Universität Stuttgart
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Analyse bestehender methodischer Ansätze zur Berücksichtigung des Recyclings von Metallen im Rahmen der Ökobilanz

Projektbericht

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Zentralabteilung Technikbedingte Stoffströme

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Vorwort

Der vorliegende Projektbericht wird herausgegeben vom Netzwerk Lebenszyklusdaten (www.netzwerk-lebenszyklusdaten.de).

Das Netzwerk Lebenszyklusdaten ist die gemeinsame Informations- und Koordinationsplattform aller in die Bereitstellung und Nutzung von Lebenszyklusdaten in Deutschland involvierten Gruppen – von Wissenschaft und Wirtschaft über Politik und Behörden hin zu Verbraucherberatung und allgemeiner interessierter Öffentlichkeit. Ziel des Netzwerks Lebenszyklusdaten ist es, das umfangreiche Knowhow auf dem Gebiet der Lebenszyklusdaten innerhalb Deutschlands zusammenzuführen und als Basis zukünftiger wissenschaftlicher Weiterentwicklung und praktischer Arbeiten für Nutzer in allen Anwendungsgebieten von Lebenszyklusanalysen bereitzustellen.

Das Netzwerk Lebenszyklusdaten wird getragen vom Forschungszentrum Karlsruhe. Die vorliegende Studie wurde im Rahmen der Projektförderung (2004 – 2008) des Bundesministeriums für Bildung und Forschung (BMBF) „Förderung der Wissenskooperation zum Aufbau und Umsetzung des deutschen Netzwerks Lebenszyklusdaten“ erstellt. Weitere im Rahmen dieser Projektförderung erstellte Studien sind erhältlich unter http://www.netzwerk-lebenszyklusdaten.de/cms/content/Projektberichte.

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Bundesministerium für Bildung und Forschung

Analyse bestehender methodischer Ansätze zur Berücksichtigung des Recyclings von Metallen im Rahmen der Ökobilanz

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Notiz:

Um der Tatsache zu genügen, dass der Metallsektor eine international tätige und vernetzte Branche darstellt, werden alle Kapitel zur Methodenbeschreibung und -diskussion (nach Absprache mit den Koordinatoren des Netzwerk Lebenszyklusdaten Deutschland) in englischer Sprache ausgeführt.

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1 Einleitung

Metalle sind für die Ökobilanzierung von zentraler Bedeutung, da sie in zahlreichen Produkten bzw. in Verfahren für die Herstellung einer großen Zahl von Werkstoffen verwendet werden. Für zahlreiche inner- und außerbetriebliche Zwecke werden heute Ökobilanzen von Metallen benötigt.

Um zuverlässige Ergebnisse zu bieten, müssen die in Ökobilanzen verwendeten Daten hohen Qualitätsanforderungen genügen, die sich beispielsweise auf die Konsistenz der Datensätze, Aktualität und Vollständigkeit beziehen. Das in den ISO-Standards 14040ff festgelegte Regelwerk bietet hierfür einen methodischen Rahmen.

Die Bereitstellung von Ökobilanzdaten auf Material- oder Halbzeugebene baut auf einer ISO-konformen Verwendung eben dieser Daten auf. Ein wichtiger Aspekt ist hierin die Berücksichtigung aller potentiellen Umweltwirkungen eines Systems im Verlauf seines gesamten Lebenswegs. Für den Bereich der Metalle liegt in diesem Kontext der besondere Fokus auf der sachgemäßen Berücksichtigung des Recyclings.

Bei vielen Anwendern von Ökobilanzen und Ökobilanzdaten fehlt jedoch das Fachwissen zu metallischen Rohstoffen und metallurgischen Prozessen, um hier eine Einschätzung der Erfüllung der vorgenannten Anforderungen vorzunehmen. Erschwerend hinzu kommt die Vielzahl an möglichen methodischen Herangehensweisen, dem Lebenszyklusvorteil von Materialien mit hoher Recyclingquote im Rahmen einer Ökobilanzstudie Rechnung zu tragen.

Der Arbeitskreis „Metallische Rohstoffe“ übernimmt im Netzwerk Lebenszyklusdaten daher die Aufgabe, ein Grundlagenkonzept für das methodische Rahmenwerk der Ökobilanzierung von Metallen zu erarbeiten bzw. aus bestehenden Arbeiten zusammenzuführen. Ziel ist es, relevante Lebenszyklusaspekte von Metallen herauszuarbeiten, die entsprechenden methodischen (und in der Praxis angewendeten) Ansätze darzustellen sowie im Hinblick auf ihre Anwendungsmöglichkeiten zu diskutieren.

Der Fokus der Arbeit liegt auf der sachgemäßen und kontextspezifischen Berücksichtigung des Recyclings von Metallen in Rahmen der Ökobilanzierung. Die Analyse der verschiedenen methodischen Ansätze zur Berücksichtigung des Recyclings findet am Beispiel Stahl statt, die Diskussion wird im Gesamtkontext Metalle geführt.

2 Lebenszyklusaspekte von Metallen

Ein wichtiger Aspekt im Rahmen von Ökobilanzen ist die Berücksichtigung aller potentiellen Umweltwirkungen eines Systems im Verlauf seines gesamten Lebenswegs.

Relevante Lebenszyklusaspekte, die durch die Verwendung von Metallen in Endprodukten von ökologischer Relevanz sind, sind beispielsweise die Materialrückgewinnung am Lebensende des Produktes sowie die Überführung in einen neuen, weiteren Lebenszyklus eines anderen Produktes. Entscheidende Faktoren sind hierbei beispielsweise die Wiedergewinnungsrate des Metalls, die sich im Wesentlichen über die Sammelquote von Altmaterial sowie die Effizienz des Recyclingprozesses bestimmt, siehe Figure 2-1.

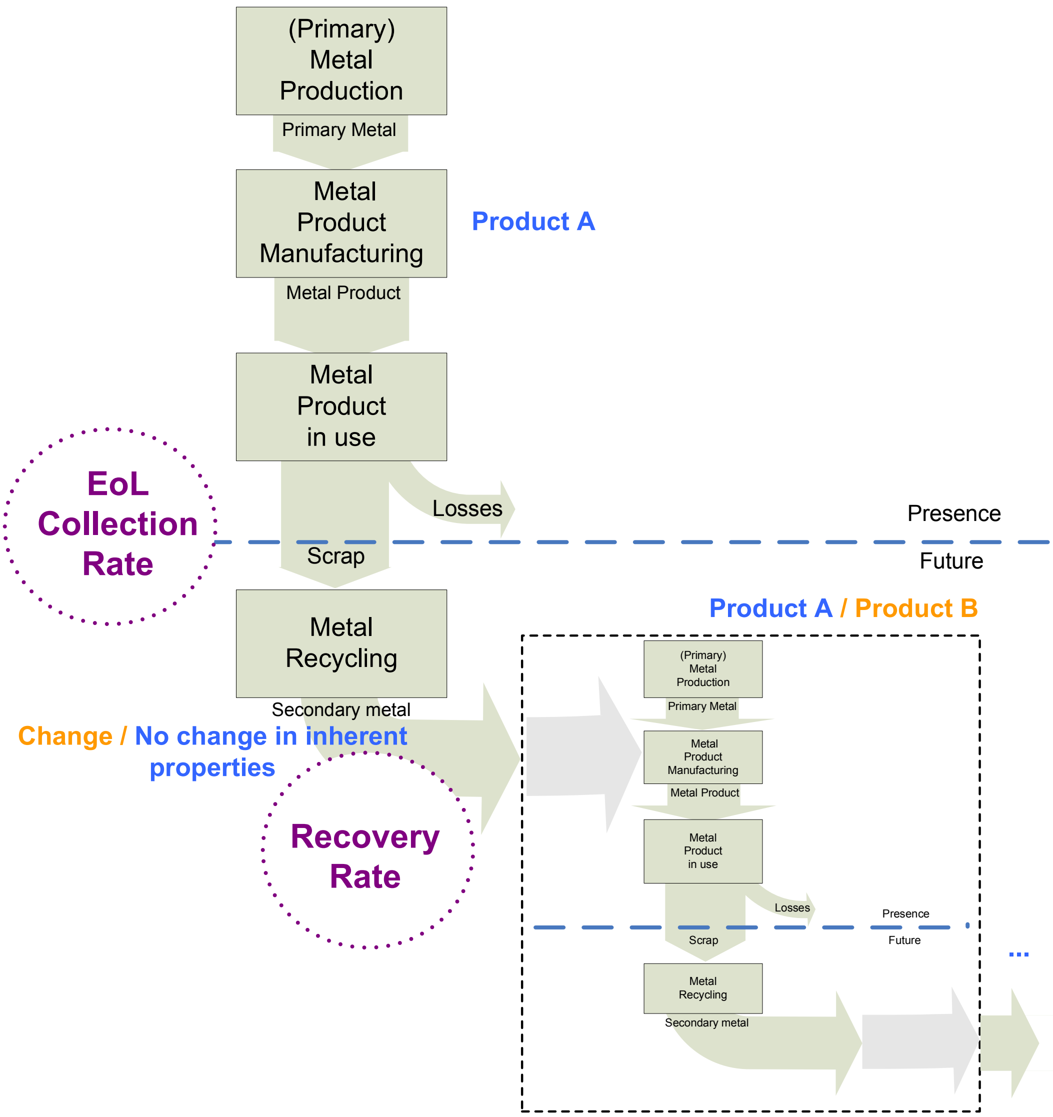

Figure 2-1: Lebenszyklusparameter von Relevanz im Kontext Recycling [PFLIEGER, ILG 2007]

Metalle werden in einer Vielzahl von Endprodukten eingesetzt, so dass sich ihr Lebensweg je nach Verwendung entsprechend differenziert darstellt.

Table 1 gibt beispielhaft für die Stahlindustrie eine Übersicht über die Verwendung der unterschiedlichen Stahlprodukte, von Bewehrungsstahl bis Weißblech, in den verschiedenen Endprodukt-Sektoren, wie beispielsweise Automobil, Bau, Verpackung, etc.

Table 1: Application (fields) for steel products [www.worldsteel.org]

Application	Sub-application blank is No; 1 = Possible;2 = preferable	Plate	Pipe	Hot Rolled Coil	Pickled Hot Rolled Coil	Cold Rolled Coil	Finished Cold Rolled Coil	Electro-Galvanized	Hot-Dip Galvanized	Organic Coated	Tin Plate	Electrolytic Chromed Coated Steel	Section Rolling	Rebar	Engineering Steel	Wire Rod	
Frame-Work	Profiles			2	2	1		1	2				2				
	Framing								2								
Automotives	Body in white				1		2	2	2	1							
	Structural parts				2		2	2	2	1							
	Engine														2		
	drives equipements														2		
	transmissions														2		
	wheels				2												
	tyres															2	
Construction	Structural parts	2	2	2					1	2			2				
	walls elements							2	2	2							
	Basement												2	2			
	Concreete reinforcement													2			
	Cladding			1				2	2	2							
	Roofing								2	2							
	Farm building walls								1	2							
	Gutter system (ducts)								2	2							
	Chimney ducts			1													
	construstion components			1	1			2	2	2							
	Farm building components								1	2							
	Doors and garages								1	2							
	Fences								1								
	Stairs			2					1								
	Tiles								1	2							
	Ceilings components							2	2	2							
	Floor components			2				1	2								
	Inside decoration panels									2							
	partition walls							1	2	2							
	inside panels food industry									2							
	security rails on roads								2								
Home appliances	furniture						1	2		2							
	white goods						2	2	2	2							
	heating, ventilation and air conditioning						2	2	2	2							
Packaging	Steel Food & General Line Cans									2	2	2					
	Pails											2					
	Beverage cans									2	2	2					
	Drums						2	2									
Machinery	Rail												2				
	Machines	1					2								2		
	Pipes		2														
Others	tubes			2	1		2										
	pools								1	1							
	water tanks								2								
	greennhouses								1	1							
	signs								1								
	tools														2		
	dies														2		
	wires													2		2	

Die Produktapplikation definiert relevante Lebenszyklusaspekte, z.B. die Wiedergewinnungsrate, oder aber den Typ (Stahl)Produkt, der zum Einsatz kommt.

3 Berücksichtigung des Recyclings von Metallen in Ökobilanzen

Ein Lebenszyklusaspekt von ökologischer Relevanz bei der Verwendung von Metallen in Produkten ist deren Recyclingfähigkeit. Um dem Ziel der Ökobilanz gerecht zu werden, alle ökologisch relevanten Aspekte über den Verlauf des Produktlebenszyklus zu berücksichtigen, sind geeignete methodische Ansätze notwendig, um der ökologischen Auswirkung des Recyclings auf den gesamten Produktlebenszyklus Rechnung zu tragen.

Der Fokus der vorliegenden Arbeit liegt auf dem Recycling am Lebensende von Produkten, nicht während der Produktion.

In der (Ökobilanz) Praxis ist hierzu eine Vielzahl von methodischen Ansätzen in der Anwendung. Das Recycling von Metallen lässt sich in der Regel nicht auf einen Lebenszyklus eingrenzen, sondern wirkt sich entsprechend auf weitere Lebenszyklen anderer Produkte, für deren Herstellung Sekundärmetalle eingesetzt werden, aus.

Eine der prinzipiellen Fragen, die es zu beantworten gilt, ist die Frage, wem der ökologische Vorteil aus der Verwendung von Sekundärmaterial gutzuschreiben ist – dem Produktlebenszyklus, in dem das Sekundärmaterial eingesetzt wird, oder dem Produktlebenszyklus, aus dem das Sekundärmaterial wieder gewonnen wird?

Eine Fragestellung ist demnach inwieweit der ökologische Vorteil aus dem Recycling den entsprechenden Produktlebenszyklen zugeordnet wird.

Ein weiterer Punkt ist die methodische Vorgehensweise, diesen ökologischen Vorteil im Rahmen der Ökobilanz, z.B. über ein Gutschriftenverfahren, zu berücksichtigen.

Im Rahmen dieses Kapitels wird die Ökobilanzpraxis im Hinblick auf die Berücksichtigung des Recyclings von Metallen am Lebensende von Produkten analysiert. Die bestehenden Ansätze werden in ihrer Methodik beschrieben; die Methodenbeschreibung dient als Basis für die weitere Analyse und Diskussion der Methoden.

Notiz:

Um der Tatsache zu genügen, dass der Metallsektor eine international tätige und vernetzte Branche darstellt, werden alle nachfolgenden Kapitel zur Methodenbeschreibung und -diskussion (nach Absprache mit den Koordinatoren des Netzwerk Lebenszyklusdaten Deutschland) in englischer Sprache ausgeführt.

3.1 Principles

In the following a few main principles to be kept in mind in discussing End of Life recycling considerations within LCA are discussed. The discussed principles are explained (exemplarily) in detail in the context of the methodology discussion of the open loop approach, see chapter 3.2.43.2.2.

3.1.1 Market situation

According to the specific market situation, the material/metal production of the system under study can be characterised as primary material/metal production, secondary material/metal production or the market mix out of possible primary and secondary production routes, see Figure 3-1.

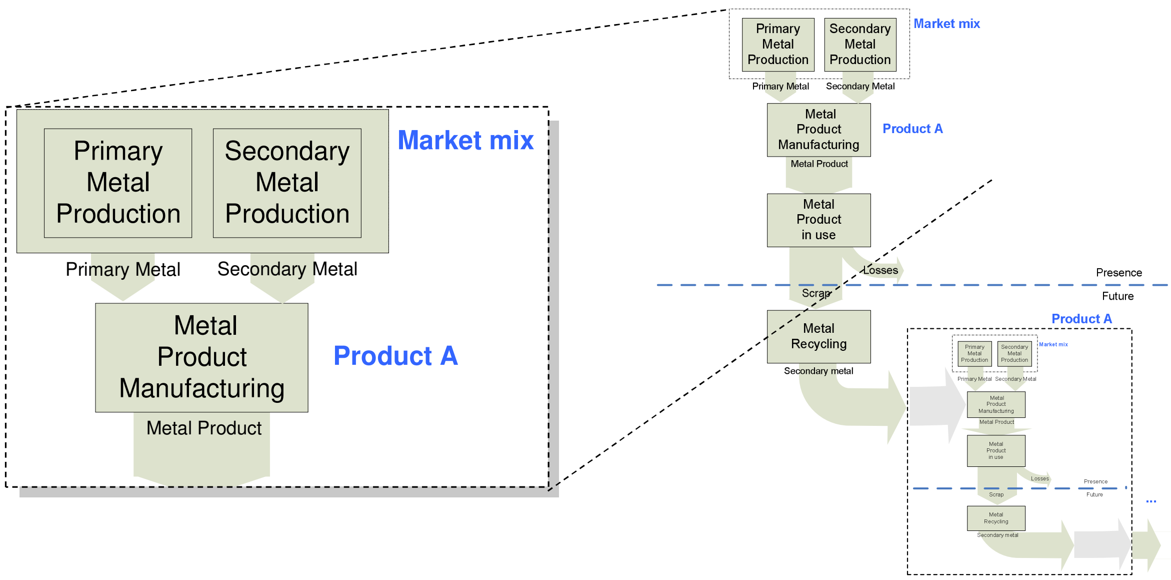

Figure 3-1: Market situation (Primary/Secondary Production)

This is to be considered in applying selected methodological approaches for EoL recycling scenarios.

3.1.2 Upstream burden and downstream credit

Talking about the recovery of materials/metals it gets clear that the end of life consideration covering the recycling of material/metal (down stream credit) at the same time turns into an upstream consideration (upstream burden) from the viewpoint of the product system consuming the recovery material/metal.

