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BIOMASS CASCADES Increasing resource efficiency by cascading use of biomass — from theory to practice

Summary

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BIOMASS CASCADES Increasing resource efficiency by cascading use of biomass — from theory to practice

Summary

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Abbreviations

bioPE	biobased polyethylene
bioPET	biobased polyethylene terephtahlat
BMUB	Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit)
BMEL	Federal Ministry of Food and Agriculture (Bundesministerium für Ernährung und Landwirtschaft)
BMBF	Federal Ministry of Education and Research (Bundesministerium für Bildung und Forschung)
BUF	Biomass Utilization Factor
CED	Cumulative energy demand
CRD	Cumulative resource demand
DG	Directorate General (of the European Commission)
EEA	European Environment Agency
EEG	(Renewable Energy Act) Erneuerbare Energie-Gesetz
GHG	Greenhouse gas
GWP	Global Warming Potential
IEA	International Energy Agency
ILUC	indirect land-use change
KrWG	Waste management Act (Kreislaufwirtschaftsgesetz)
LCA	Life Cycle Assessment
PLA	Polylactic acid
ProgRess	Deutsches Ressourceneffizienzprogramm

1 Status quo and goals of the research project

The responsible use of finite natural resources appears to be commonplace. However, is this principle put into practice? Despite improvements in raw material productivity in recent years, the actual direct or indirect access and exploitation of raw materials conflicts with the limitations of the carrying capacity of planet Earth (Steffen et al. 2015).

Biomass is a renewable resource, linked with land use and thus subject to limitation. The principle of cascading use has been proposed as a solution for a number of years. The cascading use approach could improve raw material efficiency, avoid negative environmental impacts and alleviate sustainability conflicts of biomass use. The maximum material use of biomass, i.e. as long, as often and as efficiently as possible, with subsequent energy use at the end of the product life cycle is pivotal for successful cascading use.

However, reality paints a different picture: 44% of wood from forests is incinerated without any material use—more than half as wood fuel, the remainder as sawmill by-products (Mantau 2012). The share of agricultural renewable feedstocks is even greater: only approx. 11% are used for material purposes, whereas 90% are processed into biogas and biofuels (FNR 2015).

To date, the potentials of biomass cascades have been largely ignored. The realisation of cascade potentials is in still its infancy, primarily because cascading use is rarely put into practice. The **biomass cascade** research project pursues the following goals:

- Calculation of biomass cascade potentials and analysis of reasons behind success and failure of existing approaches and concepts
- Analysis of environmental benefits of biomass cascades and assessment of existing flaws
- Development of base and key elements for an overall concept for successful implementation
- Identification of key parameters for a strategy for the implementation of the overall concept

These question were explored in the biomass cascade project by a consortium of ifeu (project coordination), nova-Institut, IZES and Wuppertal Institute on behalf of the Federal Environment Agency (project duration July 2013 to October 2016).

2 Concepts and examples of cascading use

The theory and underlying concept of cascading use as a sequential use of biomass has been addressed in an expansive body of national and international literature beginning in the 1990s (e.g. Sirkin and ten Houten 1994, Fraanje 1997). Cascading use of biomass usually follows the principle of material use first, energy use last (e.g. Federal Environment Agency (UBA) 2012, Arnold et al. 2009). More recent concepts link cascading use with comprehensive raw material use and recovery strategies (e.g. Odegard et al. 2012, BMBF 2010), or equate the cascading approach with recycling or optimised co-production and residue recovery. A consistent definition of the term cascading use is lacking across all sectors including science, economics and politics. Moreover, the integration of the cascading use approach into existing legislature differs widely among individual countries, as well as the associated effects (e.g. Olsson et al. 2016, Dammer et al. 2016).

The term "cascading use" has been included in both German and European strategy and position papers since about 2010, most frequently in explicit reference to biomass use. The inconsistencies in definition and understanding mentioned above are clearly evident in these papers (c.f. 7.1):

- The *National Research Strategy BioEconomy* (BMBF 2010) and the EU strategy *Innovating for Sustainable Growth a Bioeconomy in Europe* (EU DG Research 2012) define cascading use as the valuable use of by-products (also: co-production), in particular from biorefineries, to maximise added value of applied biomass.
- The *German Sustainability Strategy Edition 2016* and the *German Resource Efficiency Programme II* (*ProgRess II),* as well as the papers of DG Environment and EEA (2015) on circular economy in Europe, apply the term in a circular economy[1] context, i.e. long-term material preservation according to the principles of a waste hierarchy.

In response to the focus on circular economy concepts in European politics, the second definition has increasingly been accepted in the ongoing debate. Particularly in Germany, the current sustainability strategy reflects the position of the Federal Government in principle. Here, the role of cascading use is closely linked with circular economy goals. These include efforts to preserve the value of products, materials and resources within the economy for as a long as possible, thus increasing overall added value. Thus, this definition closely complies with cascading use according to the UBA 2012 resource conservation glossary.

