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DEPARTMENT OF CIVIL
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ENGINEERING

ESTIMATION OF CO2 EMISSIONS FROM THE PRODUCTION OF BICYCLES IN CHINA AND IN EUROPE

Customer: European Bicycle Manufacturers' Association (EBMA ASBL)

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INTRODUCTION

The reduction of greenhouse gas emissions is a major goal for the EU, as stated in such guidelines as "2020 climate and energy package" (European Commission, 2008), "Roadmap for moving to a competitive low-carbon economy in 2050" (European Commission, 2011) and "2030 framework for climate and energy policies" (European Commission, 2014). In addition to that, more and more attention is focused on the leakage connected with the reduction of emissions, t.i. if the reduction of emissions in some countries may cause an increase of emissions in other countries, for instance as a consequence of production dislocation.

Some studies like Davis and Caldeira's (2010) and Barret's works (2013) proved that CO2 emissions play an important role in trade exchanges, representing approximately 20-25% of global emissions.

This study compares CO2 emissions from the production of bicycles in Europe and China, considering the production of steel and aluminium and the transportation of China-made bicycles to Europe.

This estimation can be completed at a later stage through a Life Cycle Analysis (LCA), including assessments of other impact categories connected with the production of bicycles, in addition to the environmental impact.

METHODOLOGY

The comparative analysis refers to an average bicycle manufactured for the EU market, whose main characteristics are based on the data provided by European bicycle producers, consisting of 70% bicycles with aluminium frame and 30% steel bicycles, equally divided into mountain bikes (MTB) and City Bikes (CB).

As shown in table 1, the "average bicycle" weighs Kg. 17,1, and consists of 56% aluminium, 38% steel and 6% plastic components.

(Plastic components include also tyres).

Table 1: features of the bicycle models considered in the study

Type	Market share	Total weight [kg]	Main components [kg]		
			Steel	Alloy	Plastic
MTB, alloy	35%	15,9	1,4 (9%)	13,5 (85%)	1,0 (6%)
CB, alloy	35%	16,5	1,7 (10%)	13,7 (83%)	1,2 (7%)
MTB, steel	15%	18,9	17,8 (94%)	-	1,1 (6%)
CB, steel	15%	19,5	18,1 (93%)	-	1,4 (7%)
Average bike	-	17,1	6,5 (38%)	9,5 (56%)	1,1 (6%)

The assessment considers CO2 emissions from the production of both main components in the two different local areas and their transportation to the consumers, t.i.:

- Steel production, including all stages of transformation, from the extraction of raw materials to steel production.
- Alumium production, including all stages of transformation, from the extraction of raw materials to aluminium production.
- Maritime transportation of bicycles produced in China to Europe by container ships.

The production of plastic components was not considered.

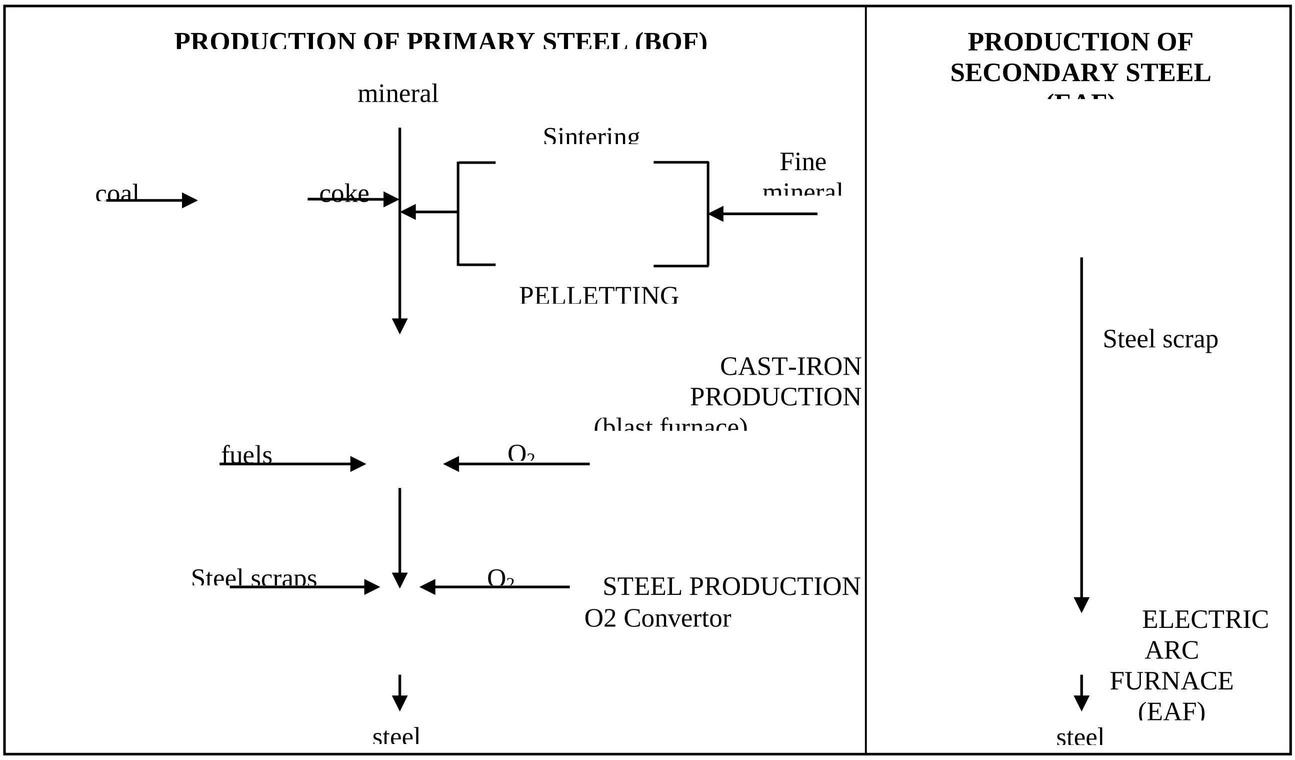
CO2 emissions from steel production.

