Application of Life Cycle Sustainability Assessment to the bamboo and aluminum-frame bicycles in surveying social risks of developing countries

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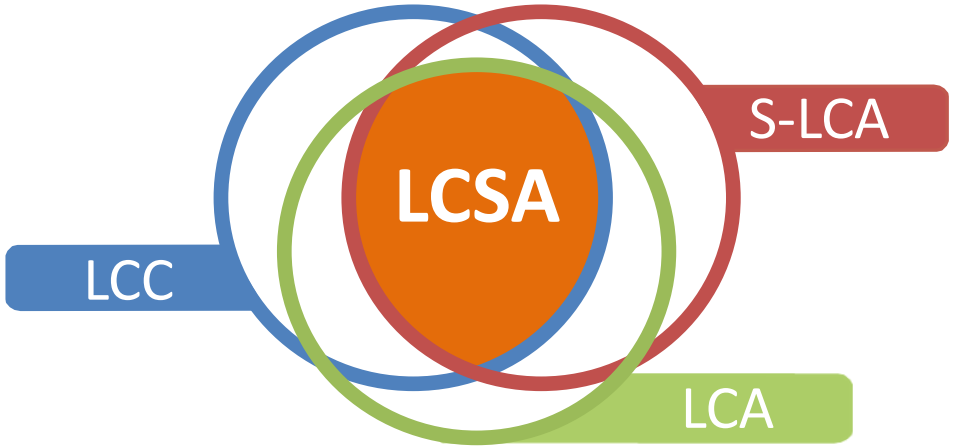
Agenda

- Introduction
- Overall goal and scope of the study
- Life Cycle Assessment (LCA)
- Environmental Life Cycle Costing (LCC)
- Social Life Cycle Assessment (SLCA)
- Discussion
- Conclusion

Introduction (1/2)

- Sustainability has become an ultimate goal for global governments and industries to pursue.
- Sustainability includes not only the environmental pillar but the economic and social ones.
- Life Cycle Sustainability Assessment (LCSA) can integrate Life Cycle Assessment (LCA), Environmental Life Cycle Costing (LCC) and Social Life Cycle Assessment (SLCA) to evaluate sustainability of services or products:

LCSA=LCA+LCC+SLCA



Introduction (2/2)

- Bicycling is generally considered as an environmentally friendly way of commuting to reduce environmental impacts
- Several studies focused on the LCA to make comparison among different transportation types in environmental impacts but lack of considering economic and social issues
- Aim of the study:
  - To introduce the bamboo bicycle-frame and the aluminium based bicycle as a case study for strengthening LCSA development
  - To practice SLCA with surveying developing countries as the origin for bamboo and bauxite from respectively China and Guinea.

(source: Frandeen, 2012)

Case study: Overall goal and scope of the study (1/3)

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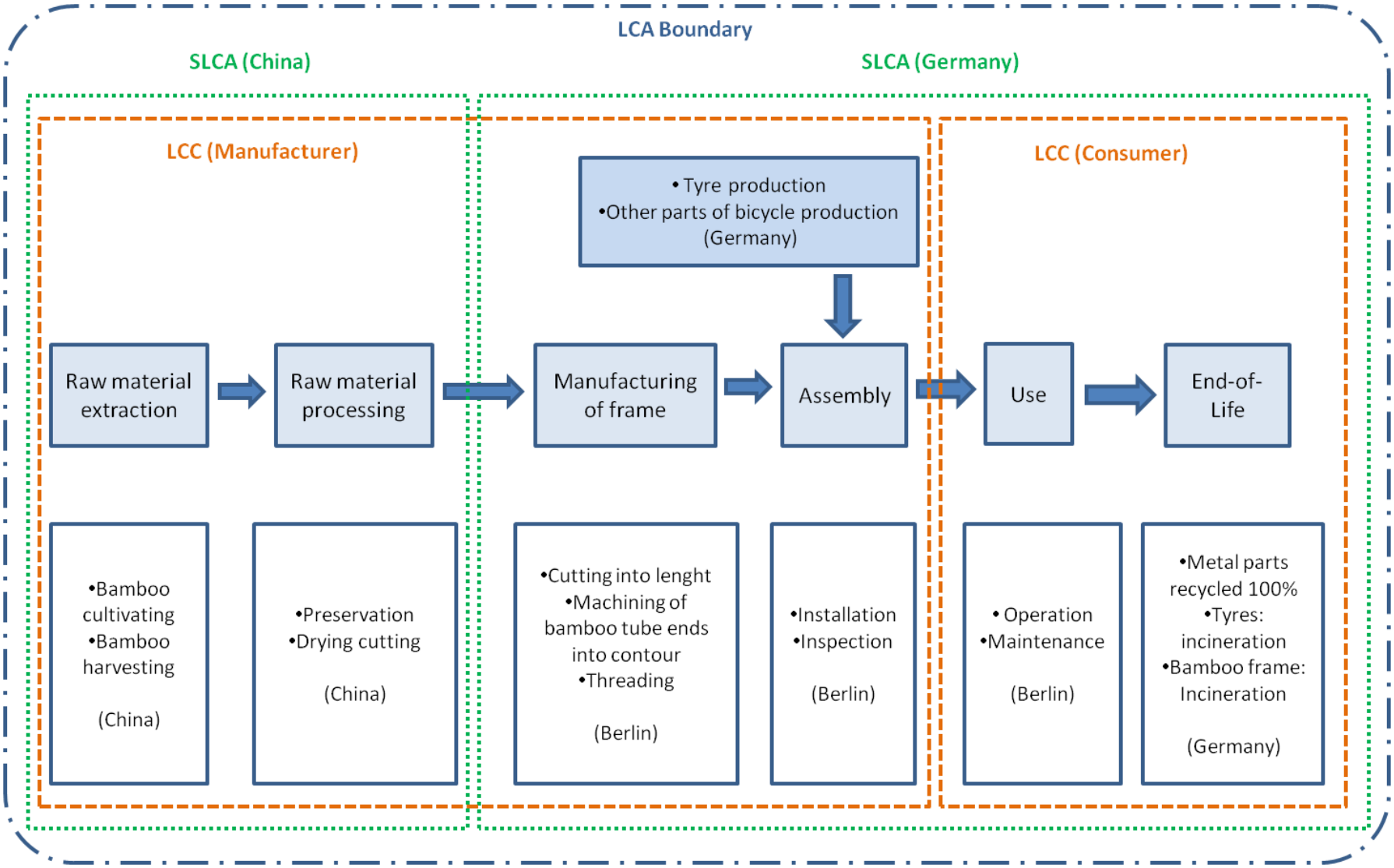
- **Main focus**: using LCA, LCC, and SLCA to evaluate the sustainability in the three dimensions of the bamboo-frame bicycle and the aluminum-frame bicycle manufactured, used, and disposed/recycled Germany
- **Life-cycle thinking:** the boundaries include raw material extraction of frame, raw material processing of frame, manufacturing of other bicycle parts, assembly, use phase, and end of life (EoL)
- **Highlight the frame differences:** the raw material extraction and raw material processing stages represent the processes only related to the frame production
- The rest components of a bicycle except the frame and tyres are sorted out in "other parts of bicycle."
- The raw material extraction of frame for the bamboo frame includes bamboo cultivation and bamboo harvest