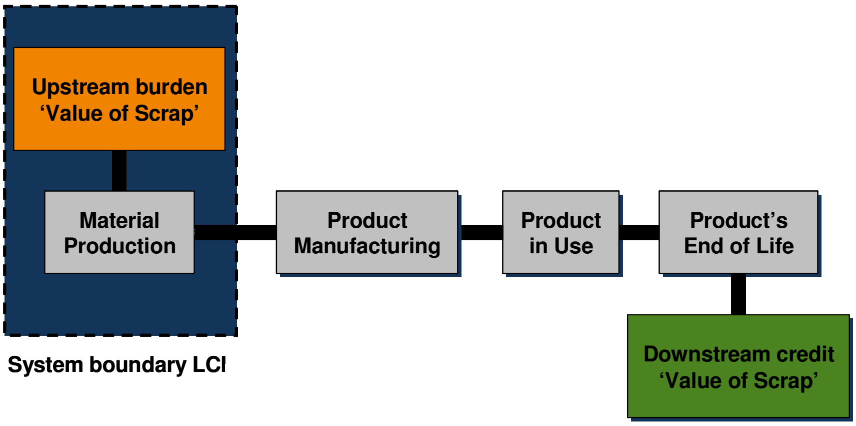

Figure 3-2: Use (= upstream burden) and production (= downstream credit) of scrap

ISO 14044 (4.3.4.2 Allocation procedure) requires that allocation procedures have to be uniformly applied to similar inputs and outputs of the product system under study, i.e. the use of recovered material/metal within a product system (= input) is to be treated equally from a methodological point of view to material/metal recovery from a product system (= output), see Figure 3-2.

Often this requirement is met by only considering the net amount of recovered material/metal to credit for material/metal recovery. The net amount of recovered material/metal is specified by the difference in amount of material/metal recovery at the end of life of a product as well as the use of recovered material/metal for production of the considered product system.

This procedure is justified as only the material/metal loss over the complete product life cycle is to be taken into account. Nevertheless in doing so the differences between the single life cycle phases (production, use and end of life) will be obliterated.

3.1.3 100% primary / 100% secondary production routes

Attention must be paid to the fact that not always a 100% primary or a 100% secondary route is given in the real world of metal production. For example the average basic oxygen furnace of an integrated steelworks has an input of 1% to 20% scrap from external supply (see Figure 3-3). [IISI 2006]

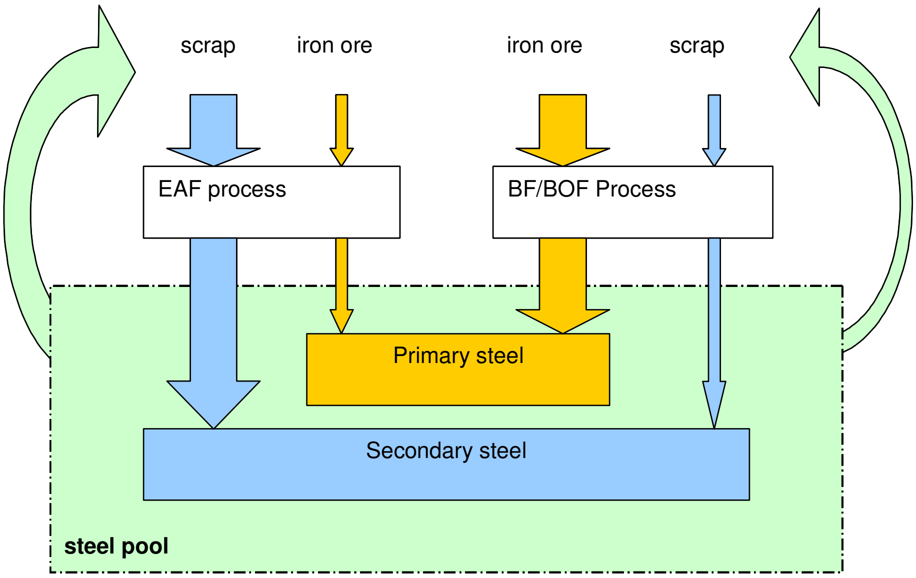

Figure 3-3: Steel production via the EAF as well as BF/BOF route

This fact can lead to the following situations:

a) A crediting system, expressed by an inverted LCI profile for primary metal production, "produces" metal scrap.
The reason is that there are primary metal production routes/processes consuming a certain amount of scrap (in addition to the raw material consumption). The inversion of such scrap-consuming production processes/LCIs turns the scrap input into an scrap output of the system, see Figure 3-4.

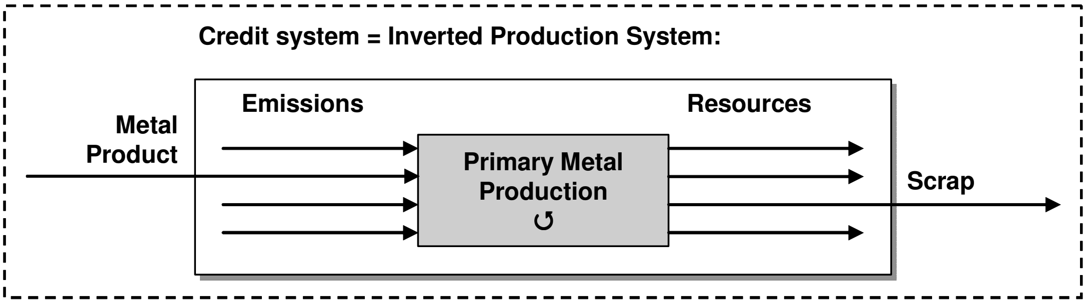

Figure 3-4: Credit system via inverted product system [PFLIEGER, ILG 2007]

b) For the "Value of scrap" calculation, following the calculation procedure of IISI, the difference between the virtual(!) 100% primary and 100% secondary metal production is to be considered.

3.1.4 Definition of key parameters

[EUROMETAUX 2006], [PFLIEGER, ILG 2006]

Of high importance is a consensual understanding of the definitions and terms used to describe the methodological approaches. For this reason the key parameters of relevance in the context of recycling at products' end of life are defined in the following – with particular consideration of the reference.

End of Life collection rate

The product application specific ratio of material/metal collected compared to the material/metal, in theory, available for recycling, i.e. introduced to the market initially.

$$\text{End of Life collection rate} = \frac{\text{Material/Metal collected}}{\text{Material/Metal available for recycling}}$$

Recycling process yield

The recycling process yield describes the efficiency of the secondary production process in terms of recycling/recovery of end of life material/metal.

Recovery/Recycling rate

The fraction of material/metal recovered during one life cycle of a product compared to the total material/metal introduced initially to the product system. The following definitions of the recovery/recycling rate (per product application = ppa) exist:

$$\text{Recovery/Recycling rate (ppa)} = \frac{\text{Amount of material recycled (ppa)}}{\text{Amount of material available for recycling (ppa)}}$$

$$\text{Recovery/Recycling rate (ppa)} = \text{End of Life collection rate (ppa)} * \text{Recycling process yield}$$

3.1.5 End of Life scenario/situation “versus” End of Life methodology/approach

It is necessary to distinguish between End of Life scenario describing the recycling situation at products’ End of Life, e.g. recycling into the same product system, no change in inherent material properties, etc. (see Figure 3-5), and the (modelling) approaches/methodologies applied to consider and describe the thereby resulting effects within LCA (see Figure 3-6).

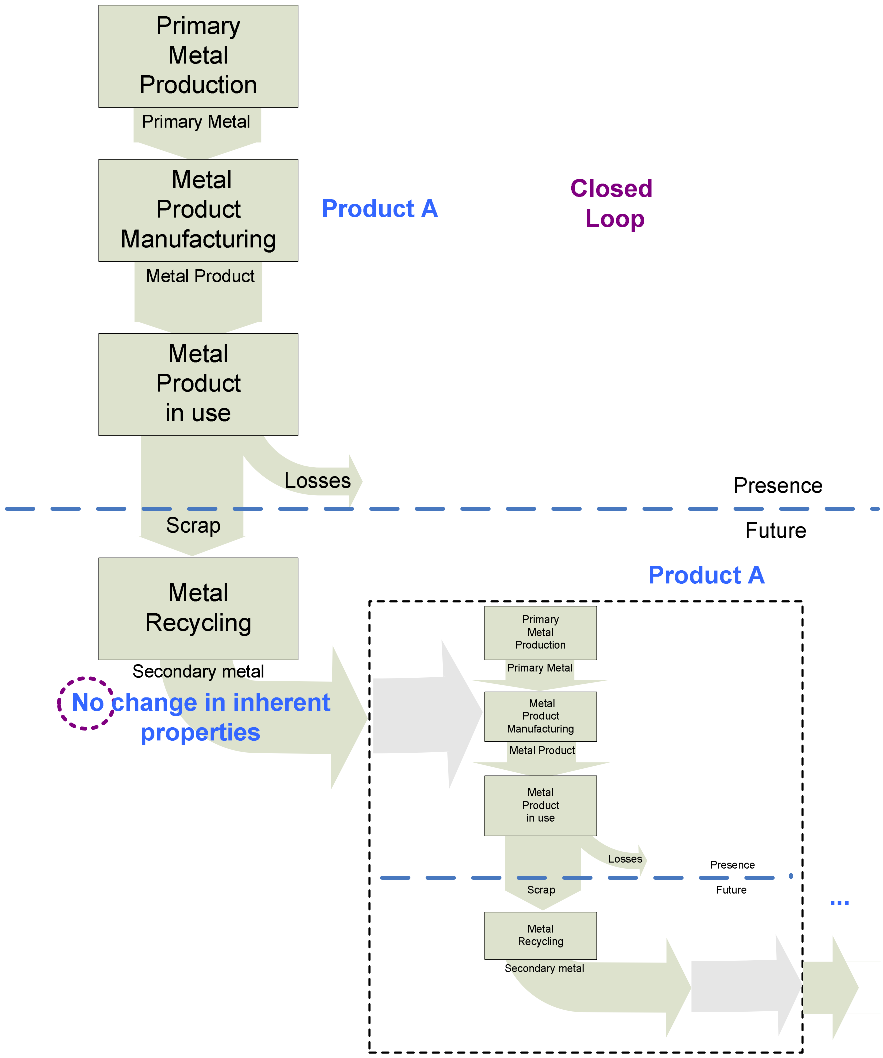

Figure 3-5: End of Life situation according to closed loop [PFLIEGER, ILG 2007]

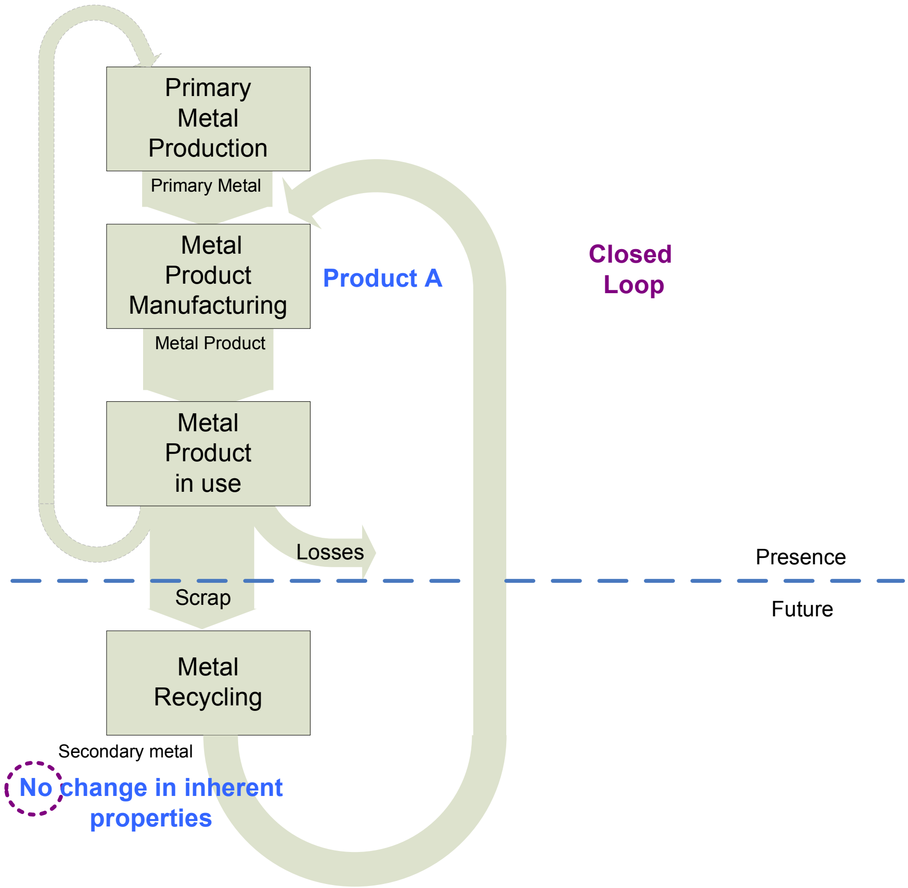

Figure 3-6: LCI modelling according to closed loop [PFLIEGER, ILG 2007]

3.2 Methodische Ansätze zur Berücksichtigung des Recyclings in Ökobilanzen

The following methodological approaches are considered and discussed in detail:

- Cut-off approach
- Closed loop approach
- System expansion by crediting
- Open loop approach
- Value-corrected substitution approach
- (Infinite) Multi-step recycling approach
- Value of scrap approach
- Cascade approach
- Recycling potential

3.2.1 Cut-off approach

Literature: [KLÖPFFER 1996]; [FRISCHKNECHT 1998]

The end of life phase is not considered in the system boundary definition of the cut-off approach, as illustrated in Figure 3-7.

Only the environmental burden caused by the actual material/metal production, the product manufacturing as well as the use phase is taken into consideration.

There is no consideration of the efforts to recover (= to collect and recycle) material/metal at products' end of life. In the same way there is no credit accounted for the use of recovered material/metal within other product life cycles different from the one under study.

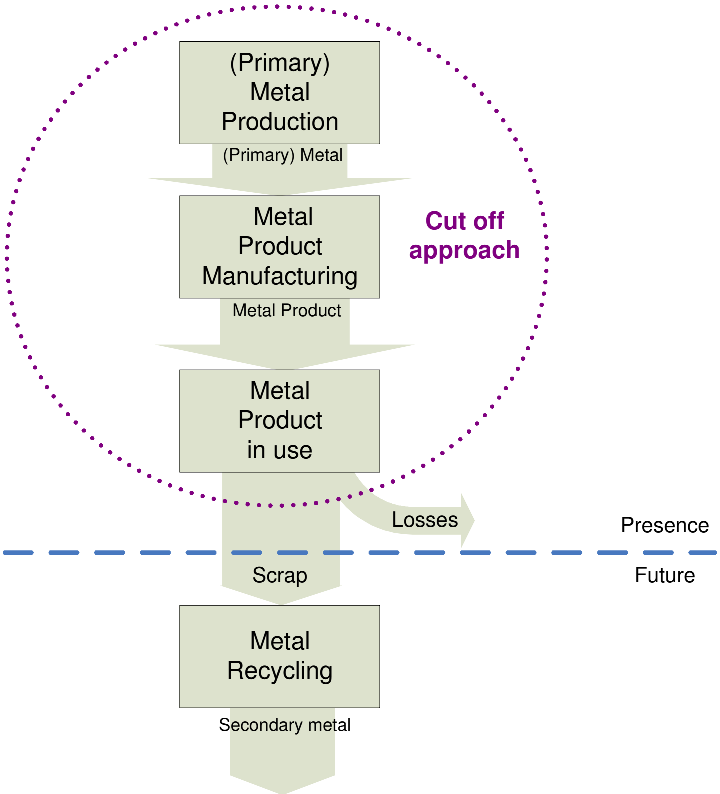

Figure 3-7: Cut-off approach [PFLIEGER, ILG 2007]

A consideration of an upstream burden for the use of recovered material/metal is not discussed within literature for this approach.

3.2.2 Closed loop approach

Literature: [ISO 14044], [ISO/TR 14049]

A closed loop allocation applies to product systems, where it is assumed that recycled material (100%) replaces virgin material (100%).

The ISO 14044 points out the following main aspects in this context:

a) No change or change of inherent properties of the recycled material

b) Recycling into the same or other product system(s)

The prerequisite for a closed loop consideration, as stated in ISO 14044, is that there are no changes in the inherent properties of the recycled material.