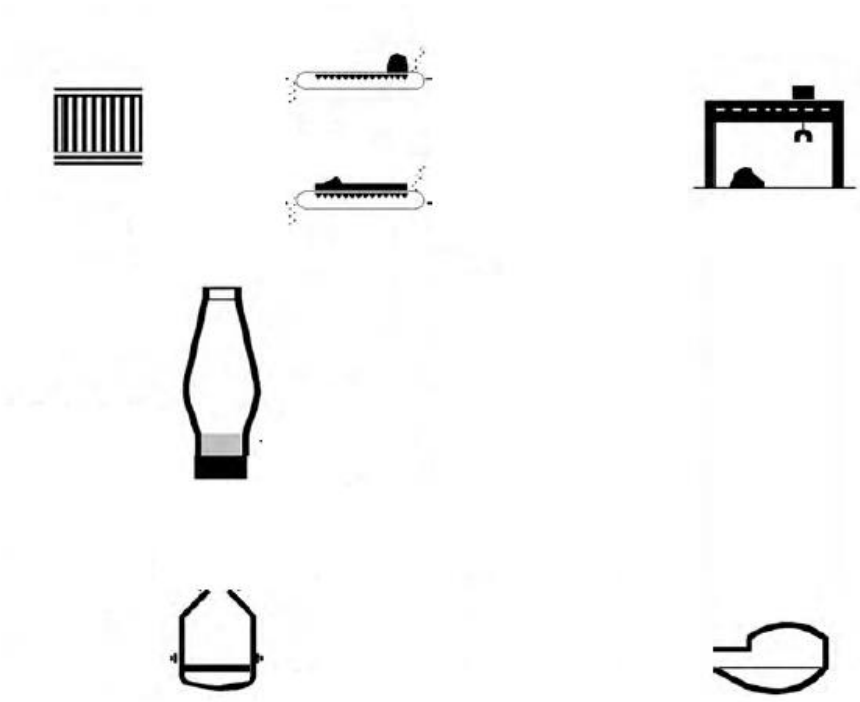
Both steel production technologies in China and Europe include manufacturing from cast iron in a Basic Oxygen Furnace (BOF)and scrap casting in an Electric Arc Furnace (EAF).

The more energy-consuming and less productive Open Hearth Furnace (OHF)method is nowadays used only in Russia and Ukraine for small productions (Price et al. 2002, WSA 2014).

According to BOF method, cast iron is produced from iron minerals smelted in blast furnace, then led into an oxygen convertor, to produce primary steel.

EAF method, which is more energy-saving compared to BOF method, uses iron scraps for the production of secondary steel. (Picture 1)





Picture 1: steel production processes : primary BOF and secondary EAF;by Yellishetty et al. (2010).

As these two production methods cause very different CO_2 emissions (Ren and Wang 2011), we have to determine their division in each local area.

Based on the date supplied by World Steel Association (WSA, 2014), the production methods in China are divided into 91,2% BOF and 8,8% EAF and in Europe 49,1% BOF and 50,9% EAF.

In particular, the assessment in Europe was based on the division between BOF and EAF methods in the single nations, referred to the annual bicycle production data (CONEBI 2015, table 2).