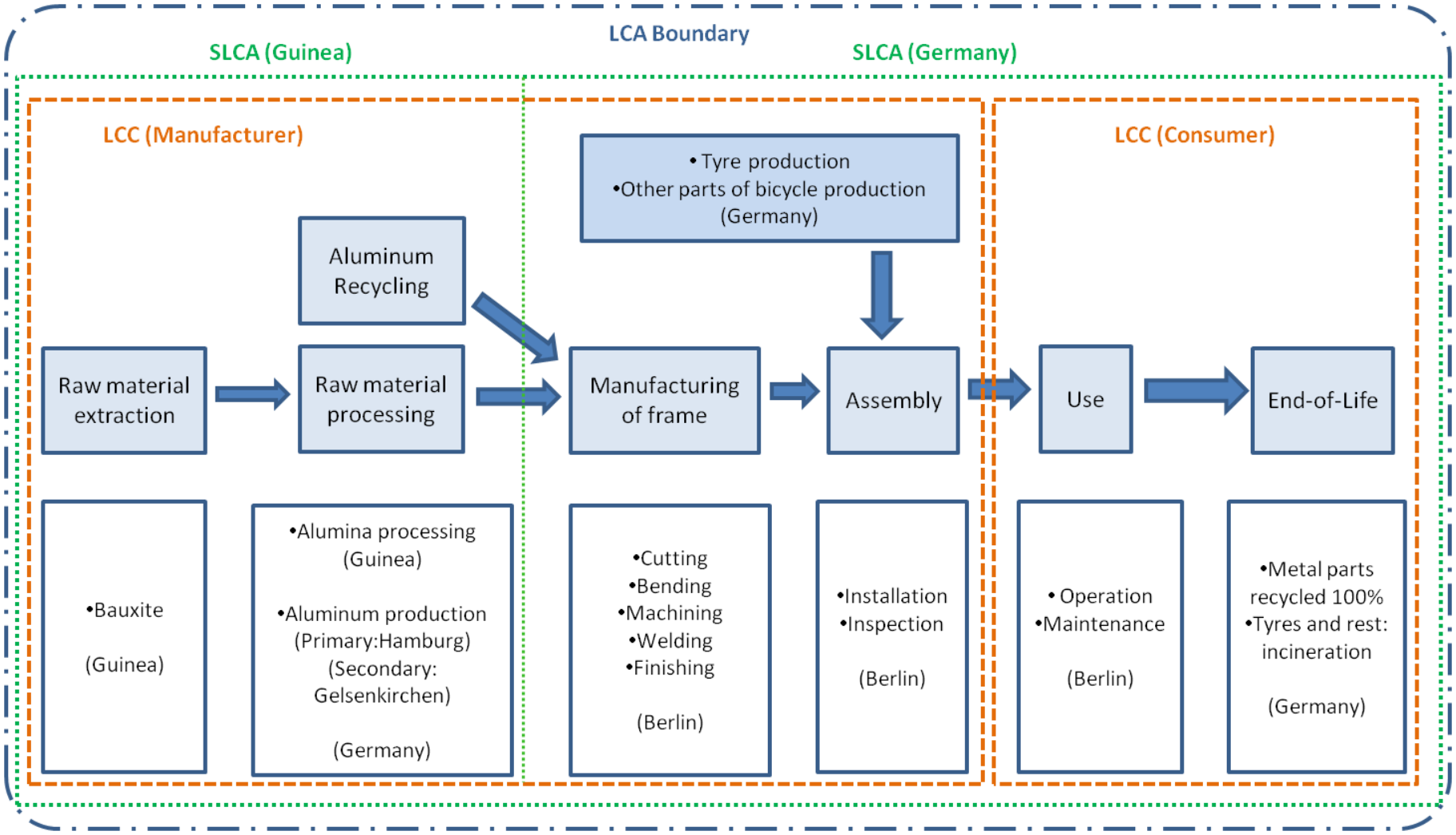
Case study: Overall goal and scope of the study (2/3)



System boundaries of the bamboo-frame bicycle

source: Schau et al, 2012

Case study: Overall goal and scope of the study (3/3)



System boundaries of the aluminum-frame bicycle

source: Schau et al, 2012

Life Cycle Assessment (LCA) (1/11)

SUSTAINABLE ENGINEERING

- **LCA structure:** goal and scope definition, life cycle inventory analysis, life cycle impact assessment, and interpretation
- **Functional unit:** 15,000 person kilometers (assuming a daily distance of 10 km for 200 days a year for 7.5 years) which is fulfilled by the reference flow of 1 bicycle
- **Life cycle impact assessment indicators:**18 mid-point ReCiPe Indicators
- **LCA software:** GaBi 4.4
- **Reference flow:**
  - Moso bamboo (Phyllostachys pubescens) planted in Anji, Zhejiang Province, China (5.33 meter in average, and cut in 2.66 meter long in processing stage)
  - Aluminum production in recent Germany: 40% primary, 60% secondary. (bauxite is mined in Guinea, and alumina is manufactured/exported from Guinea)

Life Cycle Assessment (LCA) (2/11)

SUSTAINABLE ENGINEERING

- **Assumptions/info of a Bamboo-frame bicycle:**
  - Manure is adopted as fertilizer, no pesticides used in cultivation
  - Bamboo preservation: using borate solution
  - In the assembly stage, workers all assemble the bicycles by hands without energy consumption
  - Tyres (made in Reichshof) are needed to be replaced every 4,000 km for maintenance
  - In EoL, this study assumes that all the metal parts can be reused 100%, and the tyres, the rest bicycle parts, and bamboo frame are all incinerated
- **Assumptions/info of an Aluminum-frame bicycle:**
  - The main primary aluminum production area is assumed in Hamburg; for recycled aluminum is Gelsenkirchen, Germany
  - Assumptions in assembly, maintenance, and EoL are identical with a bamboo-frame bicycle

Life Cycle Assessment (LCA) (3/11)

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Main materials and energy input of the two bicycles

Item	Bamboo-frame Bicycle	Aluminum-frame Bicycle	Unit
Fertilizer (Manure)	34.10	-	kg
Gasoline	0.00427	-	L
Boron solution	0.93	-	kg
Bamboo stem	2.04	-	kg
Hemp	0.1	-	kg
Epoxy resin	0.1	-	kg
Bauxite	8.29	12.40	kg
Primary aluminium	2.02	3.02	kg
Secondary aluminium	3.02	4.52	kg
Steel, alloyed	4.78		kg
Stainless steel	1.71		kg
High density polyethylene (HDPE)	1.96		kg
PU, flexible foam	0.03		kg
Electronic equipment	0.5		kg
Natural rubber (NR)	794.24		g
Styrene-butadiene rubber (SBR)	521.50		g
Polybutadiene (BR)	263.52		g
Butyl rubber (IIR)	98.76		g
Carbon black	867.62		g
Rubber chemicals (Benzothiadiazole compounds)	450.89		g
Bead wire (Polypropylene)	142.60		g
Viscose fibre (Rayon)	190.14		g
Tap water	0.602	0.711	kg
Energy	67.74	70.81	MJ