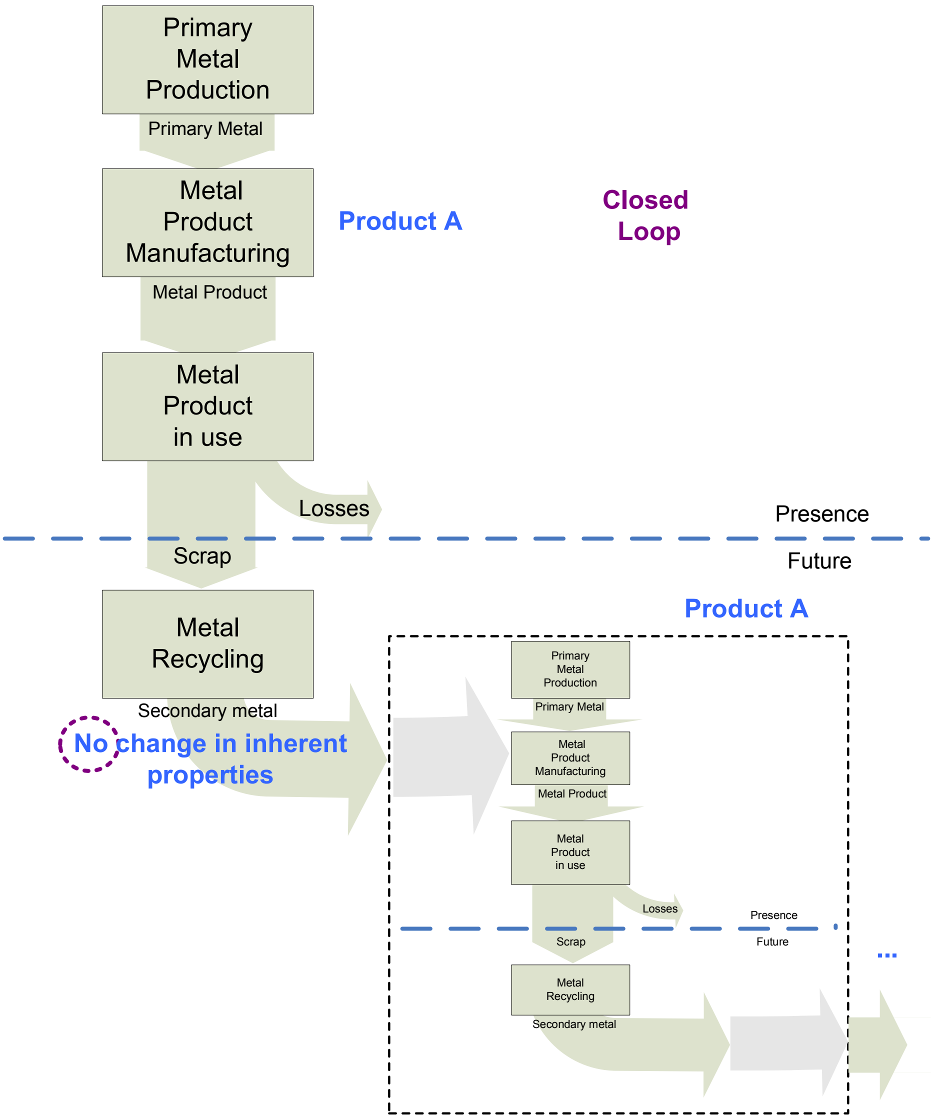

Figure 3-8: End of Life situation according to closed loop [PFLIEGER, ILG 2007]

An additional precondition (as demarcation from open loop approach) for the closed loop definition is that the material/metal is recycled into the same product system. This interpretation arises from the fact that a special case of closed loop is described as an open loop system (= material/metal recycling into other product systems) where no changes occur in the inherent properties of the recycled material. [BRIMACOMBE ET. AL 2006]

The closed loop allocation proceeds on the assumption that recycled material/metal replaces virgin material, but material losses of the use phase and end of life phase are replaced by virgin material (see Figure 3-8).

According to ISO 14044 the closed loop allocation is defined as recycling of "material from a product system … in the same product system". The thereby resulting LCI modelling structure of the closed loop approach is shown in Figure 3-9.

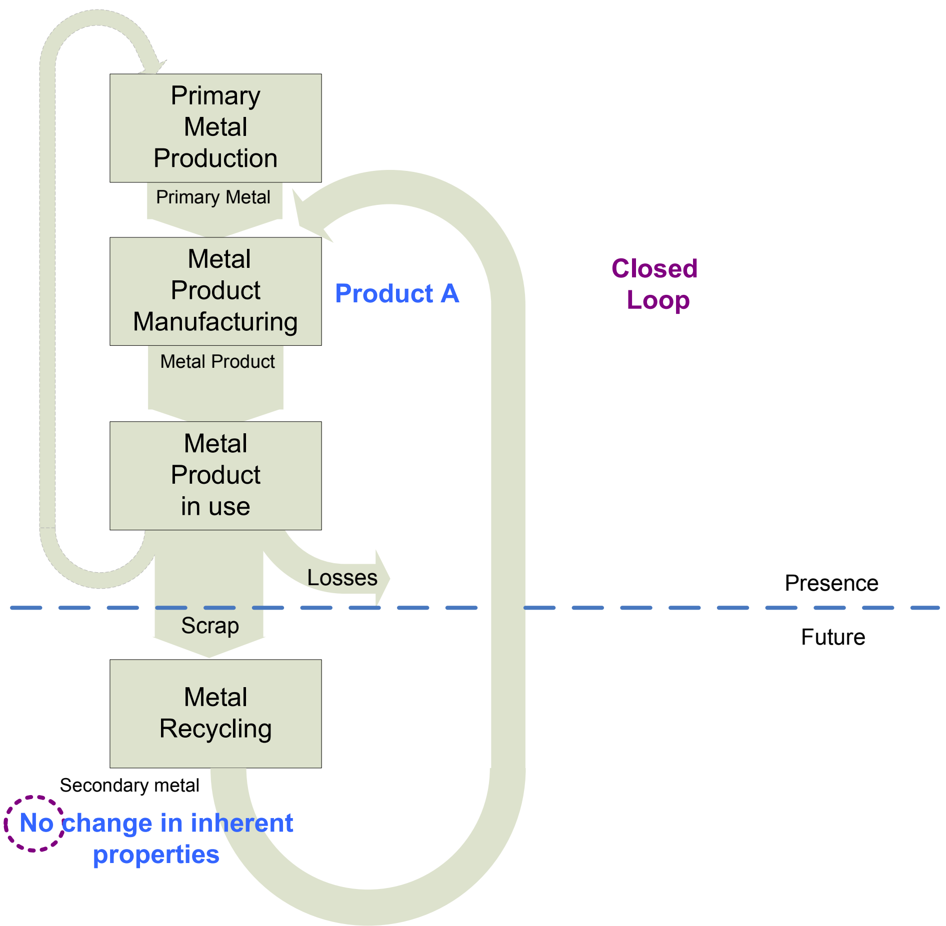

Figure 3-9: Closed loop approach (classic presentation)

3.2.3 System boundary expansion by crediting

Literature: [VIGON ET AL. 1993], [WEIDEMA 2001], [WEIDEMA 2003]

The approach of system boundary expansion by crediting proceeds on the assumption that the recycled material substitutes (due to its material/product properties) another product, see Figure 3-10.

The principle of this approach is based on the expansion of the system under study by inclusion of an inverse LCI module (= credit) describing the production/provision of a complementary product of the recycling product.

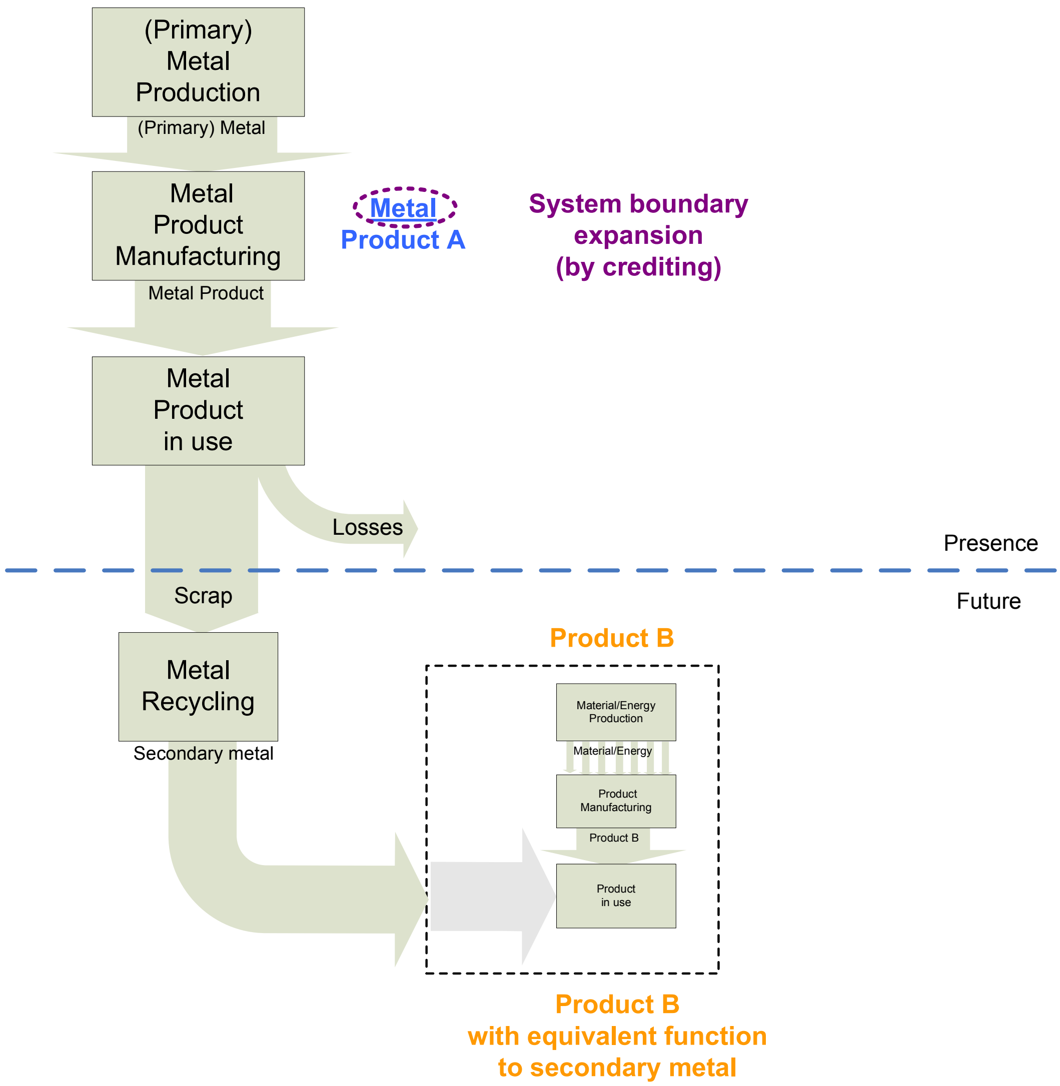

Figure 3-10: System boundary expansion by crediting [PFLIEGER, ILG 2007]

The principle of system boundary expansion by crediting is implicitly applied within other methodologies; examples covered by this report are the closed loop approach, the value-corrected substitution approach, the (infinite) multi-step recycling approach as well as the recycling potential approach, see following subchapters.

3.2.4 Open loop approach

Literature: [ISO 14044], [ISO/TR 14049], [EKVALL, TILLMAN 1997]; [LINDFORS ET AL. 1995]; [KLÖPFFER 1996]; [FLEISCHER 1994]; [BOHNACKER 1998]; [KARLSSON 1994]; [ÖSTERMARK, RYDBERG 1995]; [VIGON ET AL. 1993]; [SCHRICKER, GOLDHAHN 1994]; [FRISCHKNECHT 1998]

An open loop allocation procedure applies to open loop product systems where the material/metal is recycled into other product systems and/or the material/metal undergoes a change in its inherent properties, which is displayed in Figure 3-11.

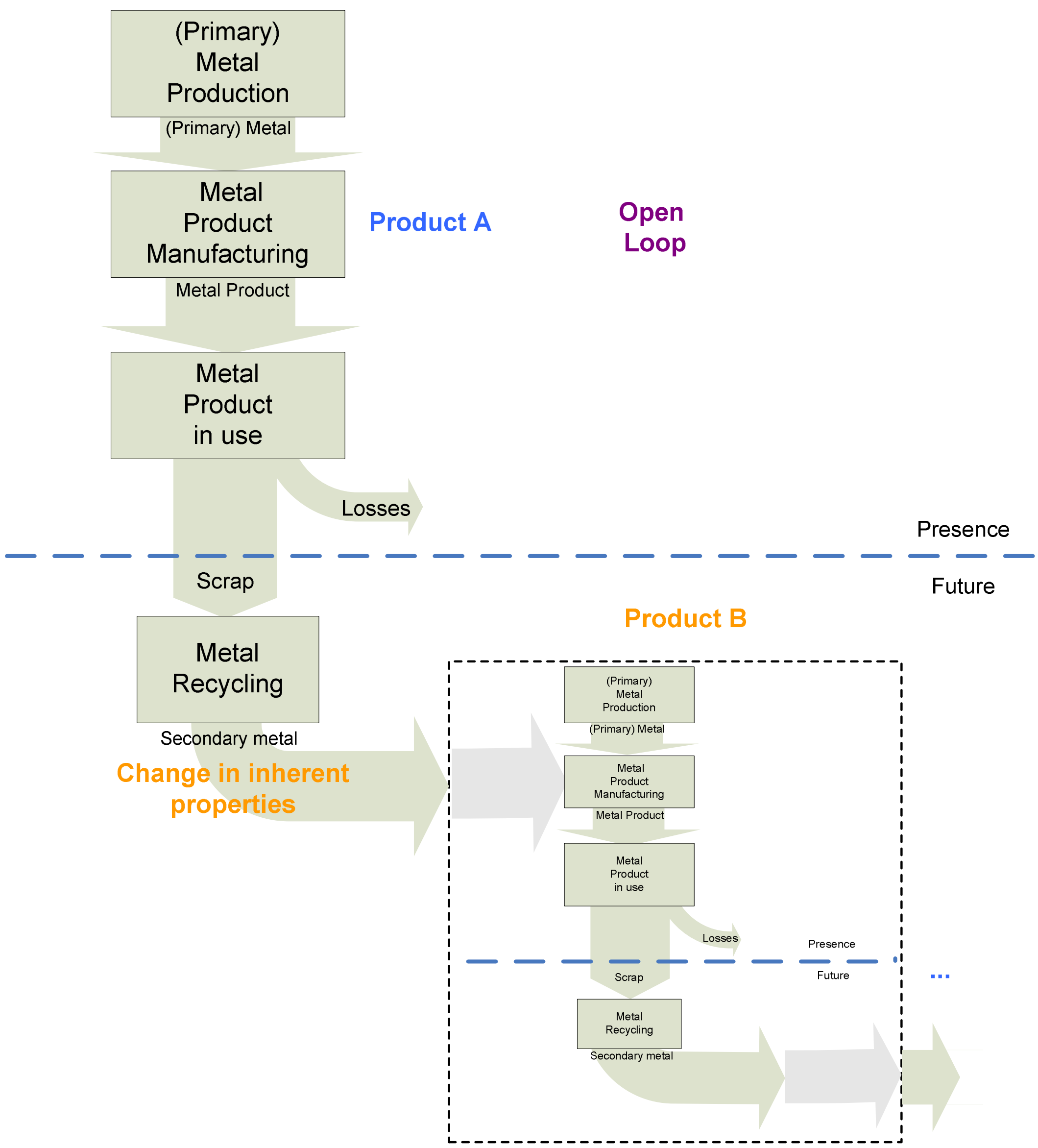

Figure 3-11: Open loop approach (classic) [PFLIEGER, ILG 2007]

In case of changed inherent properties ISO 14044 recommends to use principally physical properties (or economic values) as basis for the allocation procedure.

Within the special case of an open loop system where no changes occur in the inherent properties of the recycled material the closed loop approach is to be applied according to ISO 14044 (see Figure 3-12). This procedure is based on the assumption that in case there are no changes in inherent properties of the recycled materials the use of secondary material replaces the use of virgin (primary) materials.

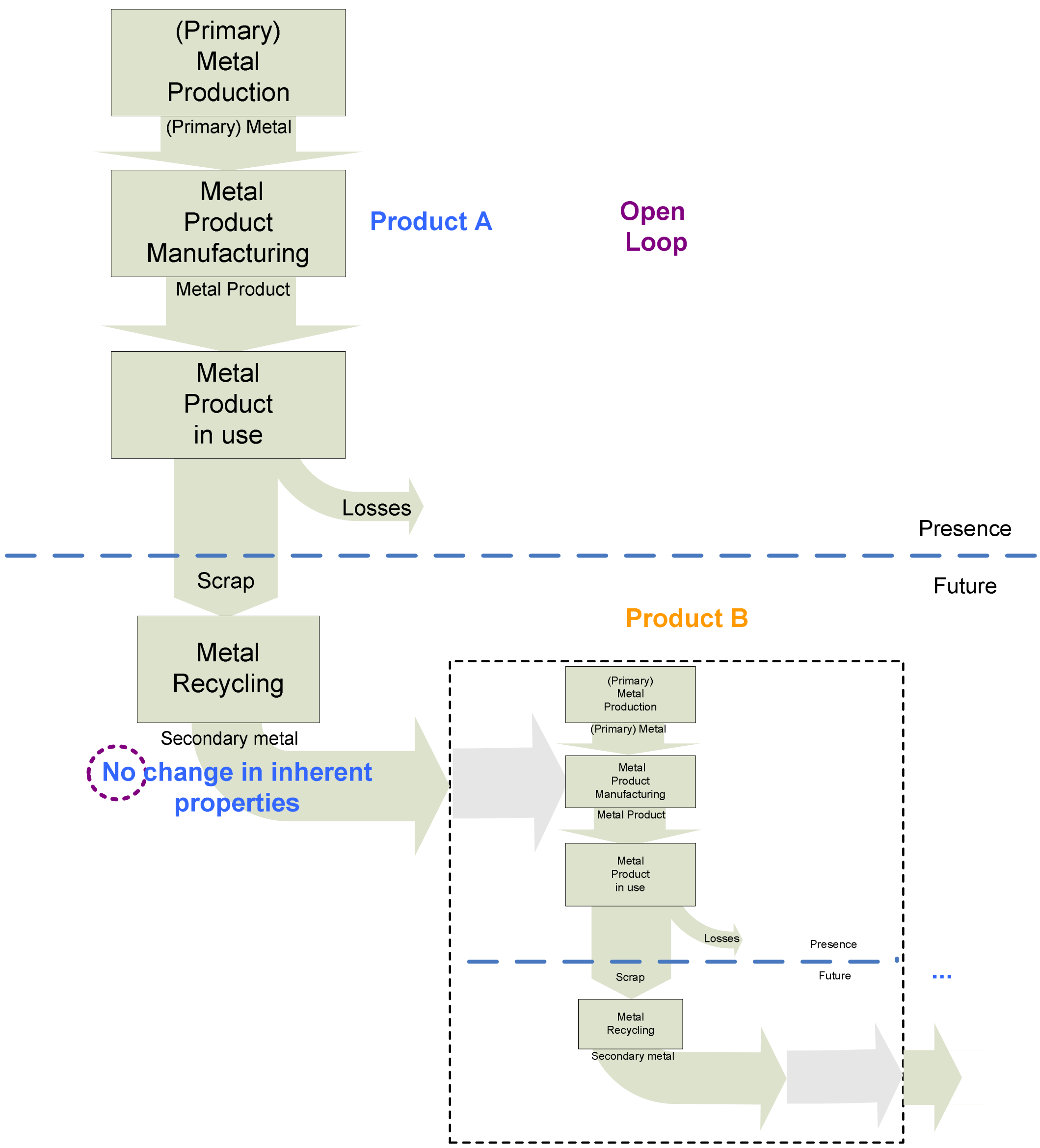

Figure 3-12: Open loop approach (no change in inherent properties) [PFLIEGER, ILG 2007]

In practice, depending on the market situation, the material/metal production of the system under study can be characterised as primary material/metal production, secondary material/metal production or the market mix out of possible primary and secondary production routes.

