The Carbon Footprints and Equipments Energy Consumption Assessment for Bicycle Rubber-Tire

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Abstract. High-priced rubber tires are important key components in the bicycle industry chain. The annual bicycle tire output is about 150,000 product lines in Taiwan. Relevant carbon emission inventory data analysis is the focus of the industry's sustainable development and circular economy. Most researches study paper did not completely disclose supply chain inventory data. Relative comparison this bicycle rubber-tire case industry chain is more complete and the inventory data is more detailed.
This tire product case study is original and compiles exclusive Taiwan local activity data and carbon emission database. The important investigation results are as follows: (1) A single product is a functional unit of 561g bicycle rubber-tire carbon emissions of 1.64kgCO2e. Internationally verified BSI certification. (2) The analysis result meets the Monte Carlo analysis requirements. (3) This important practical case study completed two major central factories and five satellite suppliers to check the local activity data, equipment energy consumption and carbon footprint emissions, confirmed by a third party international verification unit BSI. (4) The application and review of the B to B product carbon-label were completed, it can be used for international marketing. The database and practical results published in this paper can be used as a reference for academics and business circles.

1. Introduction
In order to cope with the green product policy promotion, combined with the phased joint efforts of the indicator bicycle industry chain, the practical focus is to check the carbon footprint of the functional units of the bicycle key components rubber tires. The future includes carbon footprints of aluminum rims, chains, saddles, complete cycles, etc., and can build a complete carbon footprint database of key components of bicycles in Taiwan.
According to Taiwan's Ministry of Economics product category rule (PCR), the classification of tire products into petrochemical rubber products is a high carbon emission industry. Its carbon footprint inventory needs to be put into record for a long time and requires considerable funds to support, and its related research is rarely published. Recently, Lin, et al (2017) released that the carbon footprint of tire products is concentrated in the raw material stage, and graphene materials can replace carbon black to reduce carbon emissions and environmental impact. The above research objects are small center factories, which cover rubber and yarn manufacturing process is outsourced, and the raw material activity data check is provided by the 1st-tier supplier, so the source data quality attribute
DQI (data quality Indicator) is the estimated value belonging to the third level. This paper hopes to conduct a more complete activity data check on the suppliers of the raw material stage. The data quality attribute DQI is the calculated value (level II) and the measured value (level I). The inventory data is more objective and confirmed by the third party BSI International. The research object is a large-scale and 100% self-made processing rubber factory in central Taiwan, and it has a large international scale. Its manufacturing process covers 2 major factories. All tire processes are concentrated in the former engineer in Yunlin-factory (F1) and the post-engineer in Yuanlin-factory (F2) and other five 1st-tier raw material plants (S1, S2, S3, S4, S5) practice check. Table 1 shows the general information on participating suppliers including number of employees and main products.

| Supplier | No. of Employees | Raw material | Location          |
|----------|------------------|--------------|-------------------|
| S1       | 2200             | Butadiene Rubber (PR040) | Tainan City       |
| S2       | 620              | Synthetic Rubber (BR,SBR) | Kaohsiung City   |
| S3       | 5000             | Tire cord and fabrics | Yunlin County     |
| S4       | 42               | Heavy paraffinic distillate | Hsinchu County |
| S5       | 80               | Filler (Zinc oxide) | Changhua County   |

2. Methods
Practical case study a life cycle assessment model for a rubber tire inventory database. The main materials, auxiliary materials, energy consumption and waste air, waste water and wastes discharge of the whole process of the tire process were analyzed. In-depth study of the main activity data, different factories have different system boundaries, complete the seven-factory system boundary inventory, and optimize the DQI, complete the eight-checklist database, and provide more objective applications.

2.1. Functional unit
The functional unit is the production methodology for a single piece bicycle rubber-tire with a stand weight of 561 g. The methodologies under analysis in this provide similar guidance for the establishment of the functional unit, which includes the input/output material consumption and energy resource consumption. Five 1st-tier raw material plants (S1, S2, S3, S4, S5) functional unit. Table 2 shows the suppliers including raw material weight and LCI no.
Table 2. 1st-tier suppliers functional unit weight and LCI no.

| Raw material                                      | Functional unit | LCI data-base |
|---------------------------------------------------|-----------------|---------------|
| Butadiene Rubber (PR040)                          | 35 kg           | LCI-4         |
| Synthetic Rubber (BR57%,SBR43%)                   | 35 kg           | LCI-5         |
| Tire cord and fabrics                             | 1 kg            | LCI-6         |
| Heavy paraffinic distillate                       | 1 kg            | LCI-7         |
| Filler (Zinc oxide)                               | 1 kg            | LCI-8         |
| Compound (S1,S2,S4,S5,etc.)                       | 201.66 kg       | LCI-1         |
| Yarn agglutination(S3,etc.)                       | 261.4 kg        | LCI-2         |
| Sulfur molding                                    | 565.54 g        | LCI-3         |