To promote transparent, consistent terminology and a better understanding of cascading use and similar concepts, the present project developed a novel, descriptive definition for cascading use (see box). The project definition allows distinguishing single-stage and multi-stage cascades. If the cascading principle is adopted as a strategy for increased resource efficiency, both single-stage and multi-stage cascading use may boost efforts towards an overall efficiency target. Thus, novel ways of material biomass use carry the potential for increased cascading use, even if they fail to be multi-stage applications initially.

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[1] The circular economy definition in Europe exceeds the scope of the term coined in Germany in 1996, which was shaped by the adoption of Circular Economy Act (*Kreislaufwirtschaftsgesetz* KrWG). In this project report, the term "circular economy" refers to the definition used in current strategic papers of the European Commission and the EEA. The waste hierarchy of the KrWG includes use cascades, but this approach limits its management potential to secondary raw materials and does not promote prioritised use for primary raw materials.

Definition of cascading use (developed in this project):

Biomass that has been processed into a bio-based final product is used at least once more either for material or energy purposes. Cascading use of biomass may be distinguished into:

- **Single-stage cascade**: after material use, the bio-based final product is directly used for energy purposes
- **Multi-stage cascade**: the bio-based final product is used at least once more as a material

The debate of previous years has called for the placement of different biomass flows and their applications in a wider context that includes cultivation and use of all cascades and by-products. This consensus is both correct and essential for future success. However, practical implementation is prevented due to sometimes paradoxical control mechanisms. For instance, energy use of green wood is highly subsidised under the Renewable Energy Act. In consequence, an essential material flow is applied for direct energy use only. However, the Circular Economy Act stipulates the mandatory waste hierarchy, which defines energy use as the least desirable recovery option, thus illustrating the conflicting and illogical nature of the existing framework. An integrated approach combining all material flows and assessing them from agricultural, forest or marine origin via material use to ultimate use for energy purposes is highly recommended. The present paper proposes to promote this view based on existing strategies.

However, it remains unclear whether the assumed effects of cascading use are actually realised. Reliable data measuring the contribution of cascades towards policy goals are unavailable. There are very few instruments for the quantification of cascading use, apart from the material flow analyses and calculations of the cascade factor by Mantau (2012a), and the so-called Biomass Utilization Factor (nova 2016). This factor provides information on the type and duration of use cascade, as well as the number of repeated uses of the same biomass. The present project explored potential effects of cascading use of biomass including direct effects on greenhouse gas emissions or increased added value, but also indirect effects like intensified land use due to increased use of secondary raw materials. The research assessed the few examples of established cascading use of biomass, as briefly outlined below:

- **paper, corrugated board and paperboard**: average waste paper recycling rate 74% (VDP 2016)
- **wood industry:** material waste wood recovery rate 19% , use for particle board manufacture only (Mantau et al. 2012)
- **textiles**: material recovery rate 92%, e.g. as second-hand clothing (not strictly cascading use), cascading use as cleaning materials and as a secondary raw material (Korolkov 2016)
- **bioplastics**: obtained from renewable raw materials that present identical technical properties to their fossil equivalents (drop in), recycling similar to fossil plastics (e.g. bio-PE like PE), 42% of plastics waste are recovered for material use according to UBA (2015); PLA currently not recycled due to lack of market presence

In addition to these common examples, a number of niche products derived from efficiently used biomass currently exist. These might be very suitable for inducing cascading use. The development of by-product and waste flows in particular is associated with considerable potential that has been virtually ignored to date.

In sum, it is essential that high-quality product design includes the integration of cascading use into process chain development. It is the only way to establish and permanently maintain viable value chains.

3 Analysis of raw material supply

The present study further examined the question of (sufficient) raw material availability and the adequacy of a framework for the supply of defined raw material qualities for selected biomass cascades. For this purpose, an analysis of existing and expected future increases in competition for renewable raw materials was carried out. The focus was on the raw material demand for defined cascading concepts based on existing studies, and the expected market trajectory in light of all pathways for biomass use currently under consideration. Furthermore, requirements for process-specific raw material quantities (realisable volumes) and quality (material properties, form of supply) were assessed.

The availability of renewable raw materials is governed by rising demand, particularly from the energy sector. However, availability is limited by nature conservation restrictions (at least nationally). In consequence, there is considerable pressure on land area. Efficient resource use in combination with bespoke biomass cascade processes could alleviate this pressure.

