

Logistics Carbon Footprinting in Practice

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1. Introduction

- rising importance of incorporating green business strategies within logistics and SCM
 - e.g. Sustainability and Corporate Social Responsibility (CSR)
 - hypothesis: (early) adoption of sustainable/green issues influences companies' economical success positively
- green issues within logistics do not only concern single companies but entire supply chains
 - *holistic* point of view: *total* impact of business actions on environment
 - *holistic* transparency in supply chains
 - **new controlling tools are essential!**
- demand for standardised and generally accepted carbon footprint calculation methods
 - mathematical guidelines of how to practically calculate product carbon footprints
 - ensure reliable benchmarks of product carbon footprints

problem statement/research question:

- measurement of the economic impact on environment, particularly on global warming
 - realistic, effective and efficient calculation tools
- how to **realistic** measure the environmental impact of certain products respectively services in terms of absolute greenhouse gas emissions (GHG)?

2. Carbon Footprinting (I/II)

(a) carbon footprint

- no common definition exists both in theory and practice
- tool for calculating total GHG emissions along the entire SC
- represents a new stage of development concerning the
„ecological footprint“ first revealed by WACKERNAGEL/REES
 - measure indicating the impact of human activities by relating to
the areas needed per capita
 - numerically illustrates the economical influence on certain
ecological areas used to produce resources and store waste

2. Carbon Footprinting (II/II)

(b) basic carbon footprint considerations

GHG species	scale of GHG emissions	reference parameters
<ul style="list-style-type: none"> ▪ not only CO₂ emissions have to be taken into account, but all relevant GHG emissions ▪ important GHGs according to the <i>Kyoto Protocol</i>: <ol style="list-style-type: none"> (1) Carbon dioxide (CO₂) (2) Methane (CH₄) (3) Nitrous oxide (N₂O) (4) Hydrofluorocarbons (HFCs) (5) Perfluorocarbons (PFCs) (6) Sulphur hexafluoride (SF₆) ▪ non-carbon emissions can be converted into <i>carbon dioxide equivalents</i> (CO₂e) by using <i>Global Warming Potential</i> factors (GWP) as provided by the IPCC 	<ul style="list-style-type: none"> ▪ both direct and indirect GHG emissions have to be considered: <ul style="list-style-type: none"> → <i>direct GHG emissions</i> depend on <i>system boundaries</i>, i.e. usually a single corporation → <i>indirect emissions</i> on the other hand include those GHGs that <i>occur outside a single corporation</i>, although they <i>correspond to the use of energy or raw materials within the corporation</i> ▪ accurate definition of system boundaries <ul style="list-style-type: none"> → ‘<i>concept of scope</i>’ as provided by WBCSD and WRI can be adopted 	<ul style="list-style-type: none"> ▪ in contrast to ecological footprints reference is no longer made to an ecological land area but a particular product or service ▪ an often used method to calculate a product’s impact on nature: <i>life-cycle assessment</i> (LCA) <ul style="list-style-type: none"> → <i>holistic view</i> to products or services regarding full life-cycles, i.e. ‘<i>from cradle to grave</i>’ → all corresponding <i>processes and activities</i> have to be taken into account measuring the total impact in terms of GHG emissions <ul style="list-style-type: none"> → SC-wide cooperation

A **carbon footprint** is a tool for *communicating environmental impacts of certain products (or services) to the customer*. *Measuring all direct and indirect GHGs in terms of CO₂e* it reveals the *total emission quantity* polluting our nature. Thus, *all activities and processes along an entire SC are taken into account* ensuring that the product’s entire life-cycle is included ‘*from cradle to grave*’.

3. Theoretical Approach towards Logistics and SCM Carbon Footprinting: Six Stage Calculation Model (I/IV)

methodical overview: six stage process cube footprint approach

<p>[1] Identification of core processes along the entire SC</p>	<p>[2] Analysis of the identified core processes <u>and</u> segmentation into sub-processes / process elements</p>		
	<p>[3] Estimation / measurement of all sub-process / process element related GHG emissions per CO₂ driver (e.g. driven km / used kwh)</p>	<p>[4] Identification of required CO₂ drivers <u>and</u> calculation of the total CO₂ amount caused by each sub-process / process element</p>	
		<p>[5] Aggregation of all GHG emissions concerning those sub-processes / process elements needed during the entire life-cycle of a regarded product / service category</p>	<p>[6] Division of the sum of all GHG emissions (caused by one specific category) by the total number of manufactured products (or services)</p>