Life Cycle Assessment (LCA) (4/11)

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Transportaion of the two bicycles (km)

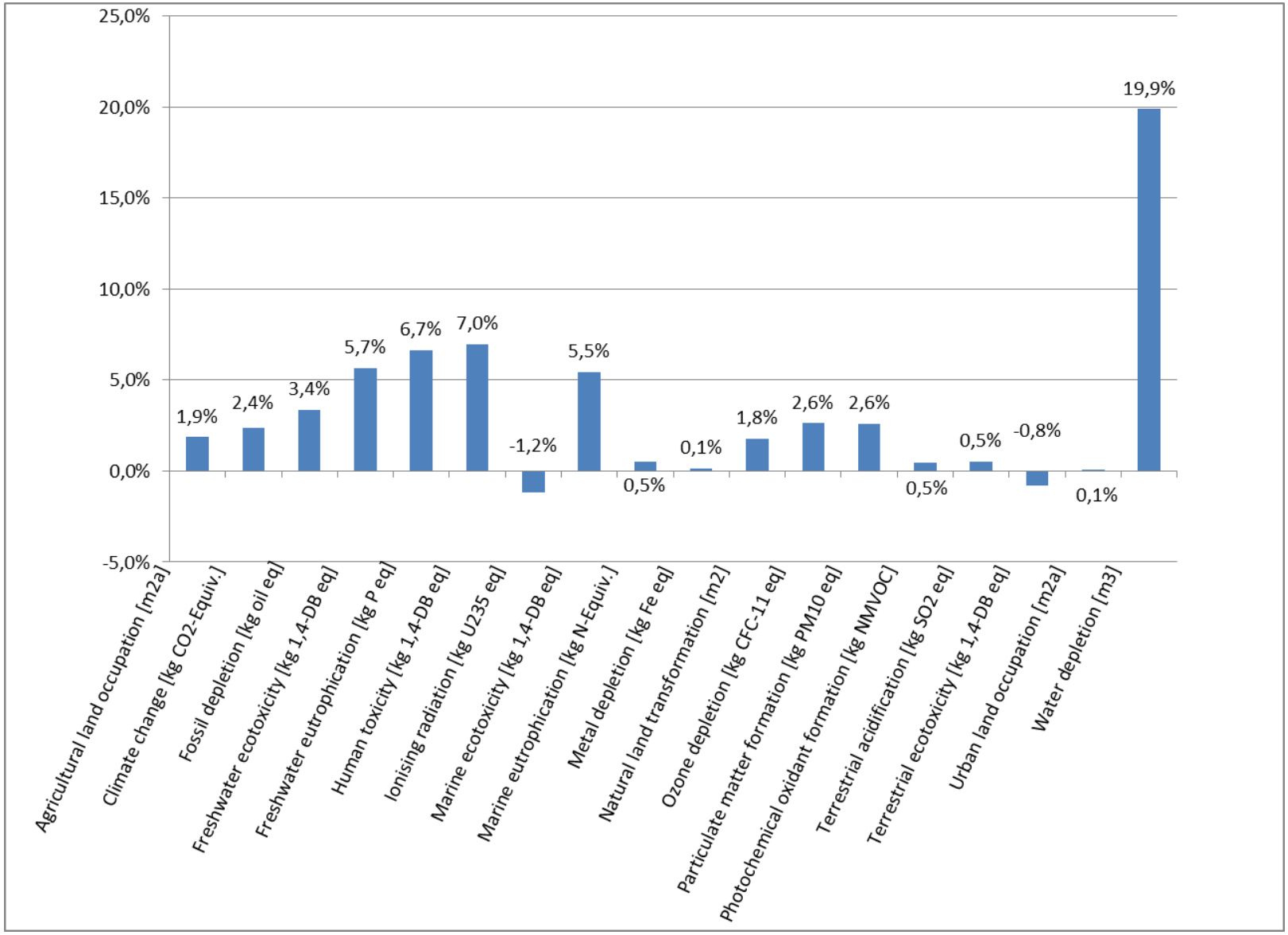
Transportation step	Site	Transportation Type	Distance
Raw material extraction/processing for the bamboo-frame bicycle			
Send bamboo stems from plantation area to processing plants	In Anji region, Zhejiang, China	5-ton truck (empty truck load for return)	30
Send processed the stems to harbour	Anji-Shanghi, China	28-ton truck (one way)	600
Export the stems	Shanghi-Hamburg, Germany	Trans-oceanic freight ship (40-foot container)	19737
Send the stems for further production	Hamburg-Berlin	28-ton truck (one way)	300
Raw material extraction/processing for the aluminium-frame bicycle			
Export alumina	Guinea-Hamburg	Trans-oceanic freight ship (40-foot container)	5961.6
For primary aluminium production	In Hamburg region	28-ton truck (one way)	20
Send primary aluminium for further production	Hamburg-Berlin	28-ton truck (one way)	300
Send secondary aluminium for further production	Gelsenkirchen-Berlin	28-ton truck (one way)	500
Frame production and assembly			
Bamboo frame/aluminium frame for production/assembly	In Berlin region	7.5-ton truck (one way)	20
Tyres for assembly	Reichshof-Berlin	7.5-ton truck (one way)	600
Collect the other parts of bike for assembly	In Berlin region	7.5-ton truck (one way)	20
Use phase			
Send bicycles to retailers	In Berlin region	7.5-ton truck (one way)	20
Tyres for maintenance	Reichshof-Berlin	7.5-ton truck (one way)	600
End-of-Life			
Incineration and metal collection	In Berlin region	7.5-ton truck (one way)	20

Life Cycle Assessment (LCA) (5/11)