* F1 factory=F1a+F1b

**Consider the text space layout is unable to disclosed LCI report

3. System boundary

3.1. Stages included
Follow the PAS 2050 system and propose cradle to gate assessments. The ISO14040/ISO14044 standards refer that the system boundary should be consistent with the goal of this study. The standards allow consideration of only parts of the life cycle.
As shown in Fig.1 the following stages are generically considered.
1. Main materials product: Consists of cradle-to-gate production using the main materials, including the Butadiene rubber, Synthetic Rubber (BR,SBR), carbon black, zinc sulphate, sodium hydroxide, yarn, steel wire, distances and energy consumption for transportation etc.
2. Auxiliary production materials: Auxiliary materials are used during the manufacturing processes, but the solvent, diesel, paraffin, natural gas, sulphuric acid, gasoline, lubricating oil etc are not contained in the products.
3. Energy consumption: Energy includes electricity, oil, water, LNG, fuel oil etc.
4. Emission to air: Waste air includes the sodium oxalate, nitrogen oxides, sulfur oxides, chemical oxygen demand (COD), volatile organic compounds (VOC) etc. Refer to the registry documents (According to local environmental protection laws and regulations).
5. Emission to water: Waste water refers to the registry documents (According to local environmental protection laws and regulations).
6. Wastes: Disposal includes the solvents mixture, textiles, digester sludge, rubber etc. and refers to the registry documents (According to local environmental protection laws and regulations).
Figure 1 shows Stages considered within the Rubber-tire carbon footprint system boundary.
3.2. Cut-off criteria
The PAS2050 recommends the inclusion of all emission sources that contribute to more than 1% of the anticipated life cycle GHG emissions from the functional unit. Additionally, it includes at least 95% of the anticipated life cycle GHG emissions from the functional unit and shall not exceed 5%. Components and materials omitted from the LCA shall be documented. Where less than 95% of the anticipated life cycle GHG emissions have been determined, the assessed emissions should be scaled to represent 100% of the GHG emissions associated with the functional unit. Under this methodology all of the processes generating GHG emissions are included inside the boundary in order to comply with the 95% criterion.

3.2.1. Other exclusions
The production of capital goods (Packaging materials, buildings, machinery and equipment), Auxiliary materials transport and the transport of employees to and from their place of work are excluded from the system boundary. This is in compliance with PAS2050:2011.

4. Data assessment

4.1. Activity data assessment
(1) Inventory the input data: List the main materials that make-up the product. Auxiliary materials are used during the manufacturing processes, but are not contained in the products. Energy and Resources includes electricity, oil, natural gas, water, etc. (2) Inventory the manufacturing process: Energy and resources used by the equipment and machinery. (3) Inventory the output data: Emissions to the air/water/wastes refers to the registry documents, according to local environmental protection laws and regulations.

Table 3 shows Single piece bicycle-tire Input/Output inventory data matrix.
Table 3. Single piece bicycle-tire Input/Output inventory data matrix.

| Input Main Material | Auxiliary Material | Energy& Resources | Bicycle-tire Process Flow(F1,F2) | Emission to Air | Emission to Water | Wastes |
|---------------------|--------------------|-------------------|-------------------------------|-----------------|-------------------|--------|
| LNG                 | Water, electric    | Steam             |                               |                 |                   |        |
| V                   | V                  | Water, electric   | Compound(F1a)                 | Little          | Recycle           |        |
| V                   | Water, electric    | Yarn Agglutination (F1b) |                   | Recycle         | Recycle           |        |
| F1 ➔ Transportation(ton-km) ➔ | | | | | | |
| V                   | Electric Power     | Blend             | V                             |                 |                   |        |
|                     | Water, electric    | pressurize         | Recycle                       | Recycle         |                   |        |
| V                   | Electric Power     | Wire mold          | Recycle                       |                 |                   |        |
|                     | Electric Power     | Mold               | Recycle                       |                 |                   |        |
| V                   | Water, electric    | vulcanization      |                               |                 |                   |        |

**4.2. Equipments energy consumption**

In the field, the F1 and F2 factories were inspected, and the three major process procedures were inspected. The number of employees in this case was about 900, and the annual bicycle-tire main products output was about 140,000.

F1 factory rubber tire manufacturing process, major equipment energy consumption inventory process with independent electricity meter as the basic requirements for inventory, functional unit inventory to compound process(LCI-1), yarn agglutination process (LCI-2) two independent plants.

Inventory the main process in the latter part of the F2 factory is the project (LCI-3), including the blend project, the pressurize project, the wire mold project, the molding project and the vulcanization project. Table 4 shows eight factories equipment energy consumption data-base.