Although the closed loop approach is starting from a primary material/metal production, the criteria of closed loop (no change in inherent properties of the recycled material) can be true for and the principle of closed loop applied to other market situations as described above – following an open loop approach, see Figure 3-13.

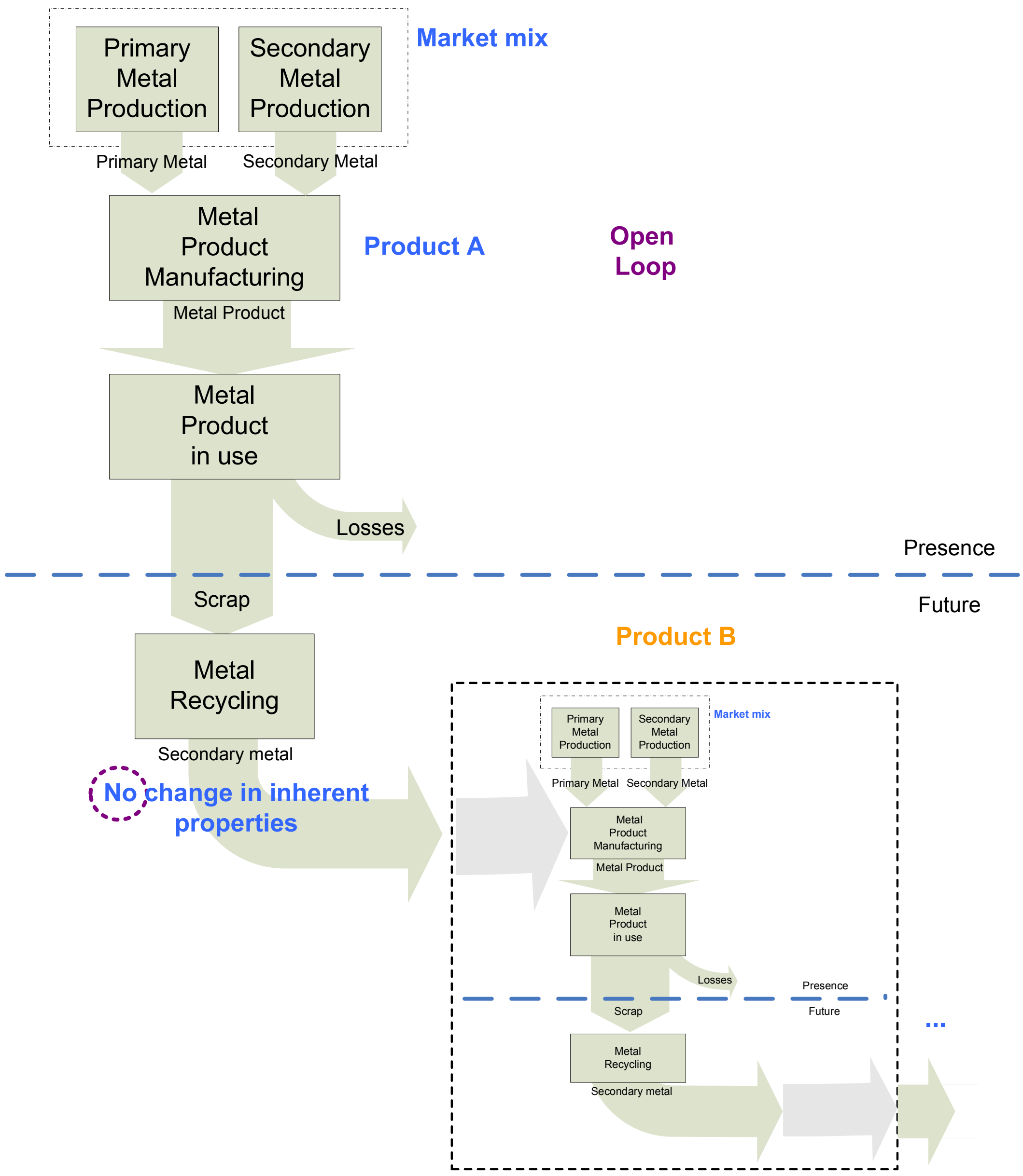

Figure 3-13: Open loop approach (no change in inherent properties, considering market mix production) [PFLIEGER, ILG 2007]

The use of recovered material/metal within a product system (= input) is to be treated equally (from a methodological point of view) to material/metal recovery from a product system (= output) – unless otherwise justified.

For this reason the upstream burden of recovered material/metal entering the production of the product system under study is to be calculated according to the same rules/procedure than the downstream credit to account for the recovery of the same material/metal at products end of life, see Figure 3-14.

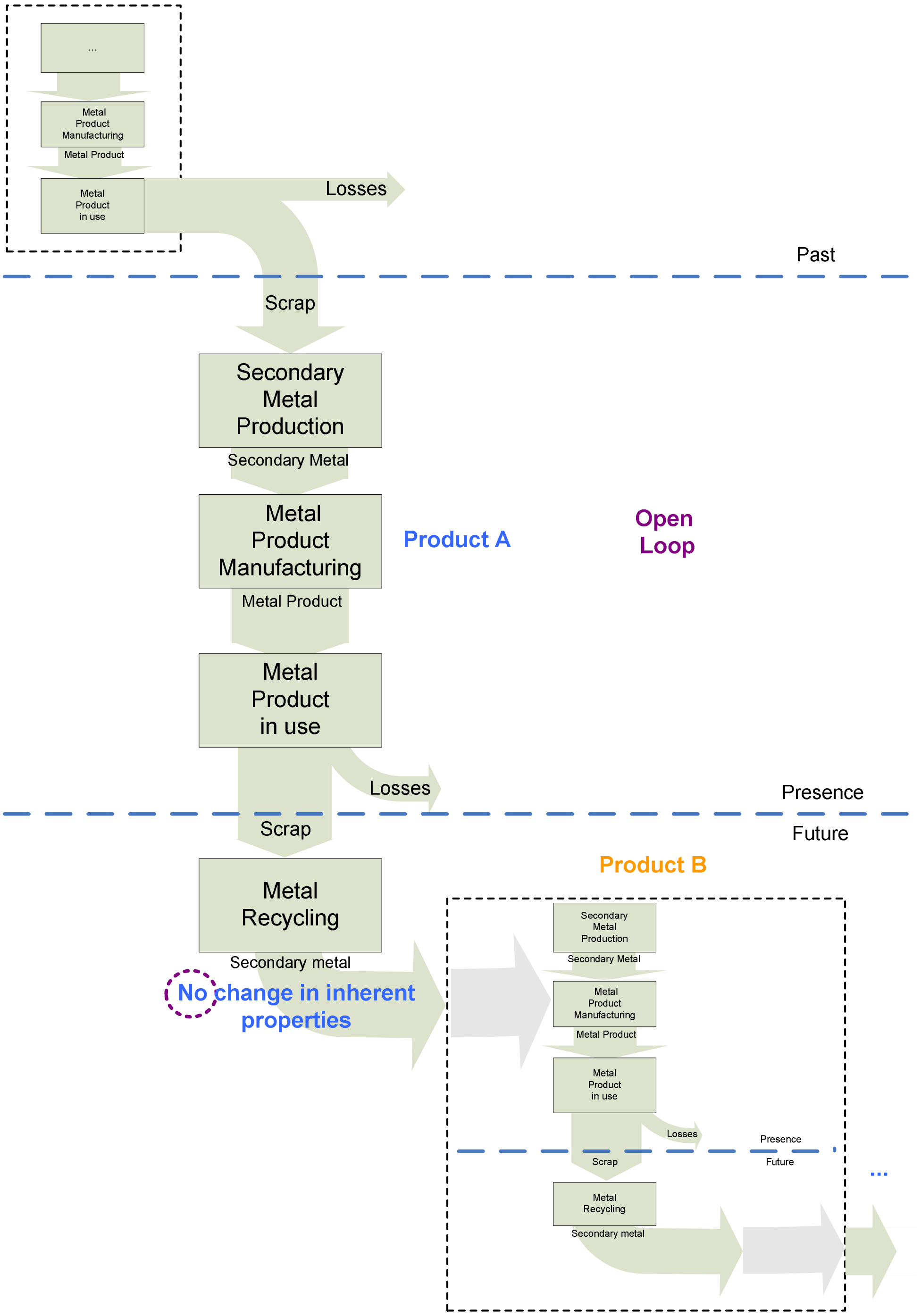

Figure 3-14: Open loop approach: Upstream burden/Downstream credit [PFLIEGER, ILG 2007]

Often this requirement is met by only considering the net amount of recovered material/metal to credit for material/metal recovery. The net amount of recovered material/metal is specified by the difference in amount of material/metal recovery at the end of life of a product as well as the recovered material/metal used for production of the considered product system, see Figure 3-15.

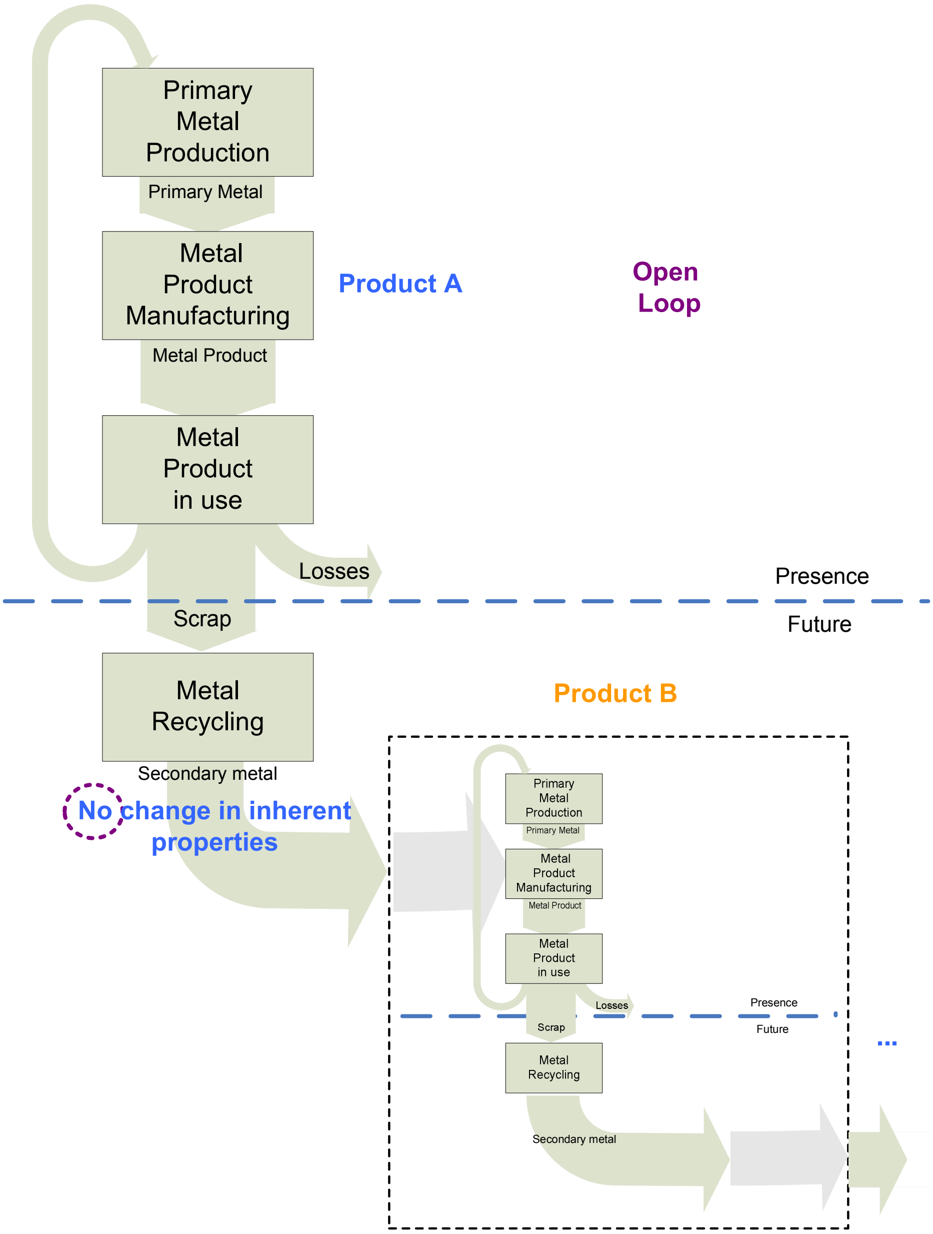

Figure 3-15: Open loop approach: Net material recovery [PFLIEGER, ILG 2007]

3.2.5 Value-corrected substitution approach

Literature: [WERNER 1999]; [WERNER 2002A]; [WERNER 2002B]; [EAA 2007]

Within the value-corrected (VC) substitution approach the underlying assumption is, analogous to the closed loop approach, that recycled material replaces virgin material.

Contrary to the closed loop approach this methodological approach considers that the recycled material is not able to fully substitute primary material. It assumes that the substitution ability is reflected by physical properties or economic values, e.g. the ratio between the market prices of the recycled and primary material (see EAA 2007):

Recycled material (100%) replaces virgin material (100%*VC; VC<1)

Material losses of the end of life processes and "value losses" are replaced by virgin material. The principle of the value-corrected substitution approach is shown in Figure 3-16.

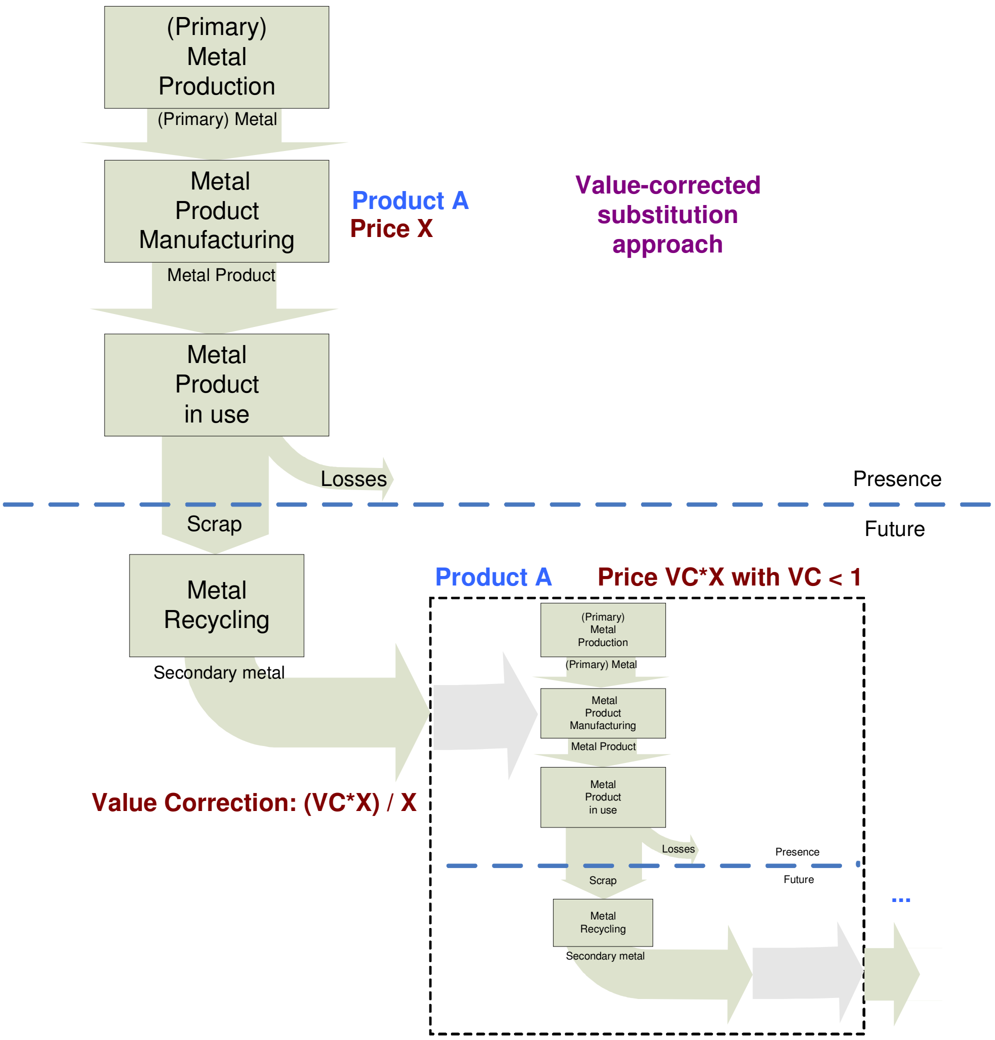

Figure 3-16: Value-corrected substitution approach [PFLIEGER, ILG 2007]

Within the value corrected substitution approach a change of the inherent properties applies, but effectively the product system is treated as a closed loop system.

3.2.6 (Infinite) Multi-step recycling approach

Literature: [ABOUSSOUAN ET AL. 2007], [BIRAT ET. AL, 2006]

Within the (infinite) multi-step recycling approach the underlying assumption is that the material, except a certain percentage of losses per life cycle loop, is recycled again and again, see Figure 3-17. The basic idea is to determine the mean environmental burden over all life cycles of e.g. 1t of material/metal.