Based on the latest literature studies on CO_2 emissions, the average CO_2 emissions for BOF method are 2240 KgCO_2/t (table 3), mainly connected with the production of cast-iron in the furnace (60% of the total amount), and 390 Kg/t for EAF method (table 4).

As a result, the average emissions for 1 ton steel produced in China are 2,08tCO_2/t and in Europe 1,30 tCO_2/t, with a difference of 0,78 tCO_2/t between the two local areas. Therefore, based on the average weight of one bicycle of Kg. 17,1, containing 6,5 Kg steel (table 1), the average emissions are 5,0 Kg. CO_2/per bicycle.

Table 2: Steel production in the bicycle producing European countries (WSA, 2014; data 2013). Yearly bicycle production is reported in each country (CONEBI, 2015; data 2014).

Country	OBF (%)	EAF (%)	Bicycle prod.(thousand)	Country	OBF %	EAF (%)	Bicycle prod. (thousand)
Austria	91,6	8,4	138	Poland	55,3	44,7	991
Belgium	66,8	33,2	99	Portugal	-	100	720
Bulgaria	-	100	950	U.K.	83,6	16,4	52
Finnland	63,1	36,9	34	Czech Rep.	92,9	7,1	333
France	65,0	35,0	630	Roumania	54,4	45,6	820
Germany	68,4	31,6	2139	Slovakia	92,5	7,5	210
Greece	-	100	108	Slovenia	-	100	5
Italy	28,2	71,8	2729	Spain	29,5	70,5	356
Lithuania	50*	50*	323	Sweden	67,8	32,2	83
Netherlands	98,0	2,0	850	Hungary	84,3	15,7	370

* presumed values, as no specific data are available.

Another assessment method considers specific emission factors for China and Europe.

As to BOF technology, no specific literature is available on China, while only one work (Pardo and Moya, 2013) is available on Europe.

As to EAF technology, a clearer difference between China and Europe is reported in literature.

The emissions are mainly connected with the electricity consumption, therefore they depend on the utilized energy mix (Orth et al,2007).

In particular, the reported average factor is 545 KgCO2/t for China (average value found in Wang et al, 2007, Orth et al,2007 for coal utilization, and Burchart-Karol,2013) and 300 KgCO2/t for Europe (average values suggested by Orth et al, 2007, for the natural gas utilization, Pardo and Moya, 2013 and Burchart-Karol, 2013).

Therefore, given 2240 KgCO2/t as average value for BOF method and considering all other aspects, Chinese emissions turn out to be 2,09 tCO2/t and European emissions 1,25 tCO2/t, so the gap between China and Europe for steel production is 0,84 tCO2/t(5,4 KgCO2/per bicycle).

Table 3: emission factors in $kgCO_2/t_{ACC}$, referring to the BOF process, found in literature.

Source / Process	Sakamoto and Tonooka (2000)	Wang et al. (2007)	Orth et al. (2007)	Pardo and Moya (2013)	Milford et al. (2013)	Average
Coke production	586	n.d.	100-103	794	430	*403*
Sintering of iron mineral	276	n.d.	272 - 285	200	220	*251*
Pelletting of iron mineral	209	n.d.	43 - 52	57	n.d.	*90*
Blast furnace	1051	1250	1505 - 1537	1219	1480	*1340*
Steel production (O_2 convertor))	100	70	220 - 250	181	120	*157*
Total	2222	n.d.	2140 - 2227	2451	2250	***2241***
Notes	Emissions in Japan	Emissions in China	Min and max emissions referred to a process based on natural gas and coal	Emissions in Europe	Emissions global average	-

Table 4: emission factors in KgCO2/t, referred to EAF process, found in literature.

Source / Process	Sakamoto-Tonooka (2000)	Wang et al. (2007)	Orth et al. (2007)	Ren e Wang (2011)	Pardo and Moya (2013)	Milford et al. (2013)	Burchart-Korol (2013)	Average
Furnace	256	640	233 - 432	400	240	330	420 - 559	***390***
Notes	Emissions in Japan	Emissions in China	Min. and Max. emissions referred to a process based on natural gas and coal	Emissions: global average	Emissions in Europe	Emissions : global average	Calculated values for Europe and China based on available data	-

CO2 emissions from aluminium production

Only wrought alloys are utilized for the production of bicycle aluminium components, while secondary aluminium produced from scrap is used only for cast alloys production, because of its impurities (Hatayama et al, 2012, Classen et al, 2009).