SUSTAINABLE ENGINEERING

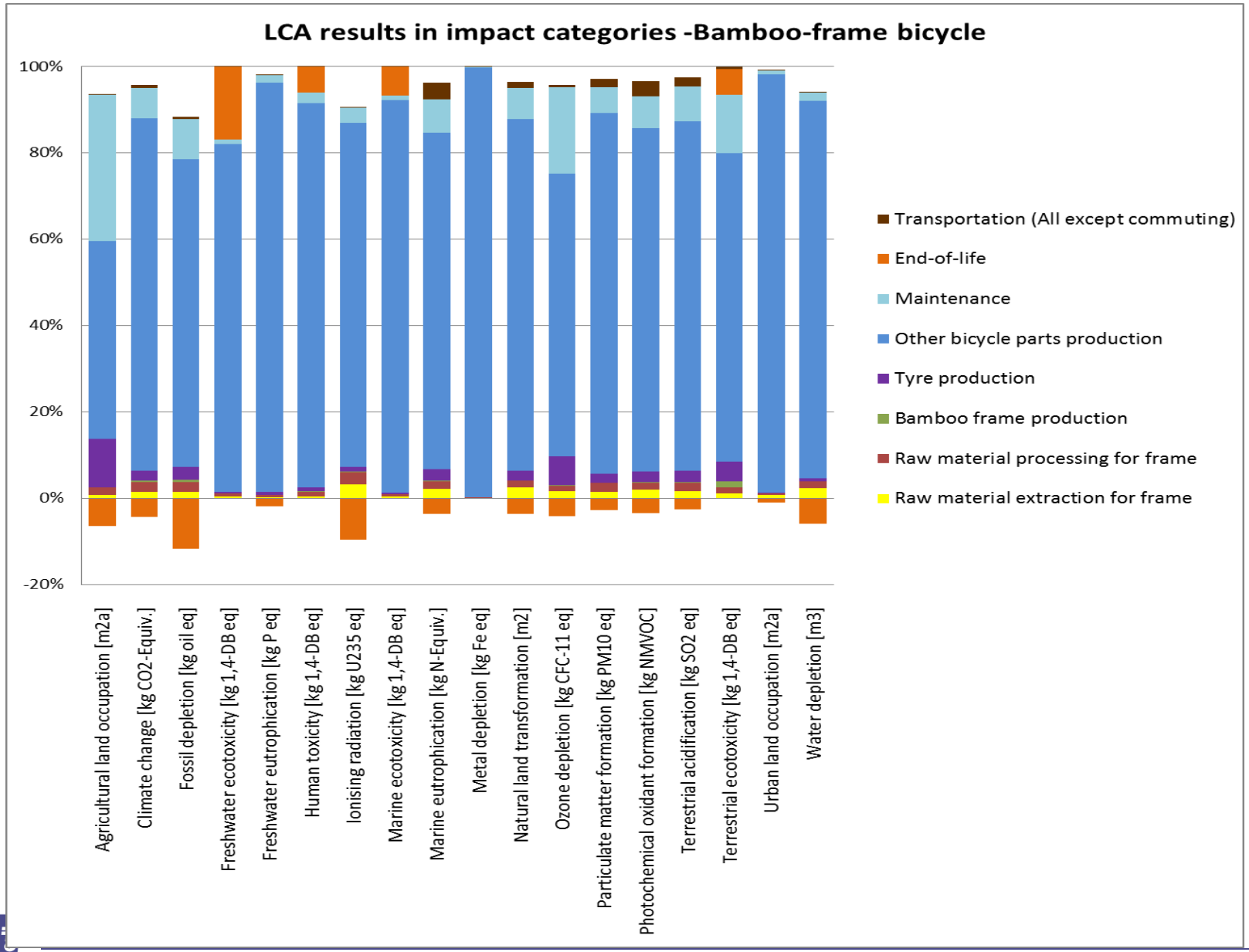
- An aluminium-frame bicycle contribute more environmental impacts than a bamboo-frame bicycle except in ionising radiation and terrestrial acidification
- Production of “other parts of bicycles” leads main environmental impacts of the both bicycles
- Impacts lead from raw material processing of frame in aluminium-frame bicycle are higher than in bamboo-frame one in life cycle
- In EoL, incinerations of bamboo and plastics produce valuable electricity and steam, providing credits; on the other hand, the incineration leads main environmental impact on freshwater ecotoxicity
- The significant gap in water depletion between the two bicycles may be resulted from the assumption: only rainfall mainly needed in bamboo plantation

Life Cycle Assessment (LCA) (6/11)



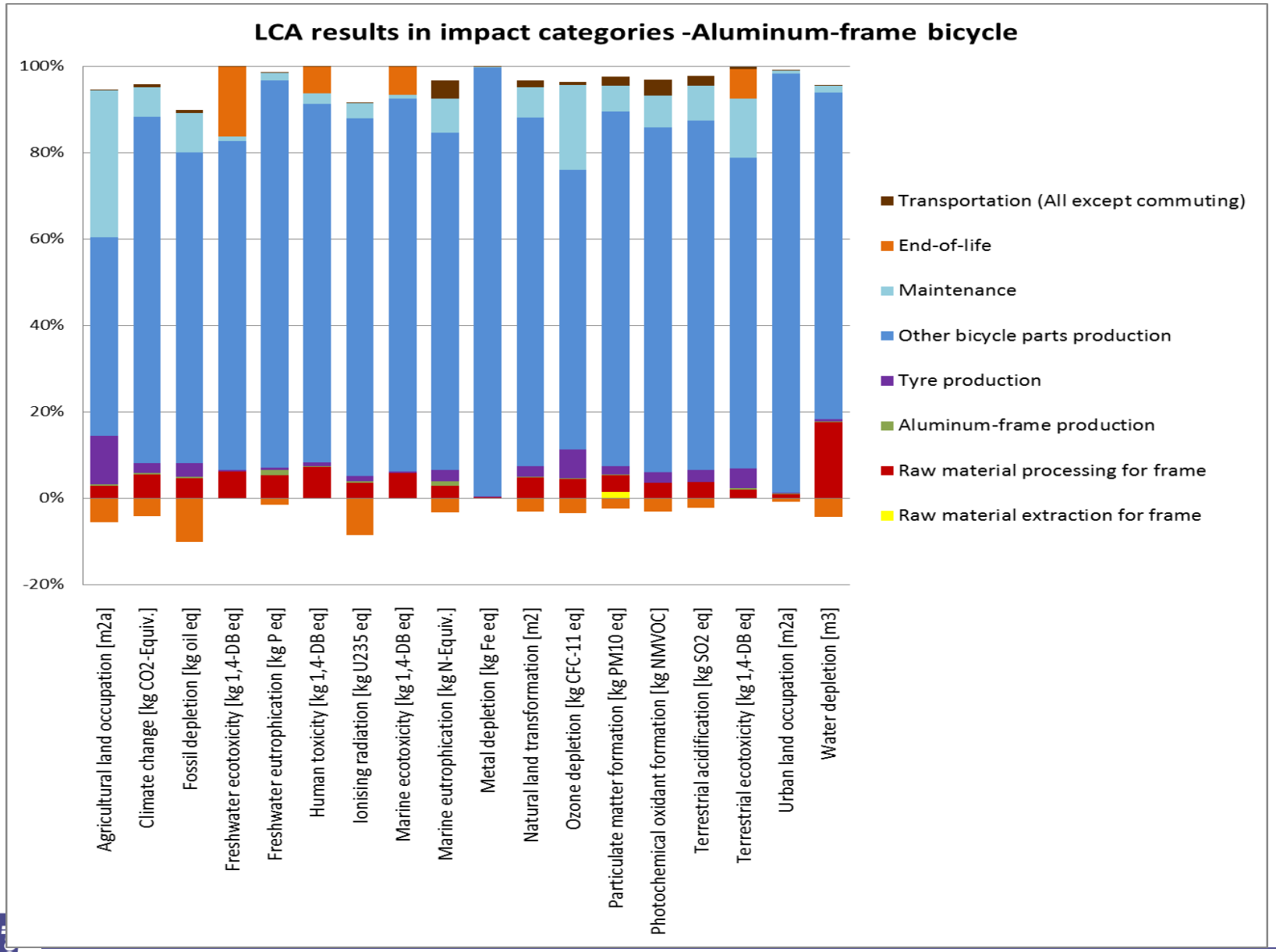
The LCA results comparison of the two bicycles, based on the bamboo-frame bike (%)