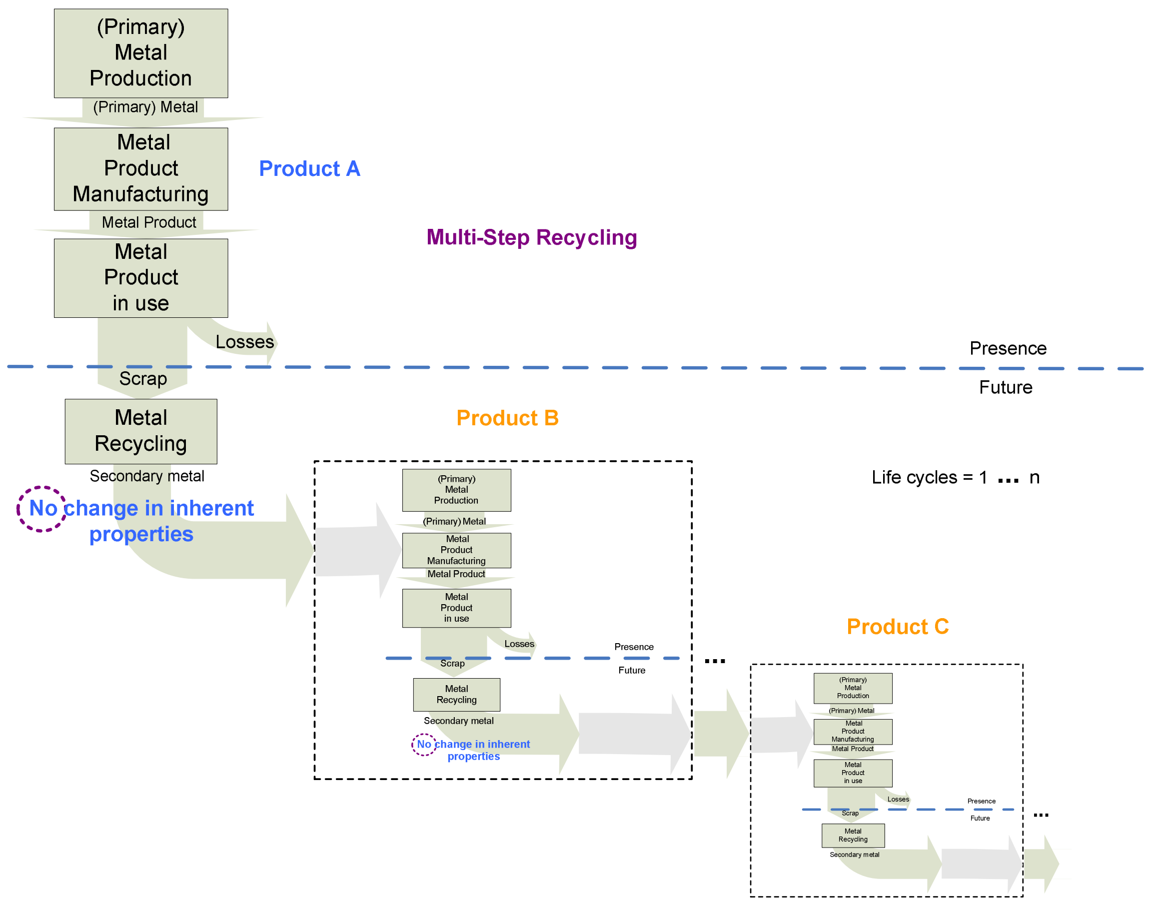

Figure 3-17: Multi-step recycling approach [PFLIEGER, ILG 2007]

A general formula for the overall impact is then written as:

$$C^n = \frac{C_{Primary} * (1 - rY) + C_{Secondary} * \left(rY - (rY)^{n+1}\right)}{1 - (rY)^{n+1}} + C_{End\ of\ Life}$$

With C^n is the average LCI for an n-step recycling, $C_{End\ of\ Life}$ is the End of Life LCI of the non-recycled material, $C_{Primary}$ is the LCI of the primary material production and $C_{Secondary}$ is the LCI of the secondary material production as well as r being the total recycling rate (pre-/post-consumer scrap) and Y being the yield of the recycling process.

For infinite loop recycling the result turns out the same (also the underlying principle is different) as considered within the closed loop approach:

$$C^\infty = C_{Primary} * (1 - rY) + C_{Secondary} * rY + C_{End\ of\ Life}$$

3.2.7 Value of scrap approach

Literature: [BRIMACOMBE ET. AL 2006]

The basic idea of the value of scrap approach is the allocation for scrap outputs from whole life systems (e.g. scrap arising from an end of life building or automobile) as well as for scrap inputs to material/metal production.

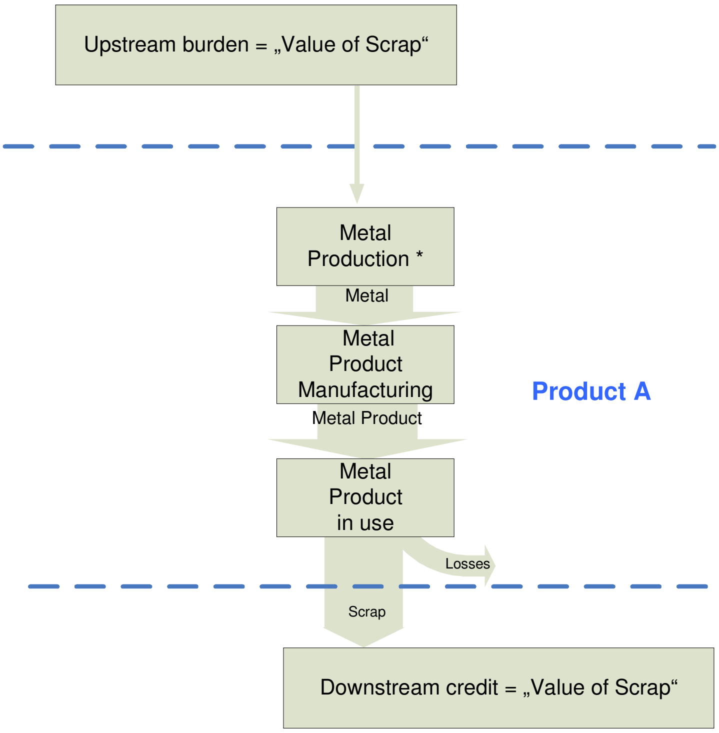

Figure 3-18: Value of scrap approach [PFLIEGER, ILG 2007]

The application of consistent allocation procedures is essential in accounting for scrap inputs and outputs of a system. Within the value of scrap approach this consistency is ensured by defining an LCI for scrap – providing a mechanism for allocating for scrap inputs (= upstream burden) as well as scrap outputs (= downstream credit).

The calculation of the value of scrap (= LCI of scrap) is based on the difference between the 100% primary (0% scrap input) and 100% secondary (100% scrap based) route – considering in addition the yield of the recycling process (see the following equation). This approach implies that recycled material/metal avoids the primary burden X_{pr} but consumes the recycling burden X_{re}:

$$LCI\ allocation\ for\ scrap = Y * \left(X_{pr} - X_{re}\right)$$

With Y being the metallic yield referring to the efficiency of the secondary process in converting scrap into recycled material/metal, X_{pr} being the LCI for primary material/metal production (0% scrap input) and X_{re} being the LCI for secondary material/metal production (100% scrap based).

In order to apply this calculation procedure LCI data for both 100% primary (material/metal) production and 100% secondary (material/metal) production is required.

3.2.8 Cascade approach

Literature: [KARLSSON 1994], [KIM, HWANG 1997], [ÖSTERMARK, RYDBERG 1995] and [EKVALL, TILLMAN 1997], [LINDFORS ET AL. 1995], [FAVA ET AL. 1991], [VIGON ET AL. 1993]

The cascade approach allocates the environmental burden of two or more (product) life cycles to two or more life cycles, see Figure 3-19, according to specific allocation rules.

Definition of the cascade approach after [Karlsson 1994] and [Kim, Hwang 1997]: A cascade approach is existent when a decrease of material quality or existing substance quality is considered in an open loop recycling model. Using this model the environmental impacts are distributed throughout the different product systems.

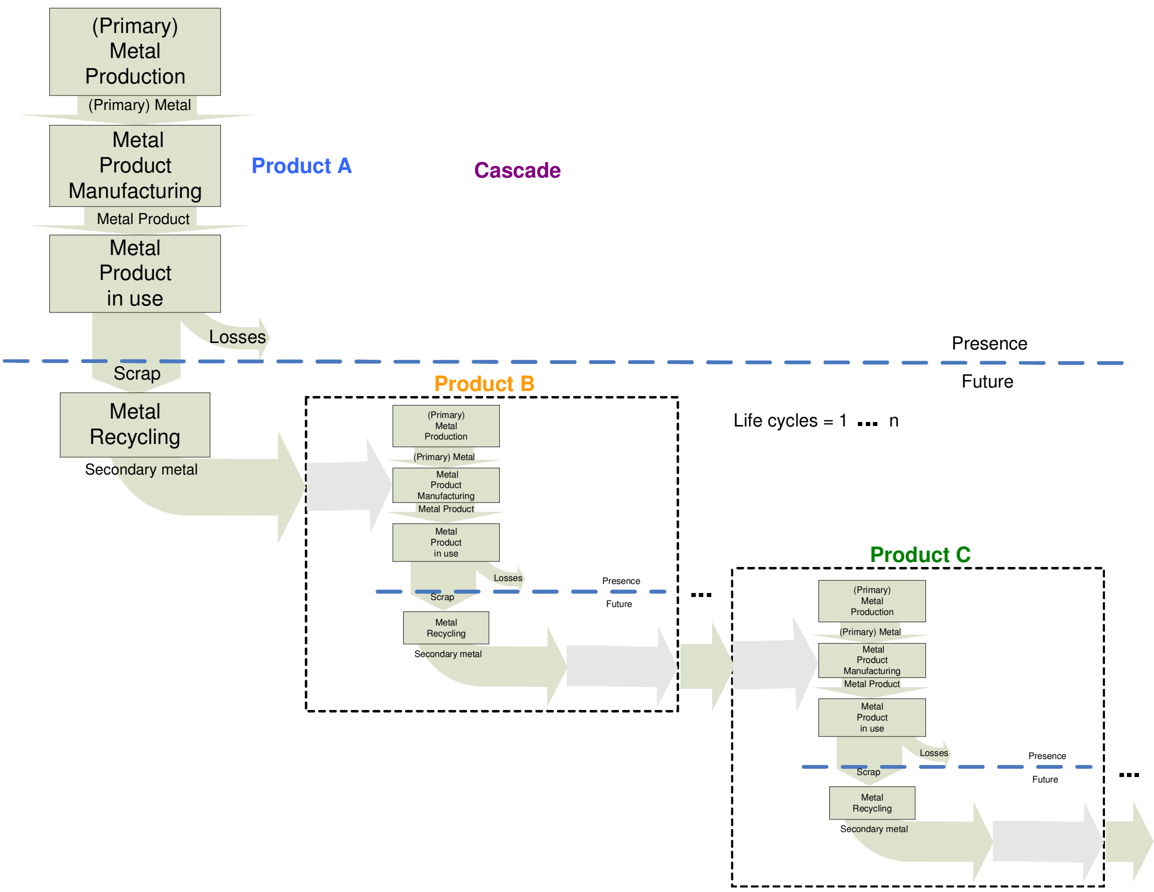

Figure 3-19: Cascade approach [PFLIEGER, ILG 2007]

There is a variety of different approaches given (and applied) to allocate the environmental burden to the different (product) life cycles under consideration.

In general there are three main approaches to allocate the environmental burden:

- according to the principle of "first responsibility"
- according to the principle of "last responsibility"
- according to the principle of "equality"

In the following only these three allocation approaches are explained in detail.

For more information, further reading is given in the literature [KARLSSON 1994], [KIM, HWANG 1997], [ÖSTERMARK, RYDBERG 1995] and [EKVALL, TILLMAN 1997], [LINDFORS ET AL. 1995], [FAVA ET AL. 1991], [VIGON ET AL. 1993] and others.

3.2.8.1 First responsibility

Literature: [BOHNACKER 1998], [ÖSTERMARK, RYDBERG 1995].

The principle of first responsibility allocates the highest environmental impact to the first product system. This principle is based on the aspect that all materials end up as waste. Therefore waste disposal is the unavoidable consequence of primary material production. The recycling process is located outside the system boundary and belongs to the subsequent product system. In order to minimize the chargeable environmental impacts of a product system it is of advantage to abandon the application of primary materials during production and using secondary materials from other product systems instead.

3.2.8.2 Last responsibility

Literature: [BOHNACKER 1998], [KARLSSON 1994]

The principle of last responsibility allocates the highest environmental impact to the last product system. Underlying is the idea that the product system which destroys (disposal, no recycling) a material or product has to carry the environmental loads of the primary production. Material losses in the techno-sphere are to be replaced by primary resources. In order to minimize the environmental impacts of a product system it is of advantage to abandon the disposal of a product by delivering secondary materials to other product systems.

3.2.8.3 Equality

Literature: [BOHNACKER 1998], [VIGON ET AL. 1993].

The principle of equality allocates the environmental impacts of the production and disposal equally to all product systems. By equal allocation of all environmental impacts neither the primary production nor the disposal (recycling and disposal) will be considered separately. Therefore the life cycles of an examined product system has to be known.

In addition a literature review is given:

- the direct polluter-pays principle [Schricker, Goldhahn 1994], allocates the environmental impact to the product system which (directly) caused the environmental impacts;
- the principle of functional compliance [SCHNEIDER 1994], which comprises material quality and considers physical functions (e.g. mass) as well as socio-economic allocation formula (e.g. current market value);
- Allocation models with different characteristics of the 50:50 Method in order to allocate environmental impacts equal to two product systems ([EKVALL, TILLMAN 1997], [LINDFORS ET AL. 1995], [FAVA ET AL. 1991], [VIGON ET AL. 1993]).

3.2.9 Recycling potential

Literature: [GABI 2007]

The recycling potential approach does justice to the fact that, depending on the life time of the product under study, it is difficult to give information on the (recycling) situation at products' end of life with reasonable certainty.

For this reason the recycling potential approach speaks of a "potential" with subsequent potential evaluation or description.

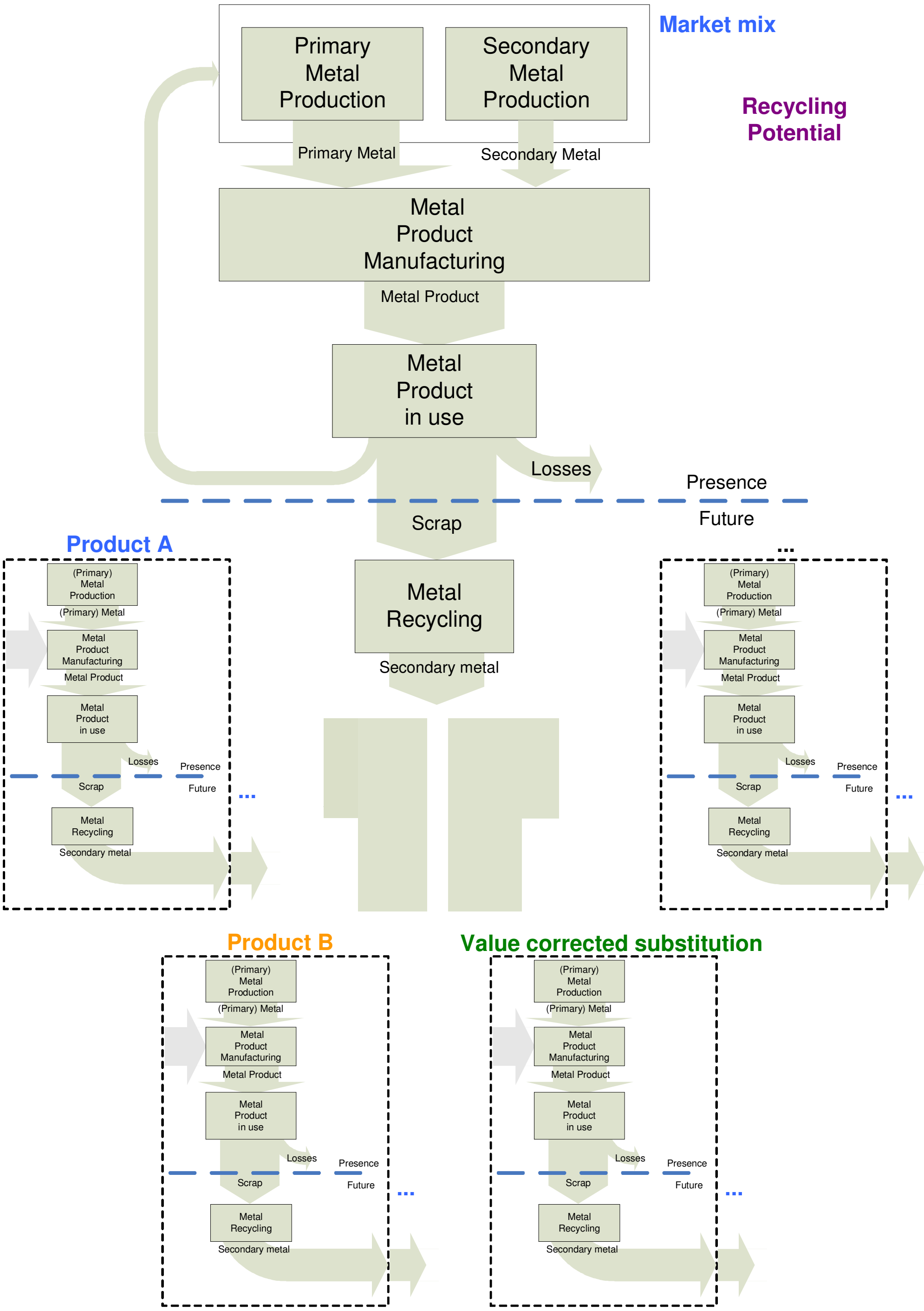

Figure 3-20: Recycling-potential [PFLIEGER, ILG 2007]

To describe the recycling potential it is evaluated according to questions such as the "possibility to replace virgin production". The evaluation can end up in existing allocation approaches such as closed loop or value-corrected substitution, see Figure 3-20.