The production process of primary aluminium consists of the following steps:

- Bauxite extraction
- Alumin production by chemical process Bayer
- Alumin transformation into aluminium by electrolysis by Hall-Hérould process (including cell anode production).
- Casting

It is a very energy-intensive process as referred to the production of alumin (thermal energy) and electrolysis (electric energy), so the CO_2 emissions connected with this process are very different (Liu and Mueller, 2012).

For the assessment of CO_2 emissions during production process in China and Europe, the following elements were considered for the calculation:

- Emissions caused by electric energy consumption

As 98% of the total electric consumption is caused by electrolysis, different data were considered in the two local areas: 15,5 MWh/t for Europe and 13,6 MWh/t for China (IAI, 2015). For the other processes, a global average consumption was considered, as no specific geographical data are available (IAI, 2013),.

The average productions in Europe and China were taken into consideration for the electric mix(The Shift Data Portal, 2015; table 5).

Table 5: Average electric mix, referred to aluminium production in Europe and China. For each energy source, the relevant emission factor is mentioned(ISPRA, 2015).

Source	**Europe**		**China**		**Emission factor [gCO_2/kWh]**
	Average mix	**Alumin.mix**	**Average mix**	**Alumin. mix**	
Coal	25%	9%	72%	90%	883
Hydroelectric	17%	82%	20%	10%	-
Oil	5%	-	1%	-	774
Nuclear	24%	7%	3%	-	-
Natural gas	16%	2%	2%	-	370
Renewable (others)	13%	-	2%	-	-

The analysis was then repeated considering for electrolysis and casting the electric mix referred only to aluminium production field in every local area. This differs a lot from the average situation, particularly for Europe. (table 5). The same approach was adopted by Koch and Harnisch (2002) for the assessment of emissions in Europe.

- <u>Emissions connected with production of thermic energy:</u>

The utilization of thermic energy for aluminium production (more than 86% of total need)is different in the two local areas: 21,9 GJ/t for Europe and 24,4 GJ/t for China (IAI 2015). The consumption of the remaining processes are referred to a global average value (IAI,2013), as no specific data are available.

As to the mix of fuels, we considered European and Chinese data for alumin production (IAI 2015: table 6) and global average data for remaining processes (IAI,2013).

Table 6: mix of fuels used in Europe and China for alumin production. The relevant emission factor is mentioned for every fuel (MATTM,2015).

Source	Thermic mix in Europe	Thermic mix China	Emission factor [tCO_2/TJ]
Coal	-	81%	93,8
Oil	15%	5%	76,3
Natural gas	85%	14%	55,8

- Direct CO2 emissions mainly caused mainly by alumin process during electrolysis (2A12O3 +3C=4A1 + 3CO2) and, in smaller quantity, by the anode production utilized in the electrolytic cell.

These emissions were presumed similar for China and Europe because mainly connectd with the internal properties of production process. The relevant emission factors were taken from IAI (2013).

Tables 7 and 8 show the assessment of CO2 emissions for aluminium production considering the average electric mix and the specific one. According to the analysis made by the average electric mix, the estimated CO2 emissions connected with primary aluminium production are 12,9 KgCO2/t in China and 8,02 KgCO2/t in Europe, so the difference is 4,88 tCO2/t (46,5 KgCO2/per bicycle).

Considering the utilization of electric energy of the aluminium field, the specific emission values are 14,9 for China and 4,48 for Europe, giving a gap of up to 10,4CO2/t(99,3 Kg CO2/per bicycle).

Table 7: CO2 emissions [$kgCO_2/t_{Al}$] caused by the production of primary alluminium, considering the average electric

mix. The values for Europe are shown in italics, those for China are underlined.

Emissions [$kgCO_2/t_{Al}$] \ Process	Bauxite extraction		Alumin production		Anode production		Electrolysis		Casting		Total process	
da energia elettrica	*2*	3	*48*	99	*16*	33	*4878*	8811	*21*	44	*4965*	8989
da energia termica	8		*1285*	2140	84		-		52		*1429*	2284
dirette	-		-		90		1538		-		1628	
totali	*10*	11	*1333*	2238	*189*	206	*6416*	10349	*73*	96	*8021*	12901

Table 8: CO_2 emissions [$kgCO_2/t_{Al}$] referred to primary aluminium production, considering the electric mix for aluminium production only. The values for Europe are shown in italics, the ones for China are underlined.

Process \ Emissions [$kgCO_2/t_{Al}$]	Bauxite extraction		Alumin production		Anode production		Electrolysis		Casting		Total process	
From electric energy	*2*	3	*48*	99	*16*	33	*1347*	10805	*6*	54	*1419*	10993
From thermic energy	8		*1285*	2140	84		-		52		*1429*	2284
direct	-		-		90		1538		-		1628	
total	*10*	11	*1333*	2238	*189*	206	*2285*	12343	*58*	106	*4475*	14904

Similar results were confirmed by a literature survey on specific emission factors for the two local areas (table 9).