Life Cycle Assessment (LCA) (7/11)



Life Cycle Assessment (LCA) (8/11)

SUSTAINABLE ENGINEERING

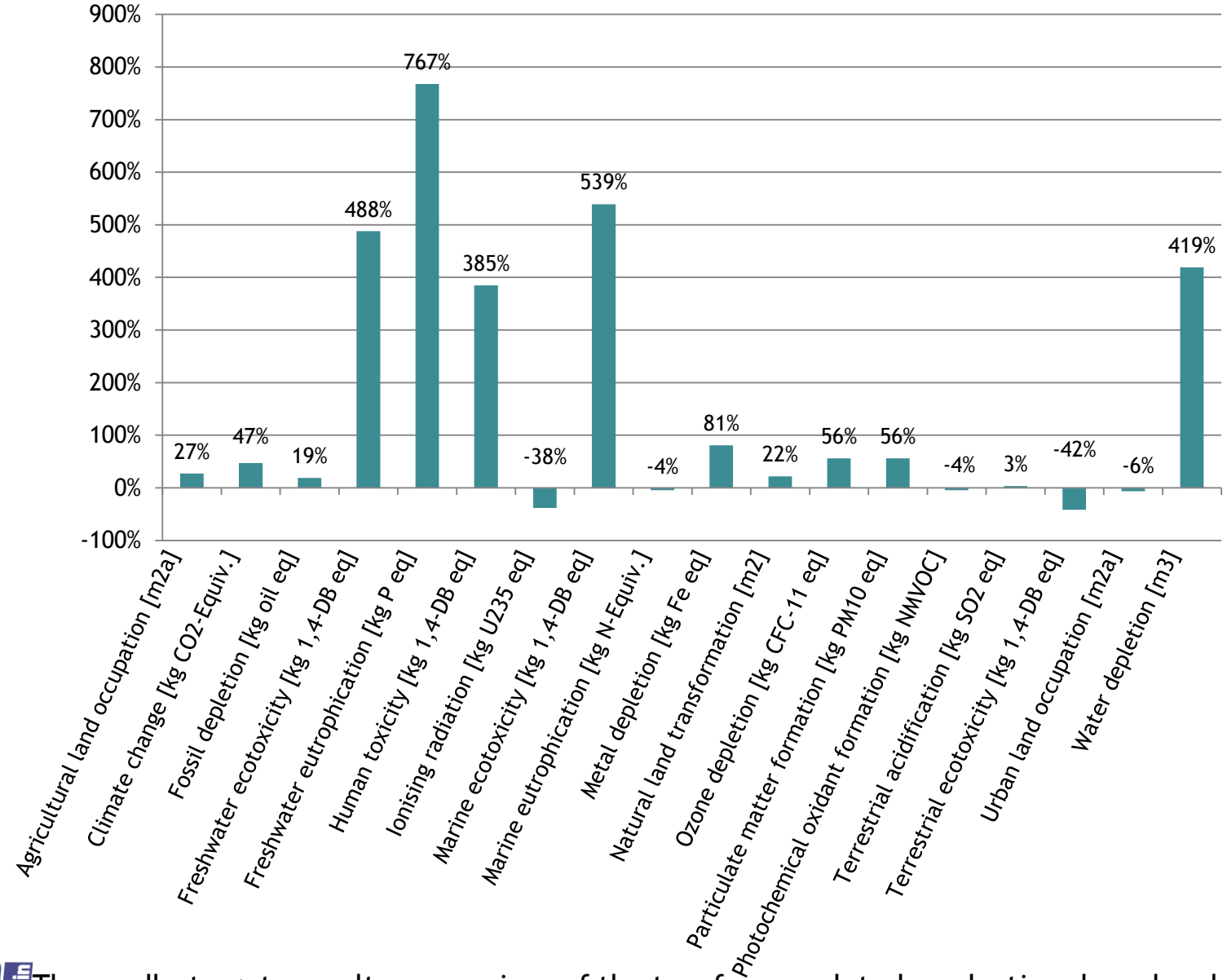


Life Cycle Assessment (LCA) (9/11)

SUSTAINABLE ENGINEERING

- **To highlight the impacts caused by different frames:**
  - aluminium-frame brings out remarkable larger environmental impacts than the bamboo-frame in *freshwater ecotoxicity, freshwater eutrophication, human toxicity, marine ecotoxicity, and water depletion*
  - In freshwater ecotoxicity, freshwater eutrophication, human toxicity, and marine ecotoxicity, redmud from bauxite digestion to residual material landfill in aluminium hydroxide production in raw material processing stage is dominant
  - In water depletion, electricity used in primary liquid aluminium production in raw material processing is dominant
  - For bamboo-frame, the sodium tetra-hydroborate usage for bamboo preservation in raw material processing makes the largest contribution

Life Cycle Assessment (LCA) (10/11)



The cradle-to-gate results comparison of the two frame-related production, based on bamboo-frame (%)

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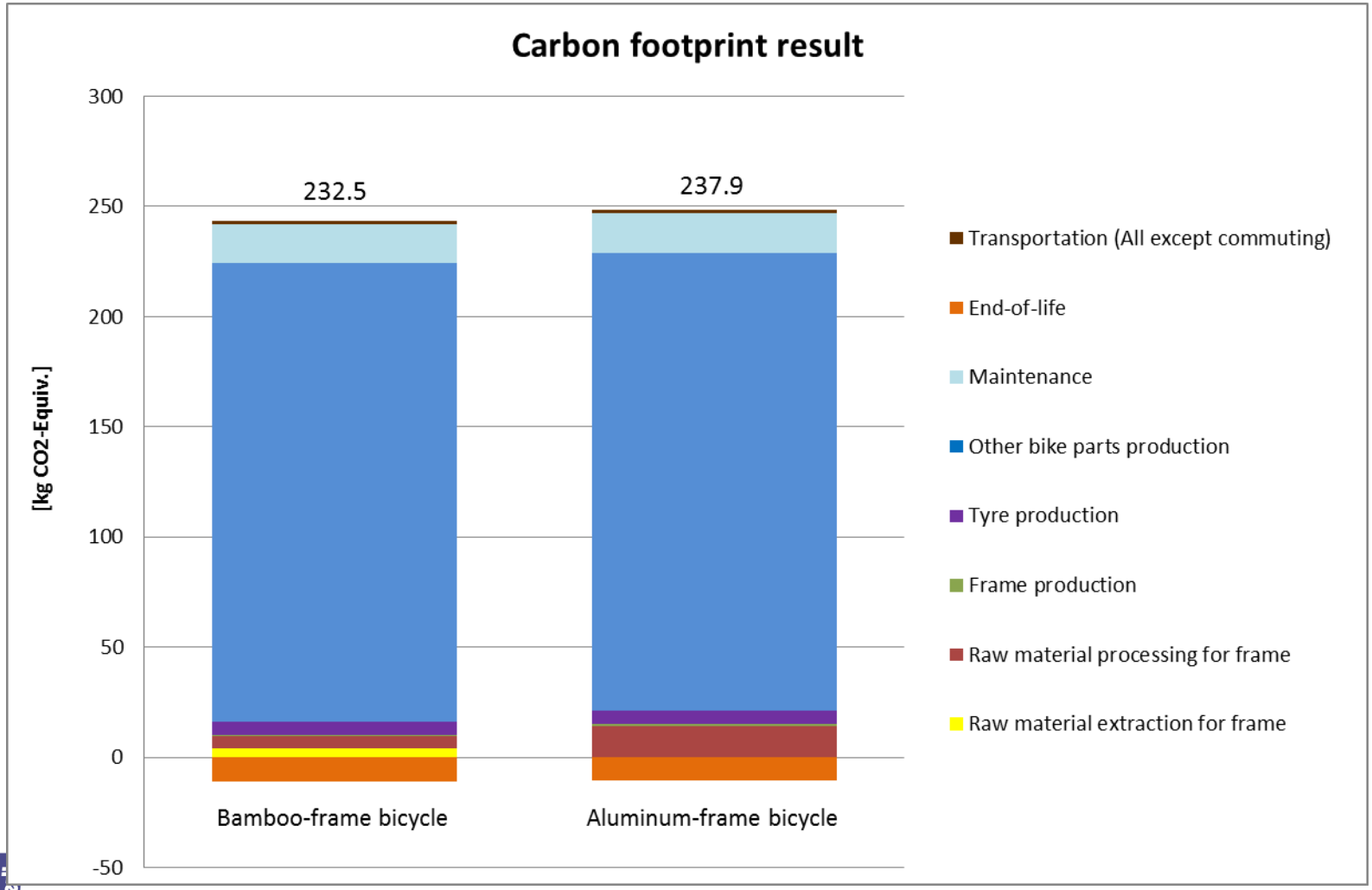
Life Cycle Assessment (LCA) (11/11)