The main principle followed is the designation of material/metal available for recovery (determined on the basis of assumptions on end of life collection rates, etc.) as well as an evaluation of the potential environmental effect of its recycling.

4 Review of methods

To systematically analyse and discuss methods/approaches to account for the recycling of material/metal at products' end of life within LCAs a criteria check list was set-up, discussed and agreed upon with the participating metal associations and applied on the described methods. In addition to the defined list of general criteria, e.g. ISO conformity, the methods were discussed in the context of potential application fields of LCA, e.g. comparative study, weak-point analysis, etc.

4.1 Criteria List

[PFLIEGER 2006]

The criteria check list takes into account the following aspects/criteria:

ISO conformity

Conformity to ISO 14044 is to be given.

With respect to the application of allocation procedures it is of particular relevance that ISO (4.2.3.3 System boundary) states that "(ideally,) the product system should be modelled in such a manner that inputs and outputs at its boundary are elementary and product flows."

The following section describes the allocation as defined by the ISO 14044:

General

The inputs and outputs shall be allocated to the different products according to clearly stated procedures that shall be documented and explained together with the allocation procedure.

The sum of the allocated inputs and outputs of a unit process shall be equal to the inputs and outputs of the unit process before allocation.

Whenever several alternative allocation procedures seem applicable, a sensitivity analysis shall be conducted to illustrate the consequences of the departure from the selected approach.

Allocation procedure

The study shall identify the processes shared with other product systems and deal with them according to the 3 stepwise procedure presented below.

a) Step 1: Wherever possible, allocation should be avoided by

1) *Dividing the unit process to be allocated into two or more sub-processes and collecting the input and output data related to these sub-processes, or*
2) *Expanding the product system to include the additional functions related to the co-products, taking into account the requirements of 4.2.3.3 (within the DIN ISO 14044, chapter system boundary).*

b) Step 2: Where allocation cannot be avoided, the inputs and outputs of the system should be partitioned between its different products or functions in a way that reflects the underlying physical relationships between them; i.e. they should reflect the way in which the inputs and outputs are changed by quantitative changes in the products or functions delivered by the system.

c) Step 3: Where physical relationship alone cannot be established or used as the basis for allocation, the inputs should be allocated between the products and functions in a way that reflects other relationships between them. For example, input and output data might be allocated between co-products in proportion to the economic value of the products.

Some outputs may be partly co-products and partly waste. In such cases, it is necessary to identify the ratio between co-products and waste since the inputs and outputs shall be allocated to the co-products part only.

Allocation procedures shall be uniformly applied to similar inputs and outputs of the system under consideration. For example, if allocation is made to usable products (e.g. intermediate or discarded products) leaving the system, then the allocation procedure shall be similar to the allocation procedure used for such products entering the system.

The inventory is based on material balances between input and output. Allocation procedures should therefore approximate as much as possible such fundamental input/output relationships and characteristics.

<u>Allocation procedures for reuse and recycling</u>

I. *The allocation principles and procedures in 2.3.4.1 and 2.3.4.2 also apply to reuse and recycling situations.*

   Changes in the inherent properties of materials shall be taken into account. In addition, particularly for the recovery processes between the original and subsequent product system, the system boundary shall be identified and explained, ensuring that the allocation principles are observed as described in 2.3.4.2.

II. *However, in these situations, additional elaboration is needed for the following reasons:*

- *reuse and recycling (as well as composting, energy recovery and other processes that can be assimilated to reuse/recycling) may imply that the inputs and outputs associated with unit processes for extraction and processing of raw materials and final disposal of products are to be shared by more than one product system;*
- *reuse and recycling may change the inherent properties of materials in subsequent use;*
- *specific care should be taken when defining system boundary with regard to recovery processes.*

III. *Several allocation procedures are applicable for reuse and recycling. The application of some procedures is outlined conceptually in Figure 2 (= Figure 4-1) and is distinguished in the following to illustrate how the above constraints can be addressed.*

a) *A closed-loop allocation procedure applies to closed-loop product systems. It also applies to open-loop product systems where no changes occur in the inherent properties of the recycled material. In such cases, the need for allocation is avoided since the use of secondary material displaces the use of virgin (primary) materials. However, the first use of virgin materials in applicable open-loop product systems may follow an open-loop allocation procedure outlined in b).*

b) *An open-loop allocation procedure applies to open-loop product systems where the material is recycled into other product systems and the material undergoes a change to its inherent properties.*

IV. *The allocation procedures for the shared unit processes mentioned in 2.3.4.3 should use, as the basis for allocation, if feasible, the following order:*

- *physical properties (e.g. mass);*
- *economic value (e.g. market value of the scrap material or recycled material in relation to market value of primary material); or*
- *the number of subsequent uses of the recycled material (see ISO/TR 14049).*

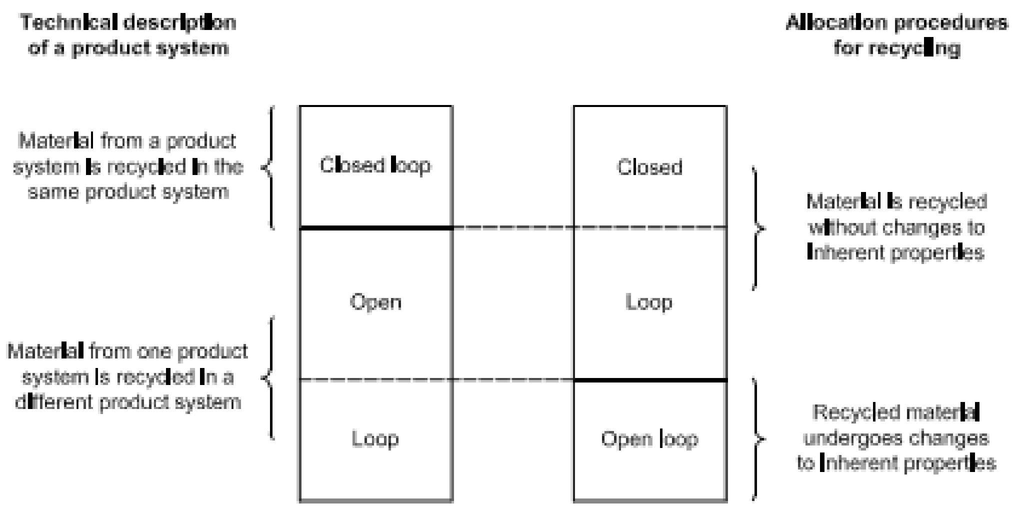

Figure 4-1: Distinction between a technical description of a product system and allocation procedures for recycling [ISO 14044]

Mass- and energy balance

Does the LCI result represent a closed mass and energy balance? This is also to be cross-checked for additional information of relevance, e.g. element content.

Reflection of optimization / reality

The LCI result has to reflect any given optimisation in view of the environmental performance e.g. improved technology, use of recycled material, increased recycling yields.

The LCI result has to reflect the reality. One main aspect in here is the consideration of the actual environmental burden. Another aspect is the consideration of the actual market situation, e.g. the production mix represented by the primary and secondary production route.

Data availability

What LCI information, e.g. on primary and secondary production as well as what kind of additional information, e.g. life time, recycling rate, is needed?

Transparency

Transparency is given if the allocation approach gives clear indication on

b) the procedure of allocation between the main product and the co-products

c) the justification applied

d) the consequences arising out of its application

e) analogies to allocation methods as described in ISO 14044

Communication / Understanding

The principle idea of the allocation approach has to be easy to communicate to support understanding and strengthen acceptance. In addition clear modelling instructions and guidelines are to be given for correct and consistent application in practice.

Field of application

It is to be clearly defined what the restrictions of the methodological approach are with respect to use and application in practice as well as considering different fields of application of LCA.

Fairness

The methodological approach should not give advantage or disadvantage to any material (or product application), should not highlight the environmental burden of different products or materials unequally. In addition there should be no overemphasizing or double-counting given in view of certain life cycle aspects.

4.2 Discussion of methods

The methodological approaches are analysed and discussed by using the example of the material steel. Where necessary exemplary calculations for the material steel are used to show the difference between single allocation approaches.

The methodological discussion about the different allocation approaches will be based on the context of metals in general.

4.2.1 Cut-off approach

Table 2: Evaluation Matrix Cut-off approach [PFLIEGER, ILG 2007]

Criterion	Comment/Explanation
ISO conformity	General description of Life Cycle Inventory according to ISO 14044: "… data collection… to quantify relevant inputs and outputs of a product system. These inputs and outputs may include the use of resources and releases to air, water and land…". Resources and releases to air, water and land represent elementary flows. The application of the cut-off approach might lead to non-elementary inputs/outputs, e.g. use and arising of metal scrap over the life cycle of products.
Mass-/Energy balance	The mass- and energy balance is consistent - just as the balance of other relevant flow properties, e.g. ferrous content, carbon content, etc.
Reflection of optimisation	It is accounted for an increased material/metal recovery rate in case collected scrap at products' end of life as well as scrap losses are accounted for within the LCI. But there is no consideration of an improvement/increase in recycling process efficiency.
Reflection of reality	Reality is reflected as well as todays' environmental burden outlined.
Data availability	Need for LCI data on primary and secondary material production as well as further information on the market mix situation and EoL collection rates.
Transparency	Transparency on methodological principle is given, but further specification is needed on the consideration of metal scrap inputs to the product system.
Communication / Understanding	Easy to communicate and understand.
Field of application	The cut-off approach can be applied to all types of materials, but does not comply with all types of possible goal & scope definitions. It is e.g. not suited for optimisation analysis (due to missing inclusion of end of life recycling) or product/material comparison (due to missing inclusion of the end of life phase).
Fairness	Due to the fact that the end of life phase is not taken into account products/materials with significant recycling at (products') end of life are treated less favourably.

4.2.2 Closed loop approach

Table 3: Evaluation Matrix Closed loop approach [PFLIEGER, ILG 2007]

Criterion	Comment/Explanation
ISO conformity	ISO conformity is given.
Mass-/Energy balance	The mass- and energy balance is consistent - just as the balance of other relevant flow properties, e.g. metal content, carbon content, etc.
Reflection of optimisation	It is accounted for an increased material/metal recovery rate as well as an improvement/increase in recycling process efficiency.
Reflection of reality	Reality is not reflected as todays' environmental burden is not outlined but artificially decreased in LCI calculation. In addition this approach can lead to the typical artefact within the application of inverse systems that emissions are entering the system as well as resources are being produced by the system. This applies in case there is a net scrap debit instead of a net scrap surplus.
Data availability	Need for LCI data on primary and secondary material production as well as further information on the recycling situation (change of inherent properties or not?), EoL collection rates, recycling process yield, etc.
Transparency	Transparency on methodological principle is given, but further specification is needed on the options to present the results.
Communication / Understanding	The principle is easy to communicate and understand - just as the result and consequences out of the application of the approach if presented in a clear way. However, the consideration of a net scrap surplus (or debit) destructs the clear differentiation of the single life cycle phases.
Field of application	The closed loop approach can be applied to all types of materials with the precondition that there are no changes in the inherent properties of the recycled material and recycling into the same product system takes place.
Fairness	Depending on the product and/or material characteristic as well as the assumptions and scenarios considered the material/metal recycling at products' end of life can significantly influence the overall LCI result. This is to be checked individually per study and goal&scope.

4.2.3 System boundary expansion by crediting

Table 4: Evaluation Matrix System boundary expansion by crediting [PFLIEGER, ILG 2007]

Criterion	Comment/Explanation
ISO conformity	ISO conformity is given.
Mass-/Energy balance	It is not ensured that the mass- and energy balance is consistent due to the fact that the crediting system does not necessarily correspond to today's material production and therefore a system with different input/output characteristic is credited.
Reflection of optimisation	It is accounted for an increased material/metal recovery rate.
Reflection of reality	Reality is not reflected as todays' environmental burden is not outlined but artificially decreased within LCI calculation. In addition this approach can lead to the typical artefact within the application of inverse systems that emissions are entering the system as well as resources are being produced by the system. This applies in case there is a net scrap debit instead of a net scrap surplus.
Data availability	Need for LCI data on today's material/metal production, the LCI data of the replaced product as well as further information on EoL collection rates.
Transparency	Transparency on methodological principle is given, but further specification is needed on the presentation of the results as well as the consequences out of the use of inverse (= crediting) systems.
Communication / Understanding	The principle is easy to communicate and understand - just as the result and consequences out of the application of the approach if presented in a clear way.
Field of application	The system boundary expansion approach can be applied to all types of materials in case the material/metal recycling at products' end of life does substitute other (material) products.
Fairness	Depending on the product and/or material characteristic as well as the assumptions and scenarios considered the material/metal recycling at products' end of life can significantly influence the overall LCI result. This is to be checked individually per study and goal&scope.

4.2.4 Open loop approach

Table 5: Evaluation Matrix Open loop approach [PFLIEGER, ILG 2007]

Criterion	Comment/Explanation
ISO conformity	ISO conformity is given.
Mass-/Energy balance	It is not ensured that the mass- and energy balance is consistent due to the fact that the crediting system does not necessarily correspond to today's material production and therefore a system with different input/output characteristic is credited.
Reflection of optimisation	It is accounted for an increased material/metal recovery rate as well as an improvement/increase in recycling process efficiency.
Reflection of reality	Reality is not reflected as todays' environmental burden is not outlined but artificially decreased in LCI calculation. In addition this approach can lead to the typical artefact within the application of inverse systems that emissions are entering the system as well as resources are being produced by the system. This applies in case there is a net scrap debit instead of a net scrap surplus.
Data availability	Need for LCI data on primary and secondary material production, the LCI of the replaced product as well as further information on the recycling situation (change of inherent properties or not?), EoL collection rates, recycling process yield, etc.
Transparency	Transparency on methodological principle is given, but further specification is needed on the presentation of the results, the option (and procedure) to consider the market mix situation instead of primary production as well as the consequences out of the use of inverse (= crediting) systems.
Communication / Understanding	The principle is easy to communicate and understand - just as the result and consequences out of the application of the approach if presented in a clear way. However, the consideration of a net scrap surplus (or debit) destructs the clear differentiation of the single life cycle phases.
Field of application	The open loop approach can be applied to all types of materials in case the material/metal is recycled into another product system and a change in inherent properties of the recycled material applies.
Fairness	Depending on the product and/or material characteristic as well as the assumptions and scenarios considered the material/metal recycling at products' end of life can significantly influence the overall LCI result. This is to be checked individually per study and goal&scope.

4.2.5 Value-corrected substitution approach

Table 6: Evaluation Matrix Value-corrected substitution approach [PFLIEGER, ILG 2007]

Criterion	Comment/Explanation
ISO conformity	ISO conformity is given.
Mass-/Energy balance	The mass- and energy balance is not consistent (even though the crediting system corresponds in terms of input/output characteristic to today's material production) as material/metal is 'lost' due to the value-correction.
Reflection of optimisation	It is accounted for an increased material/metal recovery rate as well as an improvement/increase in recycling process efficiency.
Reflection of reality	Reality is not reflected as todays' environmental burden is not outlined but artificially decreased in LCI calculation. In addition this approach can lead to the typical artefact within the application of inverse systems that emissions are entering the system as well as resources are being produced by the system. This applies in case there is a net scrap debit instead of a net scrap surplus.
Data availability	Need for LCI data on primary and secondary material production as well as further information on the recycling situation (change of inherent properties or not?), EoL collection rates, recycling process yield, market price of primary and secondary material/metal, etc.
Transparency	Transparency on methodological principle is given, but further specification is needed on the presentation of the results, the option (and procedure) to consider the market mix situation instead of primary production as well as the consequences out of the use of inverse (= crediting) systems.
Communication / Understanding	The principle is easy to communicate and understand - just as the result and consequences out of the application of the approach if presented in a clear way. However, the consideration of a net scrap surplus (or debit) destructs the clear differentiation of the single life cycle phases.
Field of application	The value-corrected substitution approach can be applied to all types of materials for which the assumption applies that recycled material replaces virgin material (independently of a change in inherent properties of the recycled material)
Fairness	Depending on the product and/or material characteristic as well as the assumptions and scenarios considered the material/metal recycling at products' end of life can significantly influence the overall LCI result. This is to be checked individually per study and goal&scope.

4.2.6 (Infinite) Multi-step recycling approach

Table 7: Evaluation Matrix (Infinite) Multi-step recycling approach [PFLIEGER, ILG 2007]

Criterion	Comment/Explanation
ISO conformity	ISO conformity is given.
Mass-/Energy balance	The mass- and energy balance is consistent - just as the balance of other relevant flow properties, e.g. metal content, carbon content, etc.
Reflection of optimisation	It is accounted for an increased material/metal recovery rate as well as an improvement/increase in recycling process efficiency.
Reflection of reality	Reality is not reflected as todays' environmental burden is not outlined but artificially decreased in LCI calculation.
Data availability	Need for LCI data on primary and secondary material production as well as further information on the recycling situation (change of inherent properties or not?), EoL collection rates, recycling process yield, etc.
Transparency	Transparency on methodological principle is given, but further specification is needed on the possible ways of presentation of the results, the option (and procedure) to consider the market mix situation instead of primary production as well as the consequences out of the use of inverse (= crediting) systems.
Communication / Understanding	The principle is easy to communicate and understand - just as the result and consequences out of the application of the approach if presented in a clear way.
Field of application	The infinite multi-step recycling approach can be applied to all types of materials with the precondition that there are no changes in the inherent properties of the recycled material, that recycling into the same product system takes place and the material is recycled again and again.
Fairness	Depending on the product and/or material characteristic as well as the assumptions and scenarios considered the material/metal recycling at products' end of life can significantly influence the overall LCI result. This is to be checked individually per study and goal&scope.