Table 9: CO_2 emissions factors, connected with primary aluminium production, available in literature.

Local area	Time	Source	Emission factor
China	2005	Wu et al., 2010 (as mentioned by Liu - Müller, 2012)	15,38 [tCO_2 eq/t_{Al}]
	unknown	Hong et al., 2011 (as mentioned by Liu - Müller, 2012)	17,05 [tCO_2 eq/t_{Al}]
Europe	2005	EAA, 2008	8,57 [tCO_2/t_{Al}]
	2005	McMillan and Keoleian, 2009	8,66 [tCO_2 eq/t_{Al}]

CO2 emissions from maritime transport

Bicycles produced in China are transported to Europe, loaded in High Cube 40' containers, with 4-ton tare (Nordana 2014), carrying 130 city bikes or 150 MTBs.

In 60% of the cases the containers go back to China empty, so CO2 emissions are calculated also for the return trip (Hamilton, 2013).

To assess CO2 emissions from maritime transport, we consider an emission factor of CO2 per each transported ton-Km.

In particular, Ecoinvent database, which is usually adopted for LCA analysis, gives an emission factor of 8,8 g/CO2/t-km (Spielmann et al, 2007), while McKinnon and Piecyck (2011) consider an emission factor of 16 gCO2/t-km, referred to the data supplied by the British Department for Environment, Food and Rural Affairs (DEFRA).

The emission factors considered by DEFRA's most recent database are between 12,5(ships with 8000 TEU and over) and 36,3 gCO2/t-km(ships under 1000 TEU) for an average 70% load (DEFRA 2013). The average emission factor reported by EEA (2013) is 14,0 gCO2/t-kg, referred to UE 15 countries).

So the emission factors adopted for the analysis were at first 16 gCO2/t-km and then a more conservative value of 8,8 gCO2/t-km.

The calculation was referred to the distance of Km. 17.700 (Tianjin-Genua) with 2,69 t/t volume per bicycle on one way and 1,01 t/t per bicycle on the way back (table 10).

Table 10: calculation of average volume transported in one way and return trip (60% of cases with empty containers).

Bicycle	Market share	Container tare [t]	Load volume per container [t]	Transported volume [t/$t_{bicicletta}$]	
				One way	Return trip
MTB, Al	35%	4	150 × 0,0159 t = 2,39	(4+2,39)/2,39 = 2,68	4/2,39 × 0,6 = 1,01
CB, Al	35%	4	130 × 0,0165 t = 2,15	2,86	1,12
MTB, ACC	15%	4	150 × 0,0189 t = 2,84	2,41	0,85
CB, ACC	15%	4	130 × 0,0195 t = 2,54	2,58	0,95
Average	-	-	-	2,69	1,01

So the estimated CO2 emissions are 18,0 Kg/bicycle (by 16gCO2/t-km factor) and 10,0 Kg/bicycle (by 8,8 gCO2/t-Km factor).

RESULTS

Therefore the total CO2 emissions deriving from the European and Chinese production of a bicycle weighing 17,1 Kg can be summarized as follows:

Table 11: total emissions connected with production of one average bicycle for the EU market.

Process	Emissions for bikes produced In China [$kgCO_2$/bike]		Emissions for bikes produced in Europe [$kgCO_2$/bikes]		Difference [$kgCO_2$/bicycle]
	Min.	Max.	Min.	Max.	
Steel production	13,4	13,5	8,1	8,4	5,0 - 5,4
Aluminium production	122,9	141,9	42,6	76,4	46,5 - 99,3
Transport	10,0	18,0	-	-	10,0 - 18,0
Total	146,3	173,4	50,7	84,8	**61,5 - 122,7**

Compared with European production, the Chinese production for the EU market causes additional emissions of min. 61,5 and max. 123 Kg CO2 per bicycle. Therefore the average value of additional emissions is 92 Kg CO2 per bicycle, divided into: 5 kg/per bicycle (6%) for steel production, 73 Kg/per bicycle (79%) per aluminium production and 14 Kg/per bicycle (15%) for maritime transport. Considering that 1 Km covered by bicycle avoids an average emission of 0,143 KgCO2 caused by travelling by car (ARPA, Lombardia 2015), the first 650 Kms run by a Chinese bicycle just compensate the extra CO_2 emissions caused by its production, compared with European production.

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