SUSTAINABLE ENGINEERING

- the aluminium-frame bicycle leads higher carbon footprint than the bamboo-frame one (due to raw material processing phase) but not significant



Environmental Life Cycle Costing (LCC) (1/4)

SUSTAINABLE ENGINEERING

- We adopt environmental life cycle costing (LCC) fitting best together with LCA as a consistent pillar of sustainability assessment
- This study focuses on the two perspectives: the manufacturers and the consumers of the two bicycles
- Considered in the manufacturer perspective
  - Acquisition cost for purchasing frame resources, tyres, other bicycle parts
  - Labor cost in assembly stage
  - Transportation cost for collecting frame, tyres, and other bicycle parts to assembly plant, and sending the bicycle to retailers
- Considered in the consumer perspective
  - acquisition cost (purchase price from retailers)
  - maintenance cost (e.g. new tyres every 4,000 km)
  - salvage value (10% of the original purchase price for turn the used bicycle back)

Environmental Life Cycle Costing (LCC) (2/4)

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The LCC in manufacturer perspective (Euro)

Item	Bamboo-frame bicycle	Aluminum-frame bicycle
Acquisition cost		
Bamboo stems	3.59	-
Epoxy resin	2.53	-
Hemp fiber	2.11	-
Aluminum frame	-	62
Tyres	48	48
Other parts of bike	299.43	299.43
Subtotal	355.66	409.43
Labor cost		
Labor for assembly	23.34	23.34
Transportation cost		
Components to assembling plant	0.09	0.09
Bike to retailers	1.7	1.7
Subtotal	1.79	1.79
Total cost	380.79	434.55

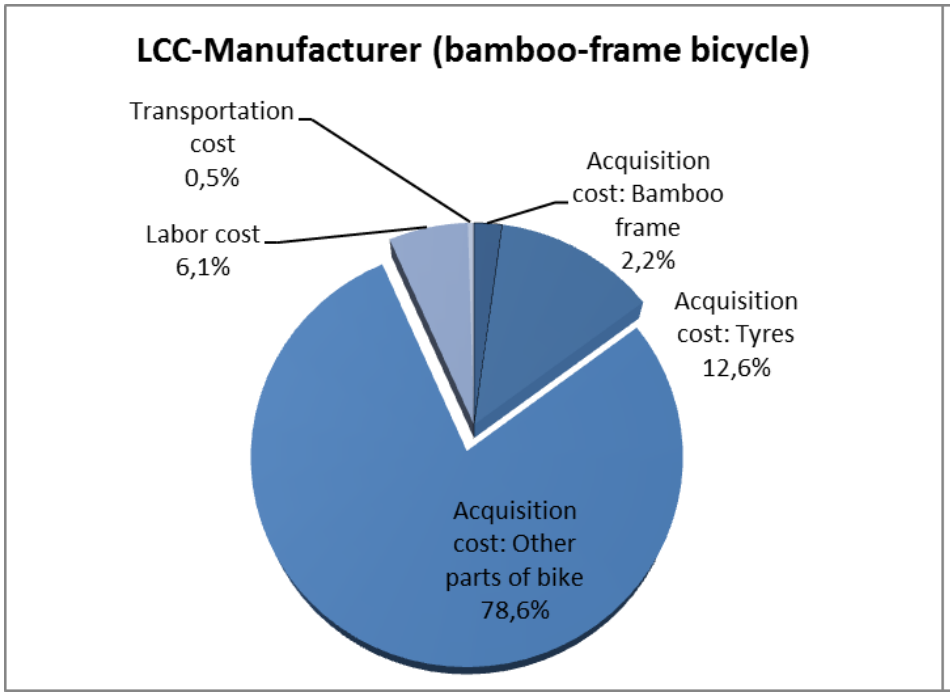
The LCC in consumer perspective (Euro)

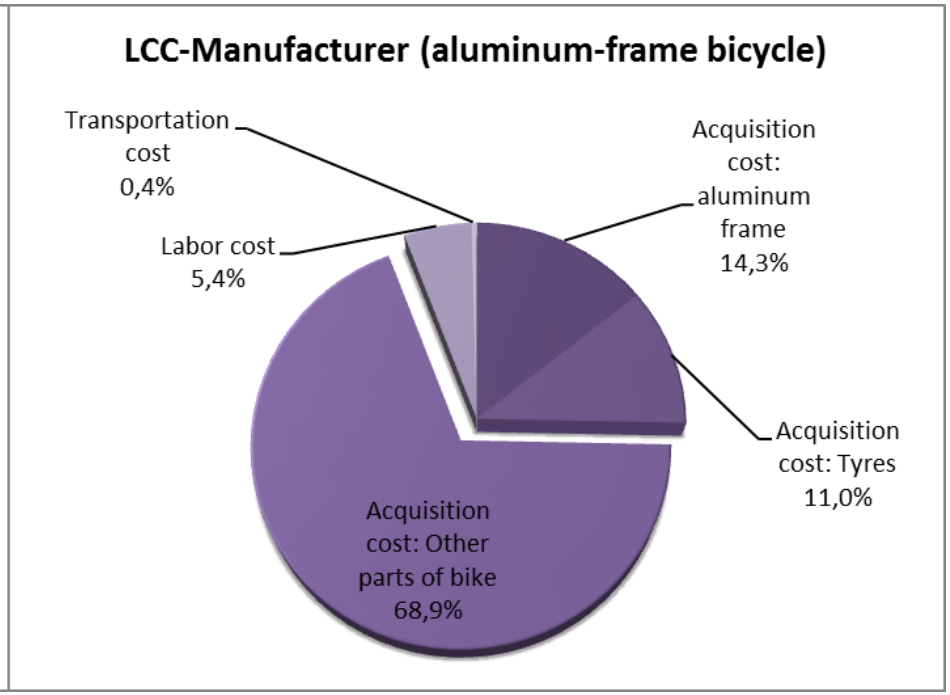
Item	Bamboo-frame bicycle	Aluminum-frame bicycle
Bicycle purchase price	945	609.5
Tyres	180	180
Salvage value	94.5	60.95
Total cost	1030.5	728.55

source: Schau et al, 2012

Environmental Life Cycle Costing (LCC) (3/4)