stage 1: identification of core processes

- development of a common understanding along the entire SC
 - idealised and standardised process categories escorting a product or service from ‚cradle to grave‘
- implementation of helpful SC frameworks, e.g. SCOR model
- identification of five core process categories (P_{total}):
 - Source (S), Make (M), Deliver (D), Consumption (C), Return (R)
 - $P_{total} = \{S; M; D; C; R\}$

stage 2: process analysis and process segmentation

- process mapping concerning the regarded product or service life-cycle as e.g. supposed by BSI British Standards, UK
 - transparency of all process interdependencies
- checking volume and content for each sub-process and its elements

$$\rightarrow P_{total} = \sum_{i=1}^n (S_i + M_i + D_i + C_i + R_i) = \sum_{i=1}^n (s_i + m_i + d_i + c_i + r_i) \quad \forall \quad i, n \in \mathbb{N}^+$$

stage 3: measurement or estimation of GHG emissions per CO₂ driver

- identification and analysis of process element related CO₂ drivers
→ e.g. km or tkm for different transport modes within delivery processes
- decision whether particular basis data should be measured (field research / primary data) or estimated (desk research / secondary data)
- mathematically calculation values can be expressed as vector (\vec{u}) indicating the CO₂ amount caused by a single CO₂ driver i concerning all process elements s, m, d, c and r .

$$\rightarrow \vec{u} = (u_{si}; u_{mi}; u_{di}; u_{ci}; u_{ri}) \quad \forall \quad i = (1, \dots, n) \in \mathbb{N}^+$$

stage 4: calculation of total GHG emissions per process element

- identification of required CO₂ drivers within product or service life-cycles
→ absolute number of demanded CO₂ driver units per process element

$$\rightarrow \vec{a} = (a_{si}; a_{mi}; a_{di}; a_{ci}; a_{ri}) \quad \forall \quad i = (1, \dots, n) \in \mathbb{N}^+$$

- calculation of the total GHG emissions (e_{ki}) per process element

$$\rightarrow e_{ki} = u_{ki} \cdot a_{ki} \quad \forall \quad k = s, m, d, c, r \wedge i = (1, \dots, n) \in \mathbb{N}^+$$

stage 5: calculation of total GHG emissions per product/service category

- consolidation of already calculated figures (stages 3/4) indicating the outcome as total CO₂ amount per product or service category ($E_{category}$):

(1) simple aggregation of all CO₂ emissions caused by each process element needed for revealing a certain product or service category

$$\rightarrow E_{category} = \sum e_{ki} \quad \forall \quad k = s, m, d, c, r \wedge i = (1, \dots, n) \in \mathbb{N}^+$$

(2) multiplication of vector (\vec{u}) [CO₂ amount caused by a single CO₂ driver i per process element s, m, d, c or r] (stage 3) by vector (\vec{a}^T) [absolute number of demanded CO₂ driver units per process element] (stage 4)

$$\rightarrow E_{category} = \vec{u} \cdot \vec{a}^T \quad \forall \quad k = s, m, d, c, r \wedge i = (1, \dots, n) \in \mathbb{N}^+$$

stage 6: calculation of product or service related GHG emissions (per unit)

- division of the category based values already calculated on stage 5 by the total number of offered products or services (x)

→ ratio represents the final product or service carbon footprint ($E_{product/service}$):

$$\rightarrow E_{product / service} = \frac{E_{category}}{x} \quad \forall \quad x \in \mathbb{N}^+$$

4. Case Study: CO₂e Emission Calculation in Last Mile Road Transportation – Objective, Instrument and Methodology

objective

- demonstrate the way of how to basically measure CO₂e emissions backpacks of pharmaceuticals and other health products caused due to last mile road transportation („product carbon footprint“)

instrument

- process analysis („activity based CO₂e emission calculation“)
 - primary data vs. secondary data
 - mixture of empirical data categories should guarantee reliable and lifelike research results

methodology

- (a) CO₂e emission measurement in last mile road transportation
- (b) CO₂e emission allocation in last mile road transportation
- (c) comparison to common (i.e. more simplifying) CO₂e emission carbon footprint allocation methods

(a) circumstances/premises:

- exemplary company:
 - NOWEDA eG Apothekergenossenschaft
 - national German service provider (‘wholesaler level’) for pharmaceuticals and other products generally found in pharmacies

