubber plantation

The strongest contributors to the plantation’s impacts are nitrogen and phosphor fertilizer, plant protection, and the felling of trees. Direct impacts are included for application of phosphor (P) and nitrogen (N) fertilizer, herbicides, and insecticides. Furthermore, the felling of trees (power sawing) and subsequent incineration of biomass residues do directly emit substances at the site. Carbon bound in fresh latex has also been included in the dataset—the uptake exceeds the emitted mass of CO2 equivalents due to other activities by a factor of 2.19 which is why the impact for climate change is negative. However, please see Section 4 for discussion on the impact of the plantation.

As outlined previously, the plantation is contributing most to terrestrial ecotoxicity. Here, 98.7% is direct emission from application of insecticides. The rest is due to direct emission of glyphosate (herbicides) application and indirect emissions from supply chain (here, mainly the fuel used for felling of trees). Looking at Fig. 3, it becomes clear that the integration of the ecotoxicity indicator was important to not underestimate the role of the plantation in the supply chain. Fertilizer’s production and application are responsible for major emissions towards eutrophication (68%), acidification (90%), and human toxicity (64.8%), while holding a share of emissions between 24 and 45% for the other indicators. Especially the direct emissions from phosphor application are responsible for more than half of the emitted substances towards eutrophication (51.9%) while direct emissions from nitrogen application are responsible for acidification emissions (69.9%).

In terms of activities related to felling of trees and incineration of residues, the relative influence on photochemical oxidation and climatic change is high: 52.3% direct emissions plus 5.9% upstream emissions from power saving and 51.9% direct emissions from biomass incineration, respectively. Otherwise, both do not contribute much to other categories.

Among other agrochemicals, especially herbicides do show a high impact (on average, 18.9% over all indicators).

3.2.2 Latex concentration

The highest contributor to emissions is consumed electricity mainly used for centrifugation of fresh latex. It holds a share within the range of about 57 to 69% within all categories except ecotoxicity. Here, the supply of fatty acids is responsible for 88% of the emissions.

Chemicals are employed for the regulation of magnesium content (DAP) preservation (LA type: ammonia, TMTD, lauric acid, and zinc oxide) and to support the coagulation of skim latex by neutralization (sulfuric acid). DAP upstream emissions always are higher than 4% and increase to close to 10% for acidification and human toxicity (average among all is 7.3%). For the preservative system, TMTD and ammonia hold the highest shares of relative impact. TMTD, though only applied on 0.013% per weight of wet latex, contributes with an average value of 4.3% and especially to acidification (7.8%) and human toxicity (9.9%). Ammonia is applied with 0.2% of wet latex weight but contributes only slightly more (average of 5.3%). The other chemicals do show a minor contribution. The environmental impact of latex concentration does not include direct emissions from activities in latex processing despite of heat production.

6 Direct emissions are understood here as those that stem from the application of chemicals, while indirect emissions stem from the supply chain.
3.2.3 Condom production

Figure 4 gives an overview of the contribution of condom production activities for climate change, water depletion (qualitatively likewise for other categories), and ecotoxicity. On top, basic activities, such as wastewater, water consumption, electricity, and transport from latex concentration, are given. Here, especially the influence of electricity consumption needs to be highlighted as it shows a contribution between 10 and 37% of the complete production process. The electricity is reflecting the Malaysian grid mix with high consumption of hard coal and natural gas (Weidema et al. 2013). It has not been allocated to different production activities here due to missing information. The other basic activities do not show high contributions.

As the inventory data are for the packed condom, the packaging material is also assessed in Fig. 4. It can be concluded that the impact of the materials is high. Despite of ecotoxicity (15%), the contributions are really high ranging from at least about 38% (eutrophication) to a maximum of 59% (water depletion). The chart furthermore highlights that the upstream activities of the primary packaging incorporate the highest share of emissions compared to other packaging which is driven by the used aluminum. For example, for climate change, aluminum in primary packaging holds 57% of the emitted CO₂ equivalents while about 23% is due to produced paper and 20% based on thin film polyethylene.