- In the manufacturer perspectives,
  - The cost of a bamboo-frame bicycle (434.55 €) is lower than an aluminum-frame ones (380.79 €) due to the main cost difference between the two frames
  - The acquisition costs account for about 93% in total; in addition, labor costs seize 5.4 -6.1%, and transportation costs occupy 0.4-0.5% of the total cost

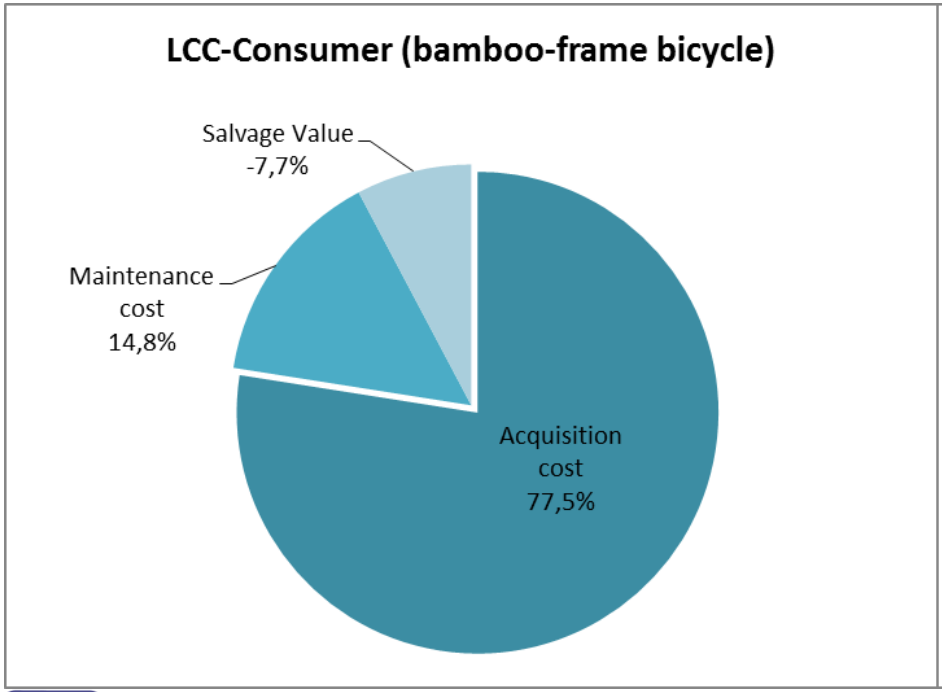


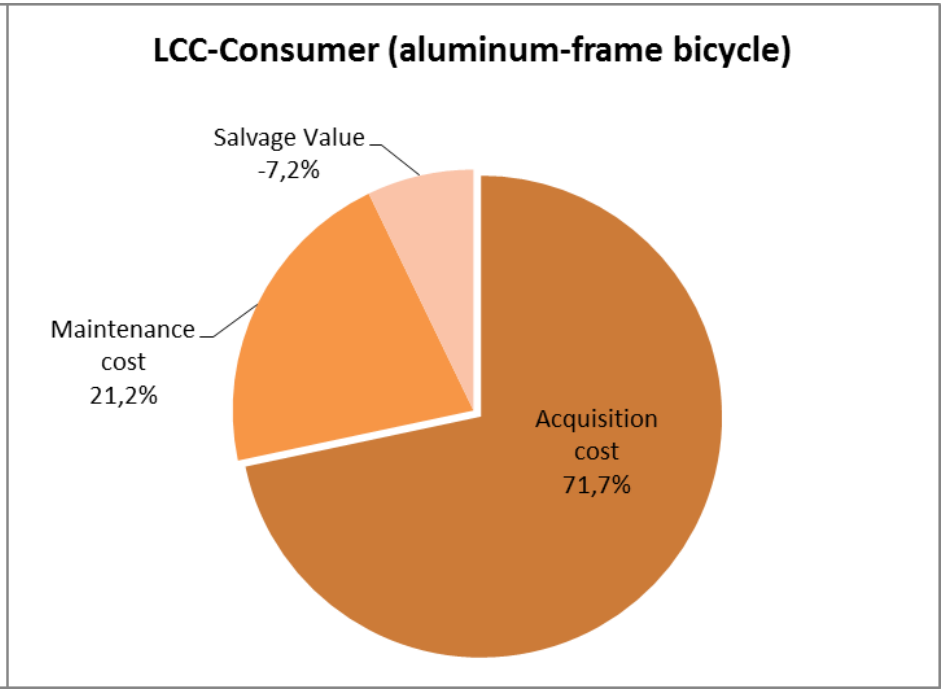


source: Schau et al, 2012

Environmental Life Cycle Costing (LCC) (4/4)

- **In consumer perspective:**
  - the cost of a bamboo-frame bicycle (1030.5 €) is significant more than aluminum-frame ones' (728.55 €)
  - the acquisition costs is major part of total costs: 77.5% in a bamboo-frame bicycle, 71.67% in an aluminum-frame one. Maintenance costs take 14.76-21.17 %; the salvage value can contribute the cost deduction in near 7-8% of total costs.





source: Schau et al, 2012

Social Life Cycle Assessment (SLCA) (1/6)

SUSTAINABLE ENGINEERING

- **The main aim:** to assess the social conditions for the workers and the local communities in China and Guinea involved in the raw material extraction and processing, and the workers, the consumers and local communities in Germany
- We adopt the Social Hotspot Database to digest the very important social risks, and use data from World Bank as assistance
- China and Guinea are developing countries which play important roles in international manufacturing and production for exporting resource or raw materials
- Via probing the social risks of China and Guinea, we can gain more completed pictures for developing countries

Social Life Cycle Assessment (SLCA) (2/6)

Social risks of China

source: Social Hotspots Database

Social Life Cycle Assessment (SLCA) (3/6)

Social risks of Germany

source: Social Hotspots Database

Social Life Cycle Assessment (SLCA) (4/6)