- tour data:
 - round tour within the city of Essen, North Rhine-Westphalia, Germany
 - operated by a second party logistics provider (‘2PL’)
 - provided once on a weekday’s morning serving five customers
 - total distance: approximate 11.10 km
 - total time span: approximate 70 minutes
 - VW Caddy van (1.9-I-TDI, 55kW, DPF, Euro 4)

ed: energy demand
wl: workload

	ed _{unloaded van}	ed _{fully loaded van}	ed _{spread}	wl _{max.}	CO ₂ e emission factor
column	A	B	C	D	E
data/formula	manufacturer data	primary data	B-A	primary data	secondary data
unit	l/100 km	l/100 km	l/100 km	kg	kg/l
value	7.60	9.00	1.40	727.00	3.174

Tab. 1: Fixed input data for CO₂e emission calculation within last mile road transportation.

→ **advice:** data are just valid for *this* single analysed tour, operated on a Thursday morning in April 2010 by NOWEDA Essen!

(b) iterative CO₂e emission measurement in last mile road transportation

- stop_i related **energy demand** (to be iterated for each stop on the tour)

$$ed_{stop_i} = ed_{unloaded\ van} + (ed_{fully\ loaded\ van} - ed_{unloaded\ van}) \cdot \frac{wl_{stop_i}}{wl_{max}} \quad \forall i \in IN^+ \quad (1)$$

ed: energy demand
wl: workload

- **CO₂e emissions actually set free** (to be iterated for each stop on the tour)

$$CO_{2e\ emissions_{stop_i}} = ed_{stop_i} \cdot CO_{2e\ emission\ factor} \quad \forall i \in IN^+ \quad (2)$$

- **total amount of CO₂e emissions** considering each stop_i (to be iterated for each stop on the tour)

$$\Delta CO_{2e\ emissions_{stop_i}} = CO_{2e\ emissions_{stop_i}} \cdot \Delta km (stop_{i+1} - stop_i) \quad \forall i \in IN^+ \quad (3)$$

	wl _{stop i}	wl _{ratio}	ed _{stop i}	CO ₂ e emissions _{stop i}	distance (Δ stop _{i+1} – stop _i)	Δ CO ₂ e emissions _{stop i}
column	F	G	H	I	J	K
data/formula	primary data	$\frac{F}{D}$	(1)	(2)	primary data	(3)
unit	kg	kg	l/100 km	kg/100 km	km	kg
stop 1	12.02	0.017	7.623	24.196	3.00	0.7259
stop 2	10.52	0.014	7.620	24.187	0.80	0.1935
stop 3	7.38	0.010	7.614	24.168	1.20	0.2900
stop 4	6.69	0.009	7.613	24.163	1.20	0.2900
stop 5	5.76	0.008	7.611	24.158	0.80	0.1933
return trip	4.00	0.006	7.608	24.147	4.10	0.9900
total	-	-	-	-	11.10	2.6826

Tab. 2: Variable input data and CO₂e emission calculation within last mile road transportation.

(c) iterative CO₂e emission allocation in last mile road transportation

(c₁) allocation based on the number of delivered products respectively shipments per stop_i (to be iterated for the total number of stops per tour):

- total amount of CO₂e emissions **per product** ($\sum CO_2e\ emissions_{prod.}$)

$$\sum CO_2e\ emissions_{prod.} = \left(\sum_{stop_i=1}^{stop_i} \frac{\Delta CO_2e\ emissions_{stop_i}}{loaded\ products_{stop_i}} \right) + \frac{\Delta CO_2e\ emissions_{return\ trip}}{loaded\ products_{stop_1}} \quad \forall i \in IN^+ \quad (4)$$

- total amount of CO₂e emissions **per shipment** ($\sum CO_2e\ emissions_{shipm.}$)

$$\sum CO_2e\ emissions_{shipm.} = \sum CO_2e\ emissions_{prod.} \cdot delivered\ products_{stop_i} \quad \forall i \in IN^+ \quad (5)$$

	loaded products _{stop i}	$\sum CO_2e\ emissions_{prod.}$	delivered products _{stop i}	$\sum CO_2e\ emissions_{shipm.}$
column	L	M	N	O
data/formula	primary data	(4)	L _i -L _{i+1}	(5)
unit	pieces	kg/piece	pieces	kg/shipment
stop 1	93	0.0185	19	0.3506
stop 2	74	0.0211	21	0.4424
stop 3	53	0.0265	19	0.5042
stop 4	34	0.0351	14	0.4909
stop 5	20	0.0447	20	0.8946
return trip	0	-	-	-
total	-	-	93	2.6826

Tab. 3: Iterative (stop_i related) CO₂e emission allocation based on number of delivered products.