4.2.7 Value of scrap approach

Table 8: Evaluation Matrix (Infinite) Value of scrap approach [PFLIEGER, ILG 2007]

Criterion	Comment/Explanation
ISO conformity	ISO conformity is given.
Mass-/Energy balance	The mass- and energy balance is consistent - just as the balance of other relevant flow properties, e.g. metal content, carbon content, etc.
Reflection of optimisation	It is accounted for an increased material/metal recovery rate as well as an improvement/increase in recycling process efficiency.
Reflection of reality	Reality is reflected as todays' environmental burden (including scrap consumption and arising) is outlined.
Data availability	Need for LCI data on primary and secondary material production as well as on scrap Further information required is on the recycling situation (change of inherent properties or not?), EoL collection rates, recycling process yield, etc.
Transparency	Transparency on methodological principle is given, but for the specific case specification and details are to be given on the way of scrap LCI calculation.
Communication / Understanding	The principle is easy to communicate and understand - just as the result and consequences out of the application of the approach if presented in a clear way.
Field of application	The value of scrap approach can be applied to all types of materials. The scrap LCI calculation has to represent and fit to the given recycling situation.
Fairness	Depending on the product and/or material characteristic as well as the assumptions and scenarios considered the material/metal recycling at products' end of life can significantly influence the overall LCI result. This is to be checked individually per study and goal&scope.

4.2.8 Cascade approach

Table 9: Evaluation Matrix Cascade approach [PFLIEGER, ILG 2007]

Criterion	Comment/Explanation
ISO conformity	Depending on the allocation rules followed within the cascade approach an ISO conformity might not be given in case today's environmental burden occuring during the life cycle of one product is allocated to other product life cycles.
Mass-/Energy balance	The mass- and energy balance is not consistent as parts of the one product life cycle are allocated to other product life cycles. In doing so an artificial partitioning of the total environmental burden/effect of and over several product life cycles is given.
Reflection of optimisation	There is no optimisation analysis possible with focus on one product life cycle (or the use of a certain material within one product application) due to the complex split of the environmental burden over more than one product life cycle.
Reflection of reality	Reality is not reflected with focus on one single product life cycle, only by simultaneous consideration of all product life cycles covered by the cascade approach.
Data availability	Need for LCI data on primary and secondary material production as well as further information on EoL collection rates, recycling process yield, number of life cycles, etc.
Transparency	Transparency on methodological principle is given.
Communication / Understanding	The principle is easy to communicate and understand, but the result and consequences out of the application of the approach difficult to understand in terms of significance.
Field of application	The cascade approach can be applied to all types of materials in case of multi-step recycling.
Fairness	Most versions of the cascade approach follow a subjective justification with respect to the allocation of the environmental burden over the considered product life cycles. However, no matter what cascade approach version is followed, the treatment of the single materials is done equally.

4.2.9 Recycling potential

Table 10: Evaluation Matrix Recycling potential approach [PFLIEGER, ILG 2007]

Criterion	Comment/Explanation
ISO conformity	ISO conformity is given.
Mass-/Energy balance	The mass- and energy balance is consistent - just as the balance of other relevant flow properties, e.g. ferrous content, carbon content, etc. - due to the fact that the recycling potential approach accounts for the environmental burden of today's material production as well as the recycling potential (= evaluation of the environmental effect of recycling) separately.
Reflection of optimisation	An increased material/metal recovery rate as well as an improvement/increase in recycling process efficiency is outlined as well as accounted for within the recycling potential evaluation.
Reflection of reality	Reality is reflected as well as todays' environmental burden outlined - in addition to the evaluation of the environmental effect of recycling.
Data availability	Need for LCI data on primary and secondary material production. In addition, depending on the selected evaluation procedure, data on the market mix, the recycling situation (change of inherent properties or not?), the EoL collection rates, the recycling process yield, the LCI of 100% primary and secondary material production, the LCI of the replaced product as well as the market price of primary and secondary material/metal is required.
Transparency	Transparency on methodological principle is given as well as on the presentation of the results. Depending on the selected evaluation procedure further details are required, but covered by existing methodological approaches.
Communication / Understanding	The principle is easy to communicate and understand - just as the result and consequences out of the application of the approach if presented in a clear way. However, the consideration of a net scrap surplus (or debit) destructs the clear differentiation of the single life cycle phases.
Field of application	The recycling potential approach can be applied to all types of materials which are recycled at products' end of life.
Fairness	Due to the detailed presentation of the environmental burden of today's material production as well as the separated outline of the evaluation of the future environmental effect of EoL recycling this approach provides an objective result. Nevertheless, depending on the product and/or material characteristic as well as the assumptions and scenarios considered the material/metal recycling at products' end of life can significantly influence the overall LCI result. This is to be checked individually per study and goal&scope.

5 Presentation of methods

To illustrate the variety of possible ways of result presentation, with respect to the application of the discussed methodologies, carbon dioxide emissions to air are selected.

The result calculation is based on Life Cycle Inventory data as provided by the International Iron and Steel Institute (IISI), but is presented in a relative manner due to the fact that the focus is on the relative presentation of the results not on the absolute result values.

The following assumptions were taken into account for the exemplary result calculation:

- Slab LCI (production via BF/BOF and EAF) as European average from IISI.
- LCI data for hot and cold rolling as expert judgement of the GaBi team.
- No focus on the use phase. The use phase is modelled as dummy process with fictitious values for illustration reasons.
- No focus on scrap collection, separation and preparation. The end of life phase is modelled as dummy process with fictitious values for illustration reasons.
- 100% slab LCI (production via BF/BOF) as European average from IISI.
- End of life collection rate considered to be 80%.

In the following the possible ways of modelling and presentation of the discussed methodologies is shown via Sankey diagrams of the LCA software system GaBi 4 as well as the possible result presentation presented using the example of carbon dioxide emissions to air.

The exemplary result presentation is detailed into

- Upstream burden = Upstream burden for the consumption of scrap
- Slab = Production of slab via BF/BOF – the primary steel production route
- HR and CR = Manufacturing processes to produce hot and cold rolled coils
- Use = Use phase of the product, not considered
- EoL Collection = Scrap collection, separation, preparation, not considered
- EoL Recycling = Recycling of steel scrap via EAF process
- Downstream credit = Credit for recovered steel scrap

5.1 Principle options of presentation

The principle options of presentation are illustrated using the examples of the cut-off approach, the closed loop approach, the "upstream burden and downstream credit approach" as well as the recycling potential approach.

For all other methods discussed the same options are given as they represent in terms of modelling and result presentation (!) analogous systems.

Example: The value-corrected substitution approach is modelled analogous to the closed loop approach but applying a correction-factor to the crediting system. For this reason the overall results will vary depending on the applied value-correction factor but the way of result presentation is the same.

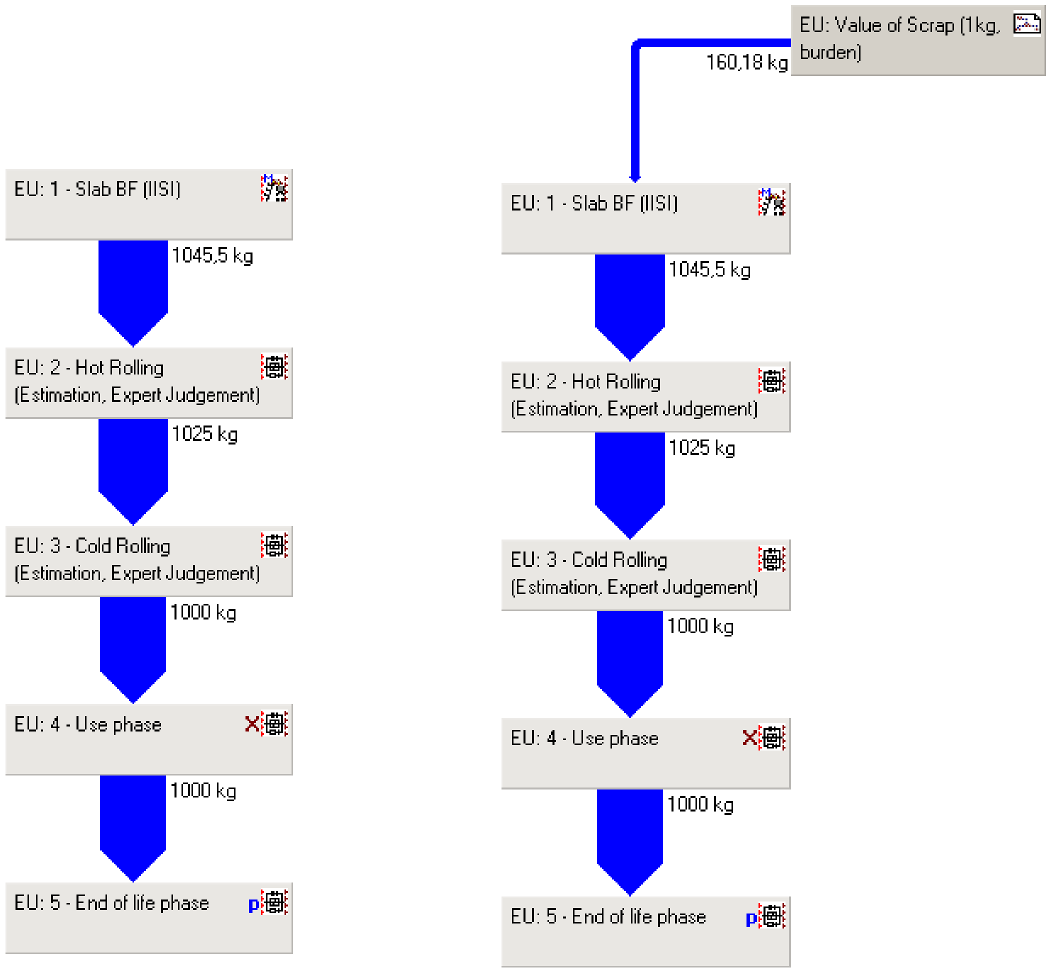

Figure 5-1: Cut-off approach: Ex- and including upstream burden for scrap input

A consideration of an upstream burden for the use of recovered material/metal is not discussed within literature for this approach. For this reasons both versions, excluding and including upstream burden for the steel scrap input of the BF/BOF route, are presented, see Figure 5-1.

The consideration of an upstream burden for steel scrap follows the calculations as defined by the methodology of the International Iron and Steel Institute (IISI) [IISI 2006].

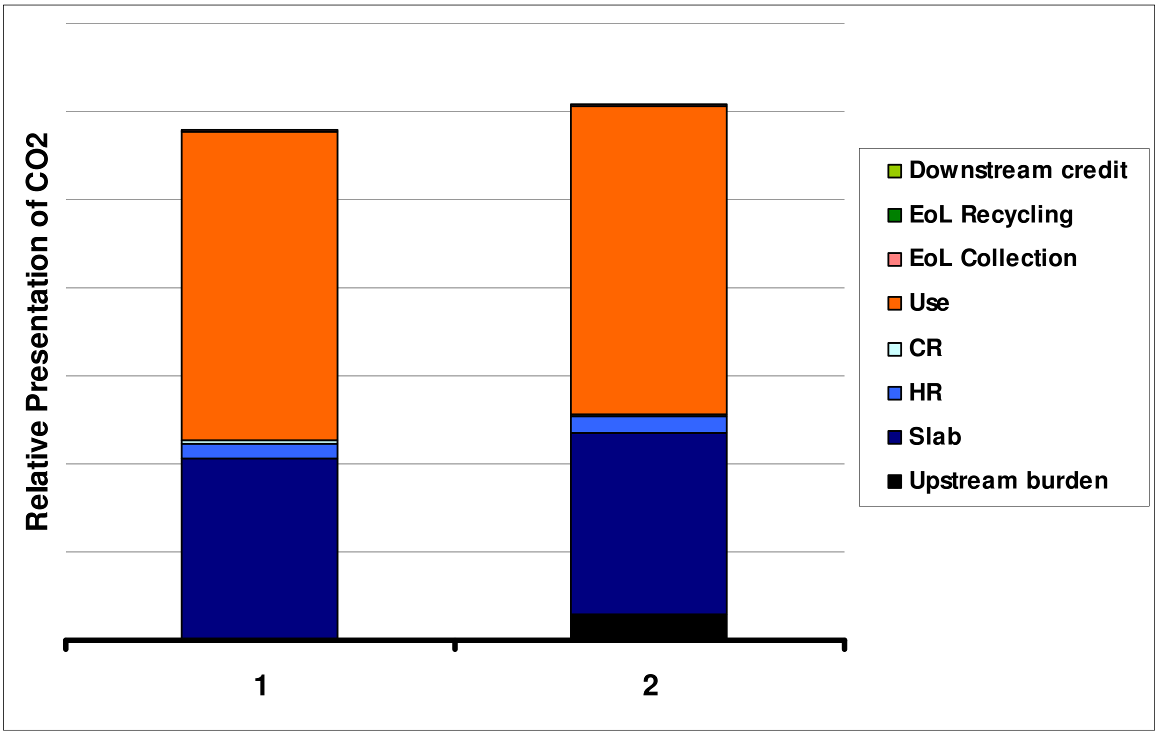

Figure 5-2: LCI result presentation for cut-off approach

Figure 5-2 illustrates the possible ways of LCI result presentation following the cut-off approach (with 1 = cut-off approach without upstream burden for scrap input to BF/BOF; 2= cut-off approach including upstream burden for scrap input to BF/BOF).

The difference in result and result presentation is given by the exclusion or inclusion of upstream burden for the scrap consumption of the primary route (= BF/BOF route).

The following example [describing an End of Life situation according to closed loop: a) no change or change of inherent properties of the recycled material, b) recycling into the same or other product system(s)] illustrates the (possible) differences in modelling

- by consideration of net scrap arising versus differentiated consideration of scrap input to the system as well as scrap output of the system.
- by consideration of classic closed loop consideration/presentation of recycled material versus differentiated consideration of downstream credit for absolute scrap arising and upstream burden for absolute scrap consumption of the system.

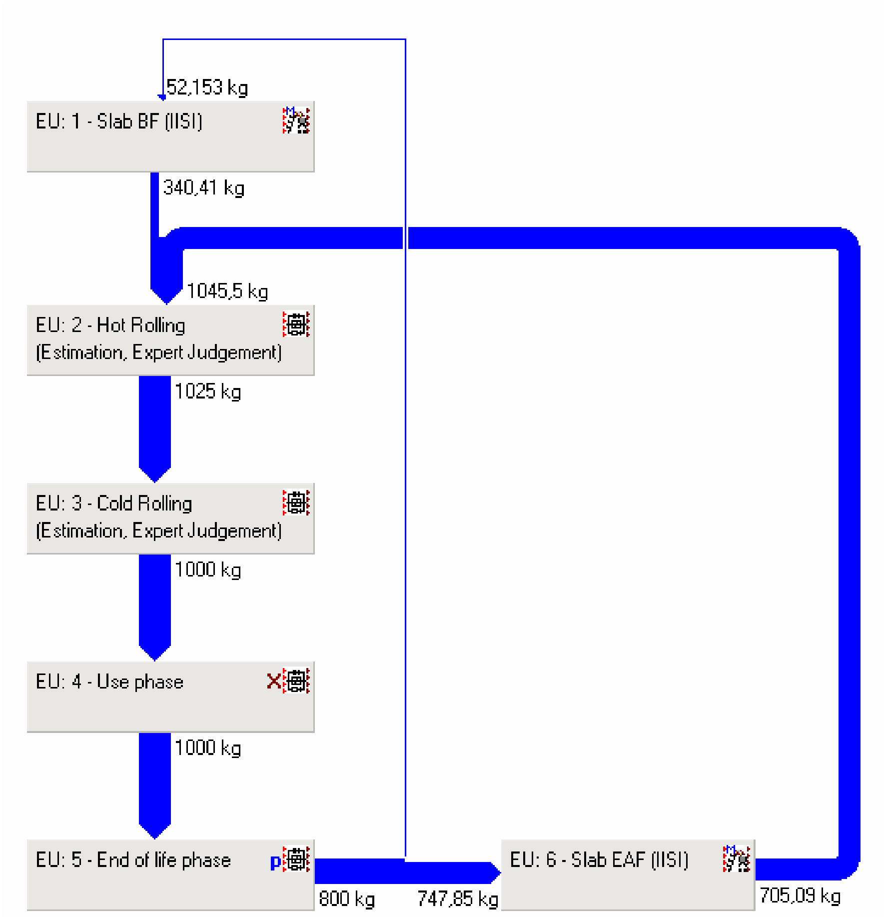

Figure 5-3: Closed loop approach: Classic

Figure 5-3 presents the classic way of LCI modelling applying the closed loop approach: Consideration of loop back of recycled material (as well as net scrap arising – if given).