SUSTAINABLE ENGINEERING

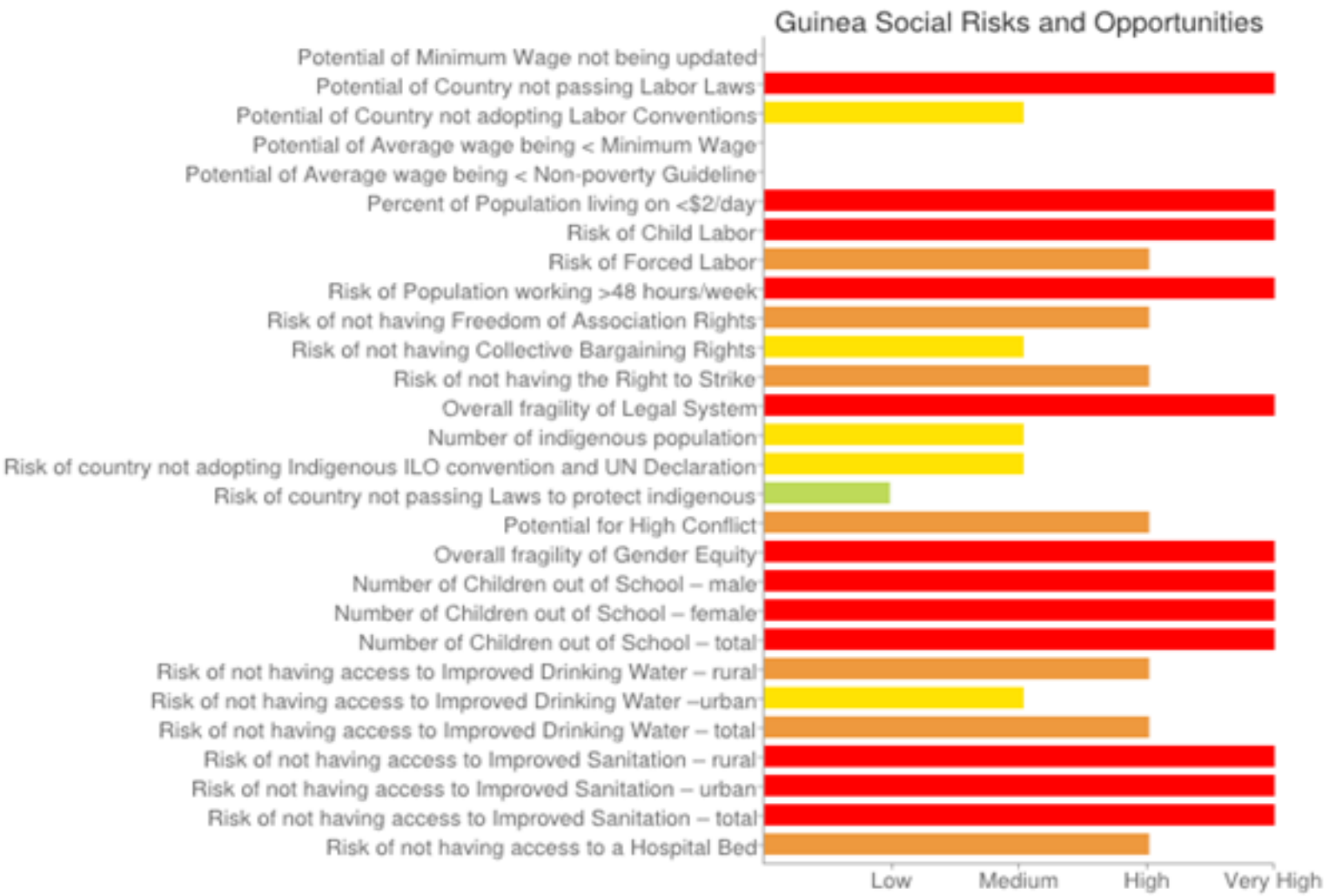
- The very high social risks in China:
  - Potential of average wage being < non-poverty guideline
    - the average wage (**1.04** $/hour)< non-poverty level (**1.49** $/hour) in 2011
  - Potential of country not adopting labor conventions
  - Risk of not having collective bargaining rights
  - Risk of not having the right to strike

  } ***Labor right***

  - Risk of not having access to improved sanitation (urban)
    - **156 million** urban people without improved sanitation (26% of urban people)

- The high concern social risks in Germany:
  - Risk of **not having the right to strike**: limited for the professional group civil servant. However, the professional group working in the bicycle manufacturing is not civil servant

Social Life Cycle Assessment (SLCA) (5/6)



Social risks of Guinea

source: Social Hotspots Database

Social Life Cycle Assessment (SLCA) (6/6)

- The very high social risks in Guinea:
  - Overall fragility of legal system
  - Overall fragility of gender equity
    - **20%** of women treated in hospitals are victims of sexual assaults
    - **96%** of women are forced to take Female Genital Mutilation (FGM)
  - Potential of country not passing labor laws/Limited wage record
  - Risk of population of working > 48 hours per week

  } ***Labor right***

  - Risk of child labor
    - many children between **5-16** years old keep working **10-15** hours a day in **mining industry** for minimal compensation and little food
  - Number of children out of school
    - primary completion rate of relevant age group is about **64%** in 2010
  - Percentage of population living < $2 per day (**70%** of population)
  - Risk of not having access to improved sanitation (overall country: **18%**)

Discussion

SUSTAINABLE ENGINEERING

- In this case study, the pesticide and irrigation information of bamboo cultivation in China is limited
- Due to relying on the database in software, the energy consumption in bauxite extraction in Guinea can be too under-estimated. That means we should probe further in mining activities to reflect real situation
- Also, the transportation information in Guinea is not concrete, indicating possible bias in the life-cycle transport evaluation
- **the LCC results may be limited since :**
  - transportation cost in China and Guinea are simply assumed that included in frame purchase price
  - the time issue of currency is ignored
  - consumer behavior of transporting bicycles and disposing the used bicycles can be really various and unpredictable
  - the purchase price of aluminum-frame bicycles varies in large gap, how to measure the price is still in challenge

Conclusion (1/2)

SUSTAINABLE ENGINEERING

- **The main contribution:** applying the integrated sustainability assessment in a practical case study of the bamboo-frame bike and the aluminum-frame bicycle
- The LCA results reveal that the aluminium-frame bicycle contribute more environmental impacts than the bamboo-frame bicycle in many impact categories but not significant. (*The other parts of bike production is dominant)*
- The aluminium-frame brings out remarkable larger environmental impacts than the bamboo-frame in freshwater ecotoxicity, freshwater eutrophication, human toxicity, marine ecotoxicity, and water depletion
  (*The redmud from bauxite digestion to residual material landfill is dominant)*
- The overall LCC results show that calculation based on different perspective can lead the LCCs in various ways
- LCC in manufacturer perspective is higher in Aluminum-frame bicycle; LCC in consumer perspective is higher in bamboo bicycle

Conclusion (2/2)

- The common topics in developing countries are low wage, harsh working condition, low living standard, and insufficient sanitation
- In China, the right to collective bargaining and the right to strike are restricted both in law and in practice
- As an African developing country, Guinea has especially severe social problems in fragility of law system and gender equity, insufficient wage standard and record, and high drop-out rate with large amount of child labor
- **Further research:**
  - focusing on including collect more detailed bamboo cultivation information and the transportation information
  - To discuss more in transportation vehicles can be one direction in the future
  - keeping further applying sustainability assessment in environmental, economic and social aspects to delicate in improving the structure of the methodology

Thank you for your attention!

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