(c₂) allocation based on products' respectively shipments' weights per stop_i

(to be iterated for the total number of stops per tour):

- allocation reference parameter that indicates the amount of CO₂e emissions per kg net workload respecting each stop_i ($CO_{2e} emissions_{wl\ net\ stop_i}$)

$$CO_{2e} emissions_{wl\ net\ stop_i} = \frac{\Delta CO_{2e} emissions_{stop_i}}{wl_{net\ stop_i}} \quad \forall i \in IN^+ \quad (6)$$

lw: load weight
wl: workload

- total amount of CO₂e emissions **per shipment** ($\sum CO_{2e} emissions_{shipm.}$)

$$\sum CO_{2e} emissions_{shipm.} = \left(\sum_{start_{i=1}}^{stop_i} CO_{2e} emissions_{wl_{net\ stop_i}} + CO_{2e} emissions_{wl_{net\ return\ trip}} \right) \cdot lw_{shipm.} \quad \forall i \in IN^+ \quad (7)$$

- total amount of CO₂e emissions **per product** ($\sum CO_{2e} emissions_{prod.}$)

$$\sum CO_{2e} emissions_{prod.} = \frac{\sum CO_{2e} emissions_{shipm.}}{delivered\ products_{stop_i}} \quad \forall i \in IN^+ \quad (8)$$

	wl _{net stop i}	CO ₂ e emissions _{wl net stop i}	lw _{shipm.}	∑ CO ₂ e emissions _{shipm.}	∑ CO ₂ e emissions _{prod.}
column	P	Q	R	S	T
data/formula	F _i -F _{return trip}	(6)	F _i -F _{i+1}	(7)	(8)
unit	kg	kg CO ₂ e/kg wl _{net stop i}	kg	kg/shipment	kg/piece
stop 1	8.02	0.0905	1.50	0.3216	0.0169
stop 2	6.52	0.0297	3.14	0.7641	0.0364
stop 3	3.38	0.0858	0.69	0.2266	0.0119
stop 4	2.69	0.1077	0.94	0.4100	0.0293
stop 5	1.76	0.1101	1.76	0.9604	0.0480
return trip	0.00	0.1234	-	-	-
total	-	-	8.02	2.6826	-

Tab. 4: Iterative (stop_i related) CO₂e emission allocation based on weight of delivered shipments.

(d) comparison: common CO₂e emission allocation methods in last mile road transportation

- rareness of iterative CO₂e emission measurement and allocation in road transportation
- often necessary aspects (e.g. actual [stop_i related] workloads) are neglected (→ complexity!)
- inconsistent use of CO₂e emission allocation keys appears
→ wide range in CO₂e emission amounts (→ incomparableness of data/benchmarking problems!)
- **linear CO₂e emission allocation keys**
 (d₁) factual air distances (d₂) factual load weights

		(d ₁) air distance based allocation		(d ₂) load weight based allocation	
	air distance	∑ CO ₂ e emissions _{shipm.}	∑ CO ₂ e emissions _{prod.}	∑ CO ₂ e emissions _{shipm.}	∑ CO ₂ e emissions _{prod.}
column	U	V	W	X	Y
data/formula	primary data	$\frac{K_{total}}{U_{total}} \cdot U_{stop_i}$	$\frac{V}{N}$	$\frac{K_{total}}{R_{total}} \cdot R_{stop_i}$	$\frac{X}{N}$
unit	km	kg/shipment	kg/piece	kg/shipment	kg/piece
stop 1	2.49	0.5357	0.0282	0.5027	0.0265
stop 2	2.49	0.5357	0.0255	1.0490	0.0500
stop 3	2.51	0.5400	0.0284	0.2301	0.0121
stop 4	2.49	0.5357	0.0383	0.3138	0.0224
stop 5	2.49	0.5357	0.0268	0.5870	0.0294
total	12.47	2.6826	-	2.6826	-

Tab. 5: Common CO₂e emission allocation methods based on air distances and load weights.