The last point is ingredients (except rubber) used to produce condoms. Together, 15 different substances make up for around 10 to 56% (ecotoxicity) of the impact depending on the category. Unfortunately, current information on the ingredients cannot be disclosed because of business secret.

Interesting about the results is that the mass of concentrated latex in the condom production exceeds well
one third of the wet mass material input (including all ingredients and packaging materials for the product). However, the impact remains low next to the consumption of energy and the primary packaging material, where especially aluminum shows high environmental burden. Section 3.4 especially highlights the overall impact of energy consumption and primary packaging used during condom production. Probably another way of sorting the materials could have changed the outcome. For instance, if all materials and ingredients (including their upstream supply chains) would have been aggregated in a process, this would have resulted in higher importance of upstream activities on the general level. However, from our perspective, this is counter-intuitive because the main ingredient is natural rubber and remaining materials are additional.

3.2.4 Intercontinental transport

Regarding those impact categories selected, the transportation has its main impacts on photochemical oxidation, terrestrial acidification, and climate change (in descending order) at 19, 15, and 7%, respectively. Although only 3.1% of the condoms have been transported by plane in the considered timeframe, they still hold an important share of emissions. Especially, they make up for over 60% of the climate change emissions.

3.2.5 Corporate activities

The impact of corporate activities is mainly driven by transport processes and electricity demand. Business travels are responsible for major contributions to climate change (68.8%), terrestrial acidification (79.2%), and photochemical oxidation (86.1%) within the life cycle stage. Passenger transport by car, high-speed train (ICE), and plane are considered for business travels. The electricity demand of office activities is responsible for about 13% of emissions (on average, ranging from 2.8 to 23.2%). The German electricity mix has been used, although einhorn is purchasing a green electricity mix that is only made from renewable energies.

3.2.6 Retailing

While the impact of sale via online shops is mainly driven by the use of new tertiary packaging material, the traditional retailing in supermarkets is mainly driven by the transportation of the condom. A real comparison between the different retailing channels is difficult because the model is based on many uncertainties and assumptions (as outlined previously).

3.2.7 End-of-life

End-of-life treatment also includes the usage of toilet paper to discard the condom (for 50% of consumers). Remaining customers only knot the condom and throw it away. Figure 5
displays the environmental contributions for acidification for end-of-life treatment and the production of toilet paper used. It becomes clear that the toilet paper production is dominating the impact of the phase. This is qualitatively the same for the other impact categories, except for climate change where end-of-life treatment is dominating while the toilet paper production is responsible for only 15% of the greenhouse gas emissions.

In general, we can record a high influence of the toilet paper production and treatment. Focusing on the end-of-life activities only, the major contributor is the condom’s incineration (contributing between 33 and 72%).

3.3 Sensitivity analysis

A sensitivity analysis has been conducted to test assumptions and informed guesses made during inventory development. A Recipe single score (hierarchist) has been employed to ease the sensitivity analysis because of the high amount of data to test. Tested parameters are the following: latex yield, amount of seeds and timber actually used, water use for agrochemicals, applied stimulation, applied preservation, distance to customer for reselling online, and amount of used toilet paper for discarding the condom. Among these, a relatively high change of impact was observed for latex yield and used toilet paper (Fig. 6).

The latex yield varies based on different variables, such as tapping systems, type of rubber tree (clone), or experience of tappers, and weather conditions (MRB 2009). The product system has been tested towards its behavior when changing the yield from current output of 613.5 kg (dry rubber content) per hectare and year to the optimum output of the tree that is planted at the plantation. The environmental impact increases for the lower yield (3.2%) and decreases for the higher yield (−1.8%). The deviation is rather high keeping in mind that the plantation share of impacts is small. Hence, the dry rubber content of the fresh latex can be important when analyzing the impact of rubber products.

The strongest deviations for environmental assessment are received for the assumed consumption of toilet paper for discarding the condom after usage. A total of 50% of einhorn’s customers use toilet paper to discard the condom. However, it was unknown how much they use. Therefore, the originally assumed value of three has been compared to six pieces of toilet paper and no use at all. As the impact of the toilet paper is generally high, this reflects in the impact assessed during sensitivity analysis (± 10.4%).