Table 4. eight factories equipment energy consumption data-base.

| Life Cycle Inventory | Factorys | Functional unit | KWH |
|----------------------|----------|-----------------|-----|
| LCI-4                | S1.      | 1 kg            | 0.77 |
| LCI-5                | S2.      | 1 kg            | 0.459 |
| LCI-6                | S3.      | 1 kg            | 2.2019 |
| LCI-7                | S4.      | 1 ton           | 0.0029 |
| LCI-8                | S5.      | 1 kg            | 0.391 |
| LCI-1                | F1a.     | 201.66 kg       | 9.7946 |
| LCI-2                | F1b.     | 261.4 kg        | 0.25 |
| LCI-3                | F2.      | 565.54 g        | 0.2389 |

**4.3. GhGs and global warming potentials**

The GHGs considered in this study, whenever they were available, are those for which the last assessed report of the Inter-governmental Panel on Climate Change (IPCC, 2007) assigns a global warming potential (GWP), as recommend by PAS 2050. The GWPs adopted in this study are also from IPCC (2007) for a time period for assessment of GHG emissions of 100 years, as show Table 5.
Table 5. IPCC (2007) fourth assessment report: global warming potential.

| GWP       | Carbon dioxide (CO2) | Methane (CH4) | Nitrous oxide (N2O) |
|-----------|----------------------|---------------|---------------------|
| 100 years | 1                    | 25            | 298                 |

4.4. Data collection
Completeness, Relevance, Consistency, Accuracy and Transparency are required. Consider the full life cycle assessment including Taiwan power line losses, the energy consumption of GHG Emission is 0.7 KgCO2e/KWH for Consistency. The verification was performed based on PAS 2050:2011(ISO/DIS 14067) and ISO14064-1:2006 Technical Guideline, given to provide for consistent product life cycle GHG emission identification, calculation, monitoring and reporting. Consider environmentally extended input-output (EEIO) analysis. Age of data and minimum length of time over which data are collected, data that are time-specific to the product being assessed shall be preferred. Follow the third party verification statement results. Analysis validity is certified by an independent third party certification in accordance with PAS 2050:2011(ISO/DIS 14067). Table 6 shows the carbon footprints for the bicycle-tire CO2e emission.

Table 6. Total CO2e emission for single product.

| Inventory IN/OUT | Rubber type | single piece Bicycle-tire |
|------------------|-------------|---------------------------|
| Factory type     | two factory | F1(LCI-1,LCI-2) F2(LCI-3) |
| Includable (Primary activity data %) | five engaging suppliers (22%) |
| Company Profile  | Functional unit / tire | 561 g |
| Employee no.     | 900         |
| Data period      | 12 month    |
| Throughput/year  | 146,868 tires |
| IN               | main materials | 1.27 kgCO2e | 77.43% |
| (transport)      | (1.61E-04)  | (lower%)      |
| Auxiliary material | 7.41E-03 | 0.45%          |
| Energy consumption | 0.3617 kgCO2e | 22.05%        |
| OUT              | Emission to air | Lower | Lower |
|                  | Energy to water | 3.98E-04 | 0.02% |
|                  | Wastes         | Lower | Lower |
| Emission carbon footprint/Functional unit | 1.64 kgCO2e | 100.00 wt% |
| Level of assurance | (Third party verification) | *Reasonable level of assurance(BSI) |
| Carbon footprint logo | *cradle-to-gate | TEEMA Empowered Certification N0. CFP00030 |

5. Calculation of inventory analysis

5.1. Emission summary
Total carbon emissions from 561 g bicycle-tire is 1.64 KgCO2e which is composed of the carbon footprint emission 1.27 Kg CO2e from raw materials (ratio 77.43%), the carbon footprint emission 0.3617 Kg CO2e from the energy consumption(ratio 22.05%), and another lower emission.
The unit process emissions comprising the product system are grouped into life-cycle stages, that is, raw material stage, manufacturing stage, transportation stage, the PCF calculation is based on the product life cycle. Table 7 shows the product carbon footprint calculation output.

### Table 7. Product carbon footprint calculation.

| Category       | Raw material | manufacturing | Transportation |
|----------------|--------------|---------------|----------------|
| Carbon emission per unit (%) | 1.347 kgCO2e/unit (82%) | 0.295 kgCO2e/unit (18%) | Lower |
| Total          | 1.64 kgCO2e/functional unit (100%) |

#### 5.2. Inventory analysis

The carbon footprint has been determined from cradle to gate. The life cycle assessment software Simapro7.3 (as Figure 2 & Figure 3) was used to simulate the GWP factors used in GHG inventories for a 100-year time horizon.