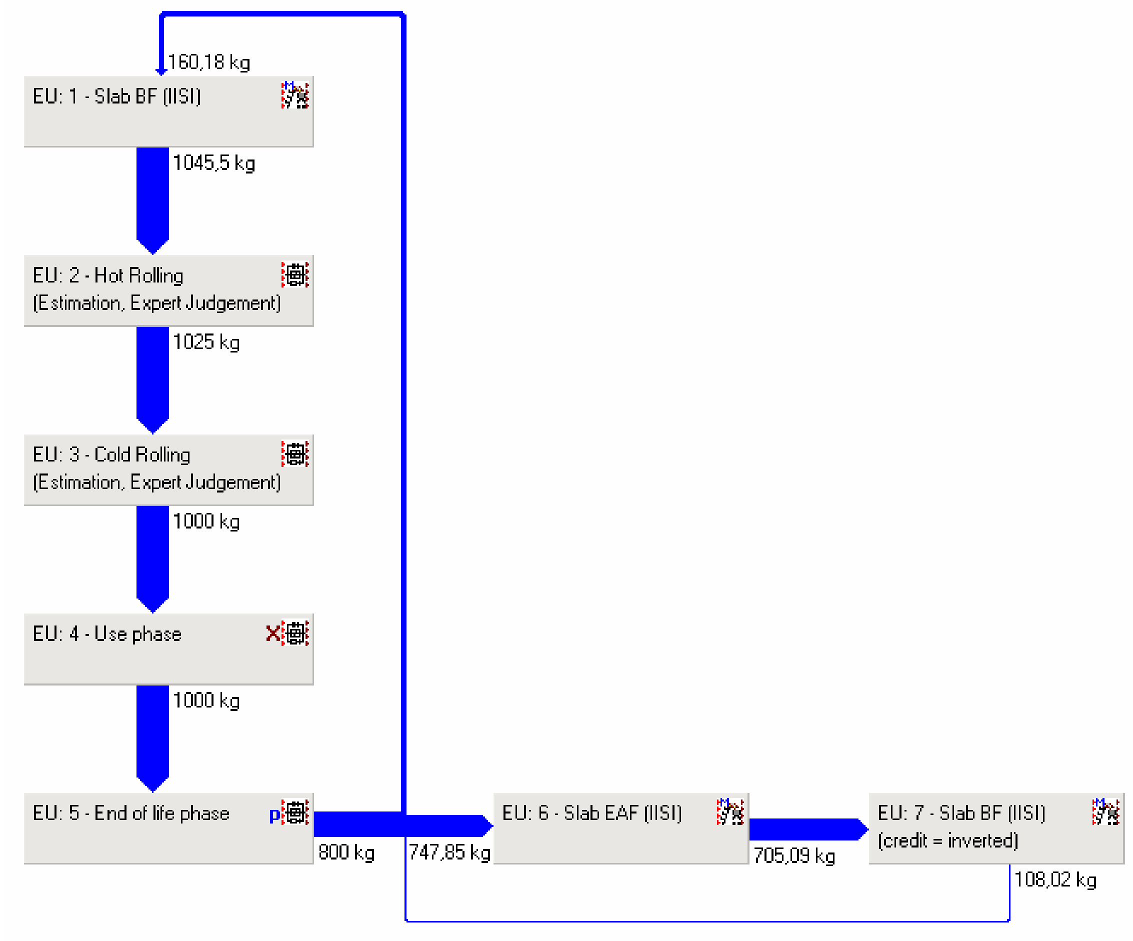

Figure 5-4: Net scrap, downstream credit (incl. scrap output)

Another option to present an End of Life situation as given according to closed loop is considering as well the net scrap arising but a downstream credit (based on inverted primary production) for the recycled material, see Figure 5-4.

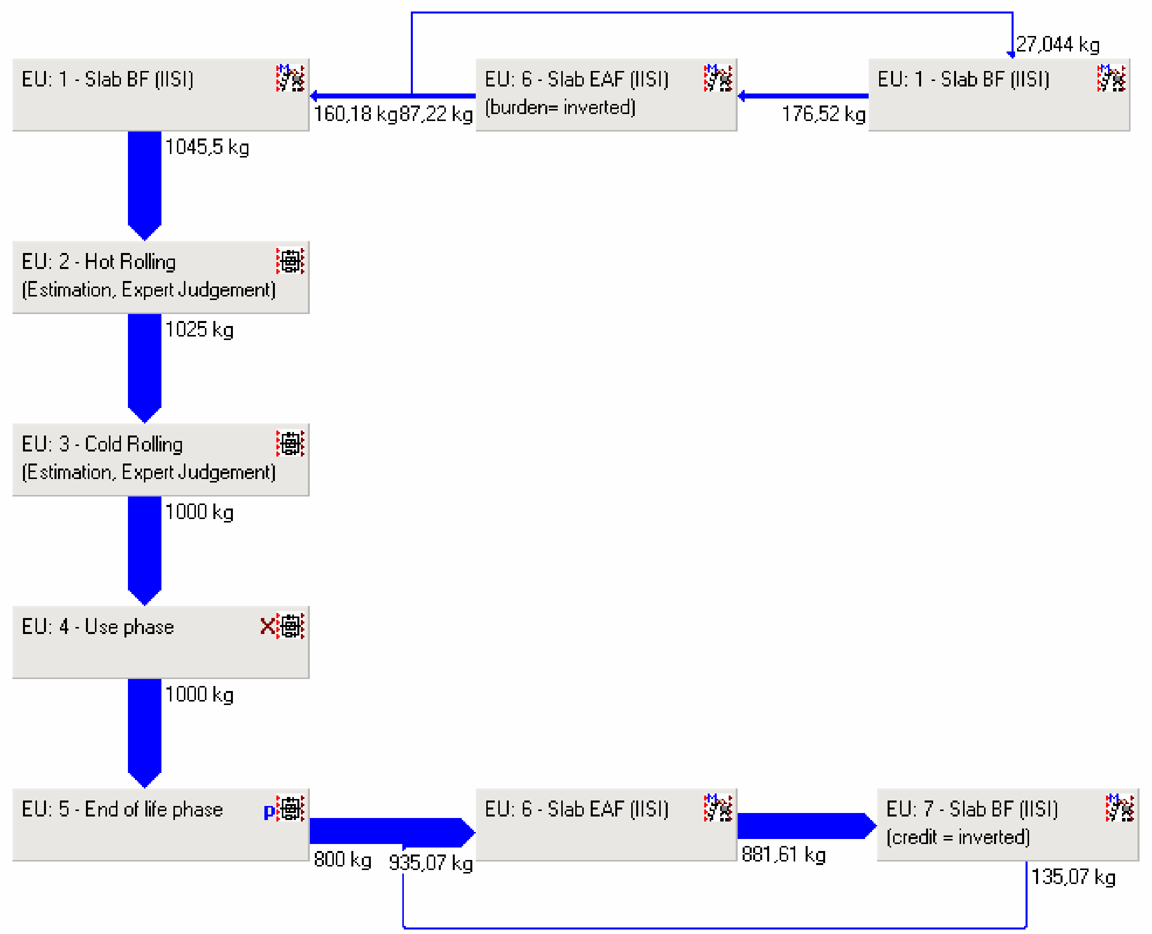

Figure 5-5: Upstream burden, downstream credit (incl. scrap in-/output)

In addition there is the option given to present an End of Life situation as given according to closed loop by considering an upstream burden for the input of scrap to the system as well as a downstream credit for the recycled material, see Figure 5-5.

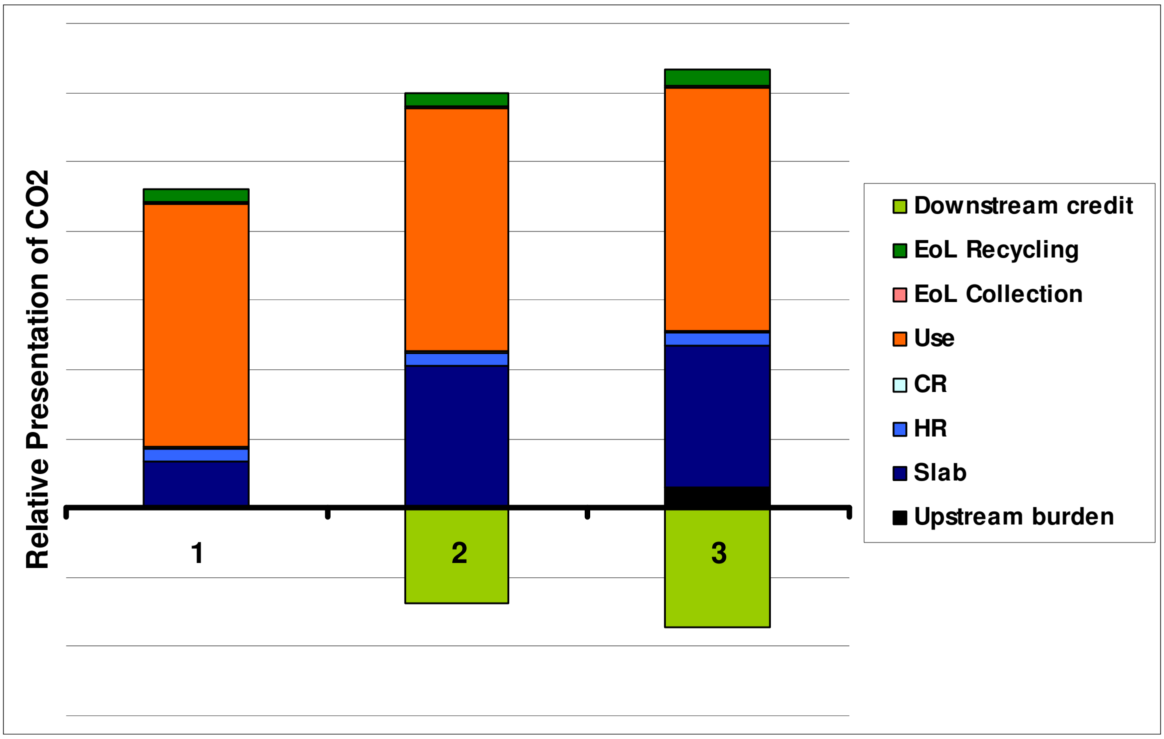

Figure 5-6: LCI result presentation for "closed loop EoL situations"

Figure 5-6 illustrates possible ways of LCI result presentation for End of Life situations as given according to closed loop (with 1 = modelled classic loop, 2 = modelled with net scrap and downstream credit (incl. scrap output), 3= modelled with upstream burden and downstream credit (incl. scrap in-/output)).

The difference in result presentation is given by the net or gross consideration of the scrap input and output flows related to the product system under study.

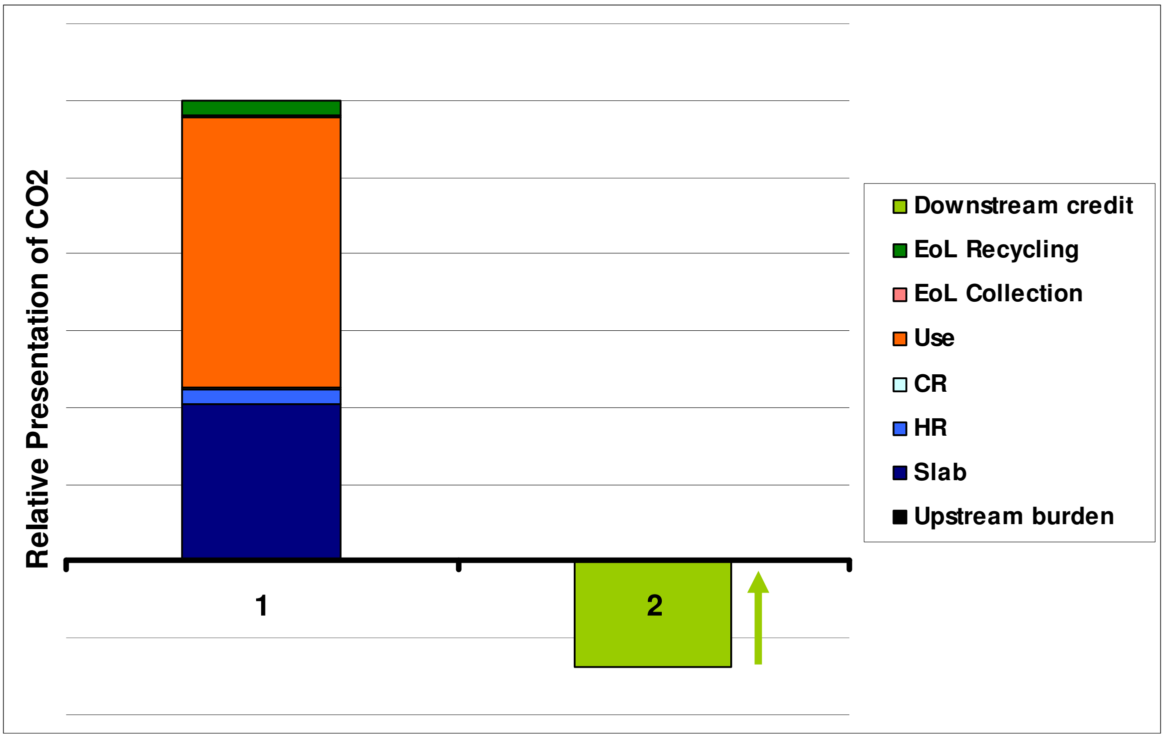

Figure 5-7: LCI result presentation for recycling potential approach

Figure 5-7 illustrates the principle way of LCI result presentation following the recycling potential approach (with 1 = the environmental profile over the product life cycle, 2 = the environmental effect of recycling (considering net scrap arising) evaluated according to the closed loop principle).

The difference in result presentation compared to the other methods under study within this report is given by the isolated presentation of today's environmental burden over the products life cycle as well as a potential environmental effect (most probably benefit) due to recycling at products end of life.

The environmental effect of recycling can be evaluated according to the principles of closed loop, open loop, value-correction, cut-off and others.

5.2 Comparative presentation of methods

For the comparative presentation of the methods under study again the examples of the cut-off approach, the closed loop approach, the upstream burden and downstream credit approach as well as the recycling potential approach are taken into account.

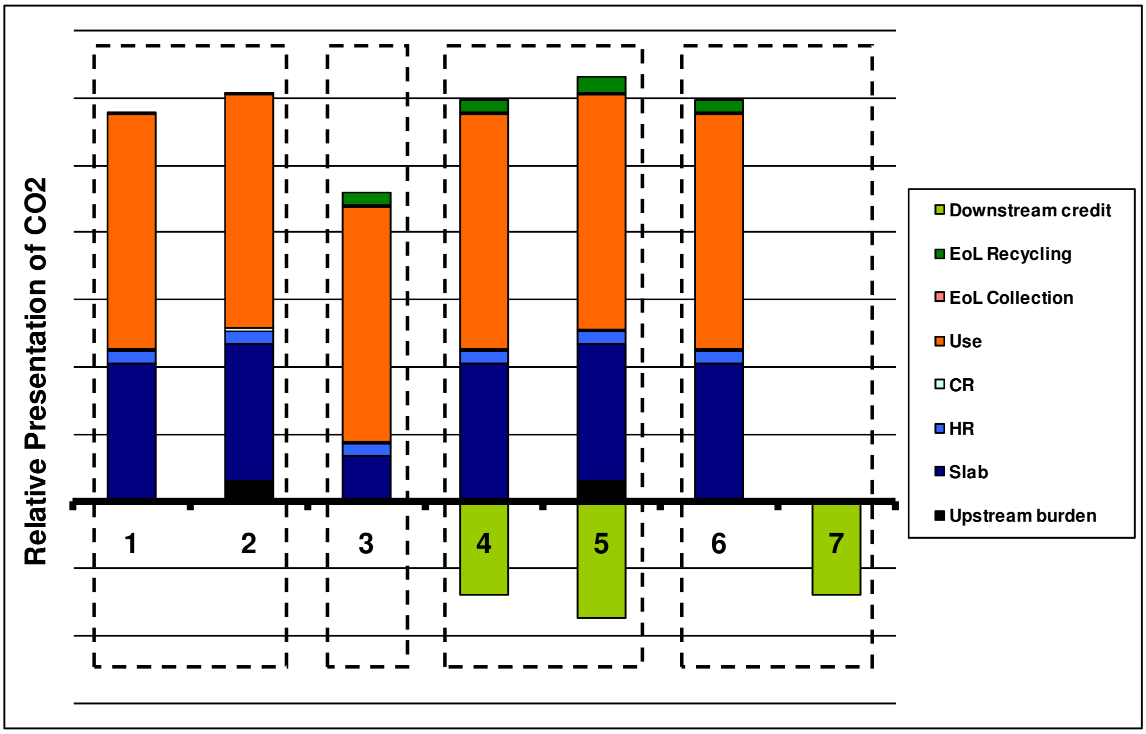

Figure 5-8: Comparative presentation of selected methods

Figure 5-8 provides a comparative overview of result presentation options for the above mentioned approaches. The graph presents the following methodological situations:

<u>Cut-off approach</u>

1 = excluding the upstream burden for scrap consumption of the primary route (= BF/BOF)

2= including the upstream burden for scrap consumption of the primary route (= BF/BOF)

<u>Closed loop approach</u>

3 = classic loop modelling with net scrap arising and loop back of recycled material

<u>Upstream burden and downstream credit approach</u>

4 = modelling with net scrap and downstream credit including scrap output of the credit system due to inversion

5= modelling with upstream burden and downstream credit including scrap input and output of the credit system due to inversion

<u>Recycling potential approach</u>

6 = the environmental profile over the product life cycle

7 = the environmental effect of recycling (considering net scrap arising) evaluated according to the closed loop principle

6 Conclusion

The current document provides a harmonised as well as consistent description and discussion of methods, as applied in practice, to consider recycling at products end of life within LCA.

It counteracts unintended misuse and provides support in appropriate application of the considered methodologies with respect to the specific characteristic and goal of the study.

The work undertaken and resulting discussions underlined the need for explicit definitions and clear demarcation of the single methodologies under study.

Particular need for harmonisation work appeared with respect to the following topics:

- Consistent use of terms
- Specification of methodological system boundaries
- Definition of scope of application
- Presentation and illustration of LCI results

In addition a clear indication is to be given with respect to the overall Life Cycle Inventory method principle, attributional or consequential, addressed: Substitution by other product systems describes a consequential effect [GEYER 2007].

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