4. Case Study: CO₂e Emission Calculation in Last Mile Road Transportation – Research Results

▪ iterative CO₂e emission measurement

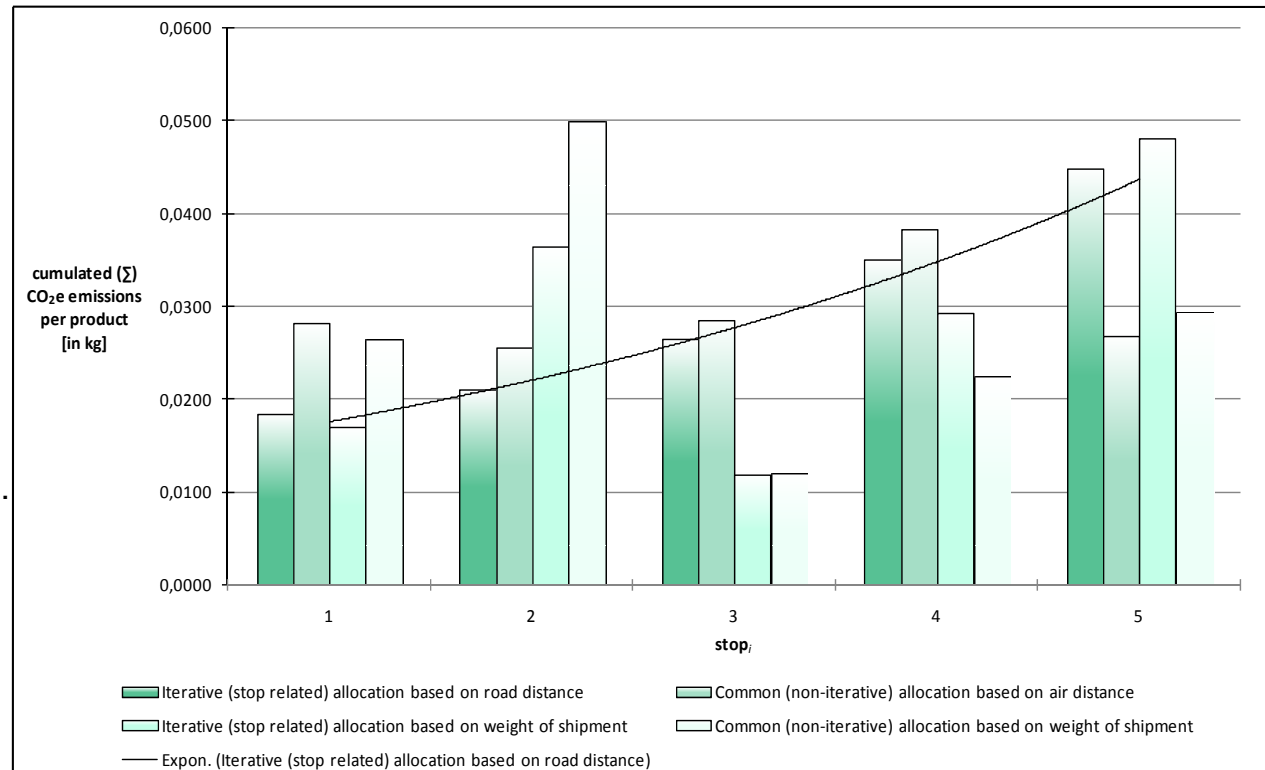
- positive – even if decreasing – increments of CO₂e emission deviations
- simultaneously dropping number of products/load weight
- accumulation of stop_i related CO₂e emissions per product or shipment
 - products delivered at the end of a tour ('latecomers') are charged with CO₂e emissions above average – compared to those products delivered at an earlier stage of the tour

▪ iterative CO₂e emission allocation

- interrelation of cumulated CO₂e emissions per product and each stop_i characterised by a *progressive rising scale* can be supposed

▪ common CO₂e emission allocation

- simplifying by using constant (i.e. linear) allocation values
 - average values of CO₂e emissions do not consider single product related circumstances



problem of missing CO₂ emission calculation standards

- diverging calculation methods: major discrepancies in announcing product carbon footprints
 - marginal possibility to benchmark carbon footprints of different companies
 - currently **no existence** of consistent product carbon footprints!

- designing **standardised global calculation guidelines** necessary!
 - proposed six stage total CO₂ calculation model in logistics and SCM can be interpreted as a first step towards an effective and efficient problem solution
- iterative (i.e. stop_i related) calculation approach in last mile road transportation effects **fair and lifelike** product carbon footprints
 - larger sample sizes: guaranteeing reliable average values of product related CO₂ emissions
 - further field research

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Thank you for your kind attention.

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