Other parameters only show minor deviations to the overall system’s impact when tested. However, it should be noted that no interrelation of the parameters is established in the inventory model (i.e., static model). For example, a change in the application rate of stimulation methods should lead to a different yield which has not been realized in the model. This can be marked as research question.

3.4 Hotspot assessment

The identification of hotspot life cycle stages is based on the methodology as described in Section 2.2. It is based on equal weighting of all impact categories, resulting in a single score average contribution. The approach has been favored instead of the Recipe methodology (compare sensitivity analysis) because it was more transparent and easy to understand for decision makers in the company environment of einhorn. A color scheme has been applied to categorize life cycle stages to highest (contribution 20–40%), high (contribution 10–20%), medium (contribution 5–10%), and minor (contribution less than 5%) impacts. Figure 7 shows the outcome of the assessment. Activities that contribute most to the emissions of each stage are added, as well. Subsequently, the impact of the highest hotspots is described more in detail. To avoid repetitive information, please refer to Section 3.2 for details on the other life cycle stages.

The figure highlights the importance of condom production stage and downstream phases that together are responsible for more than 91.3% of the average contribution. The average contribution of the highest hotspots equals 62% of the condom’s life.

Condom production contributes with 41.7%, thus is dominating the condom’s impact. Here, energy consumption and primary packaging are the major contributors (making up more than 60%). Looking on the condom’s whole life, primary packaging materials and energy consumption at condom production do contribute close to one third to the environmental impact of the condom’s life (28%). Further important activities at condom production are additional packaging and some ingredients.

The end-of-life stage is the second highest contributor to environmental impacts (on average 20.7%). However, most of
its emissions are due to the production of used toilet paper when discarding the condoms (on average, 74%). The incineration of the condom is the second highest contributor (12%) when it comes to end-of-life activities.

The top five activities are tissue paper production (15%), primary packaging material (14%), energy consumption at condom production (13%), business travel (7%), and international transport of condoms (7%).

4 Conclusions and outlook

This paper presented the first life cycle assessment of a condom. The goal was to provide an overview of environmental hotspots along the life cycle and to identify data gaps (an overview of included data and data gaps is provided in the Electronic Supplementary Material). Therefore, inventory data for the assessment were obtained in intensive literature research and consultation with stakeholder in the supply chain. Regularly updated inventory data can be found on www.einhorn.my/science.

Despite of ecotoxicity, it can be concluded that the major environmental impacts assessed for the given impact categories can be found in the condom production and downstream phases (on average, 91.3%). Alternative options for the hotspot phases and activities can be a starting point for decreasing the environmental impact in the condom’s life. For example, the impact of electricity consumption during condom production might be changed using renewable energy sources (e.g., a solar system has been installed at condom production site after this study was conducted). It can be analyzed if substitutes or alternative production pathways are available for used ingredients, such as lubricants. Furthermore, the choice of packaging material used can help to reduce burdens during production, transportation, and end-of-life. For example, applying mono-materials where possible could increase recyclability of the materials used. Furthermore, trying to avoid aluminum—as currently recommended in ISO/DIS 16038:2016 (a drafted site document to ISO 4074 on condoms) and used for many condoms—and finding alternative materials with appropriate barrier for primary packaging could be an interesting way of substantially decreasing the condom’s burdens on environment. Understanding the fate of chemicals applied during condom production and the contribution of capital goods, such as machinery, are data gaps to be addressed. The intercontinental transport of condoms is strongly influenced by air transport (although only about 3% of condoms were transported by plane in the analyzed timeframe). We conclude that a company policy of further avoiding air transport can result in lower emissions. The same recommendation can be suggested for companies that produce condoms elsewhere but need to transport concentrated latex from South East Asia to production facilities.