A 561 g bicycle-tire product carbon footprint, total emission is 1.64 KgCO2e, by international certified organization (The British Standard Institute, BSI). The primary activity data includes related facilities from its own processes under the operational control of the organization and its suppliers. The secondary data includes the relative factors from public sources and LCA software Simapro 7.3. TEEMA empowered a carbon footprint logo to certification. This label states that 1.64 KgCO2e is emission per use for the one piece tire. The value of the standard error of mean is especially important to monitor. Method: IPCC2007 GWP 100a (confidence intervals: 95%; unit: kgCO2e). Figure 4 shows bicycle-tire rubber type the Monte Carlo analysis in SimaPro.
Figure 4. Monte Carlo analysis in SimaPro.

The simulation use over 1000 runs in SimaPro. You are asked to specify the 2XSD value. This is useful as the 95% confidence interval lies between -2xSD and +2xSD. In practice this means that only 2.5% of the data points lie above or below these points, and 95% lie between these points. For obtaining a quick impression, a standard error of mean below 0.01 is quite acceptable. Table 8 shows the simulation standard error data.

| 95% 1000 runs | Median value | Mean | S.D. | Coefficient Variability | 2.5% | 97.5% | Standard error of mean <0.01 |
|---------------|--------------|------|------|-------------------------|------|-------|------------------------------|
| bicycle-tire rubber | 1.06         | 1.06 | 0.0507 | 4.77%                    | 0.973 | 1.17  | 0.00151                      |

6. Results and discussion

There is very little LCA inventory data on rubber factories in the scientific literature. The results are complete and reveal the single piece rubber-tire of different function units from five factories and 1st-tier suppliers in Taiwan. This paper evaluated the potential impact on the carbon footprint of raw materials, energy consumption and pollutant emissions in the throughput process for 1kg tire at its output life cycle from the “cradle to gate” using the Simapro 7.3 software. The overall majority of these results carry out product life cycle greenhouse gas emissions verification. These are the opinions of BSI with reasonable assurance. Certified and Use carbon footprint labels on products are currently being used by a limited number of companies. It is expected that more businesses will seek carbon labeling as Climate Change and Corporate Social Responsibility continues to receive more attention. Identifying and measuring carbon footprint can be a useful source of carbon competitiveness. This paper is of benefit to academics and managers by providing a detail way to integrate carbon emissions in supply chain management. Managing the carbon footprint of a product across the supply chain is another strategically important next step for businesses to reduce carbon emissions and mitigate climate risks.

More than 1000 SimaPro simulation runs were conducted to obtain a quick impression. A standard error of mean below 0.01 is quite acceptable. The calculation and analysis results show that the material consumption and energy consumption are the main factors that produce the environmental load.

The obtained carbon footprint for the rubber-tire has been 1.64 KgCO2e per bicycle, with the PAS2050:2011(ISO/DIS 14067) standards. That is an international standard for the carbon footprinting of goods and services across the full product life cycle (BSI,2011). As shows Figure 5.
Taiwan Electrical & Electronic Manufacturers’ Association (TEEMA) empowered a carbon footprint logo to certify that the Carbon Footprint of these products was independently verified (as Figure 6) to meet all of the necessary requirements under ISO 14025 standard and BSI PAS 2050, with regard to the corresponding Product Category Rules and Life Cycle Analysis results.

Overall reviews of the Life cycle inventory report and subsequent follow-up interviews have provided BSI with sufficient evidence to determine the stated criteria is fulfilled. The inventory report correctly complies with the PAS2050:2011(ISO/DIS 14067) requirement. The inventory report results in quantification of product life cycle GHG emissions that are real, transparent and measurable.

7. Conclusions
In future, research an energy and climate action plan will be developed with energy-saving opportunities in heat recovery, utilization and environmental improvement. As an example, the thermo-electric heat-pump and heat exchanger techniques will be used to permit industrial heat recovery applications and environmental improvement.

This tire product case study is original and is exclusive to Taiwan local activity data and carbon emission database. The important investigation results are as follows: (1) The carbon footprint of 561g bicycle rubber-tire carbon emissions of 1.64kgCO2e with independent third parties certified our statement results. (2)The error requirement meets the standard error of mean<0.01, and meets the Monte Carlo analysis requirements. (3)This important practical case study completed two major
central factories and five satellite suppliers to check the local activity data, equipments energy consumption and carbon footprint emissions, including eight factories inventory checklists. The primary activity data was confirmed by a third party international verification unit BSI. (4) The application and review of the B to B product carbon-label for this bicycle tire product were completed. It can be used for international marketing and brand value added. Track 48 period study found that regression analysis \( Y=1,592,775+1.483689X \), correlation the throughput\( (X \text{ kg}) \) and \( LNG(Y \text{ kcal}) \) can be applied to Boiler-equipment management and energy management analysis. These database and practical results published in this paper can be used as a reference for academics and business circles.

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