In terms of einhorn’s business activities, it can be recommended to check options towards energy consumption and less business travel to Malaysia. However, building good relationship to supply chain stakeholder will be contradictory to reducing business travels to the region. In terms of data gaps, especially produced waste and more recent data need to be included in future assessments to give a more comprehensive picture. Looking at retail, a medium contribution to the environmental impact has been observed. However, a review of van Loon et al. (2014, p. 291) showed that the environmental impact of online and traditional retailing is prone to high uncertainties based on assumptions made. This highlights the urgent need to improve the model used here in order to show the complete picture. In terms of end-of-life, a customer survey by einhorn suggested that the majority uses residual waste bins, but also not recommended options like organic waste or toilet are used to discard condoms. This issue can probably be met by a clear and transparent communication strategy. The same accounts for additional toilet paper used by half of the customers to wrap and discard condoms. It was found to be one of the major sources of emissions in the life of condoms. Around 50% of consumers simply knot the condoms without using toilet paper to discard them. Hence, increasing the share of customers doing so would be a way to decrease the environmental burden. However, further research on how much toilet paper people really use would be of importance.

In comparison to the only existing earlier study (cp. Dresen et al. 1993), we found that condom production and its...
downstream phases are responsible for a very high share of environmental impacts. We assume that they were not able to put the activities in the different life cycle phases into relationship with each other because they did not use a quantitative life cycle approach but rather a descriptive one. We found that the impact of natural rubber plantation was rather low for most of the analyzed impact categories except for ecotoxicity. However, this is only partly in contrast of what has been suggested by Dresen et al. (1993): “[the] most important environmental problems [within the life cycle of condoms] occur during the stage of primary production: the cutting down of tropical forests; the use of herbicides and the emissions that occur when raw latex is being processed.” It needs to be highlighted that no indicator for biodiversity or land use change is included in the study at hand. Furthermore, no rainforest has been cut down for the studied plantation in the last 20 years and the rubber sector in Malaysia is decreasing, which is why deforestation and related impact on climate change have not been assessed here. The picture may change if we analyze plantations in countries where the rubber sector is currently growing strongly as is the case in Cambodia (Rubber Asia 2017). The results presented here can only be understood in the given system boundary and the plantation’s impact might be small compared to other locations. The high influence on terrestrial ecotoxicity underlines the findings of Dresen et al. (1993) and other more recent publications (Haustermann and Knoke 2018) on environmental problems of rubber plantation. This highlights the importance of the integration of the ecotoxicity indicator to not underestimate the rubber plantations’ role in the supply chain. Integrating further indicator on ecotoxicity, biodiversity, and land use change as well as the impact on climate change for newly developed plantations on former rainforest area will most likely show a higher impact of the rubber plantations. This may change the picture provided here. We can conclude that the role of rubber plantation towards the ecosystem needs to be addressed in more detail in future life cycle studies to draw a more general picture.

Although it was not the aim of this study to provide policy recommendations, some points can be concluded for the policy level. Even if the picture of rubber plantation in the condom supply chain is not completely clear, it can be highlighted that incentives to stop deforestation of rainforest for plantations and moving towards sustainable rubber cultivation without monoculture plantation with a high need for agrochemicals should be addressed (cp. Haustermann and Knoke 2018). The case of condom production shows again that the amount of energy needed for production is an important driver for environmental burdens. The shift towards renewable energy sources can minimize the resulting negative impacts. The global waste problems further demands for sustainable packaging solutions. The condom’s individual packaging is neither recyclable because of the material mix used nor resource efficient using aluminum foil. Incentives to push companies using less material and mono materials are needed. In addition, including well-defined barrier thresholds into the international standard for condoms (ISO 4074 2015) could help companies to move away from aluminum and finding a more sustainable material that also fits the barrier needs of the product.

Quite general, it can be stated that the results are prone to uncertainties related to data limitations as listed in the Electronic Supplementary Material. Decreasing these uncertainties should be addressed in future research. It can also be concluded that testing the results with further indicators (i.e., those recommended by Life Cycle Initiative) would be advisable for future research on this issue. However, to our knowledge, no other recent study exists that analyzes the environmental impact of the life cycle of a condom. Thus, it is the intention of the authors to initiate a discussion and future research on sustainability of condoms and to invite interested stakeholder to participate.

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