The analysis focused on raw materials for which cascading use has been trialled, or those for which cascading use is already established on the market:

- waste wood market
- (used) paper market
- natural fibre or (used) textile market
- sugar market
- starch market
- biodegradable waste market

The general application of cascading use in these markets is regulated by the waste hierarchy stipulations for secondary raw materials (waste) defined in § 6 Section 1 Circular Economy Act. However, the necessity to observe the hierarchy according to § 6 Section 2 Circular Economy Act is governed by a number of criteria[2]. Among these criteria, “Accumulation of pollutants in products” may be potentially interfere with cascading use approaches. Moreover, applications of cascading use should include primary raw materials. However, regulations for such an extended circular economy concept are currently lacking.

From a national (potential) perspective, relevant raw materials for cascading approaches that have already been identified include the pulp (incl. processes for paper recycling) and waste wood market, and agricultural raw materials for the plastics market.

Cascading processes in the **waste wood sector** are readily established primarily for particle board production. With a given waste wood volume of approx. 9.3 million t annually (market volume and residues), extended cascading use might be realised with intensified material use of raw wood. Due to limited wood potentials, a market displacement of energy use, particularly of firewood in the heat market, is the likely consequence. Simultaneously, cascading use implies an increased waste wood content in wood products (primarily particle board).

Due to stagnating production capacities, efforts for extended material use of raw wood require distinct market stimulation. Moreover, material use of hardwood should be encouraged. To date, this type of woody biomass is almost exclusively used for energy purposes. However, forest restructuring efforts are likely to produce hardwood in much higher quantities.

At present, there is no extended application of waste wood in wood products despite ample wood stock. The main barrier, in consideration of both functional and a pollutant aspects, appears to be matters of quality assurance. Anecdotal evidence for increased pollutant content as defined in § 6 Section 2 Circular

[2] (1) emissions, (2) natural resource consumption, (3) energy balance (4) pollutant accumulation in products

Economy Act has been reported for wood products with recycled wood content (Schrägle 2015). Optimised material flow management requires additional instruments to facilitate the assessment and collection of waste wood according to quality, i.e. fitness for material use (e.g. removal of PVC coating).

The cultivation of **renewable raw materials from the agricultural sector** for (highly heterogeneous) material use in Germany is currently carried out on approx. 268.000 ha of agricultural area used for non-food purposes. Thus, 11% of the total is used for material biomass use, whereas energy crops for biogas and biofuels cover approx. 56% and 33%, respectively (FNR 2015). In consequence, the present study modelled a number of land use scenarios, e.g. assuming the availability of agricultural land currently used for energy crop cultivation after expiry of subsidies under the Renewable Energy Act. Depending on the model, up to one million ha could be available until 2030. This represents a fivefold increase in land area available for conversion. Thus, the development of sustainable land use strategies for the agricultural sector under consideration of temporal scales could be very rewarding. These temporal scales should refrain from isolating energy and material use potentials, adopting a perspective of log-term gradual shifts from energy to material use instead. The errors of past land use concepts should be avoided for material use, and the establishment of sustainable cultivation systems and concept for residue use should be promoted from the start.

The material flow perspective on effects of cascading use of bioplastics suggests that an isolated recovery and recycling chain for products of purely biogenic origin is highly unlikely. In contrast, products based on biomass enter established plastic recycling chains, or arrive at mixed-waste processing facilities for final disposal. Thus, a compatible waste management system is required.

In sum, the raw material supply perspective suggests the following key points as relevant:

- In principle, the shift from energy to material use of primary raw materials in the coming decades is feasible. Biomass will enter other energy production systems with a temporal delay.
- The intended application of a raw material should be integrated into production design (no pollutants)
- Systems for separate collection, sorting, quality assurance and recovery of biobased products require optimisation. Thus, interlinkage with the municipal solid waste sector is crucial.
- A sustainable land use strategy that balances material and energy use is required. Thus, demands of the food and feed sector may be integrated across the temporal scale.

4 Barriers and success factors for cascading use

Cascading use in the economic system in general is primarily a resource concept. In other words, cascades are usually most successful if the recycled material may be applied as an inexpensive raw material in an existing value chain, or if the recycled material initiates the establishment of novel value chains.

A characteristic of successful concepts is the high functionality of products. Product success of the products of a cascade is usually dependent on the satisfaction of high functional and qualitative expectations of potential customers, and by reasonable pricing. Environmental credentials and sustainability aspects are largely perceived as an added bonus (Holmberg 2014a). Lasting success has been associated with concepts that were able to carry themselves and persist without state funding. Government initiatives for initial funding or bridging funds to cover product development efforts preceding industrial production are helpful. However, they should not form the ongoing basis of the business model.

Implementation barriers exist in the areas of action waste management, collection and recovery. The legal framework for their regulation is provided by the Circular Economy Act based on the European Waste Framework Directive. It is noteworthy that the practical implementation for different material flows varies greatly in progress and success. Whereas the separate collection of wood and used paper is well established and regulated by law, the textile cascade has been out of balance in recent years due to vested economic interests. In addition to non-profit and private collectors, municipalities have entered the market as new stakeholders. Illegal collection and an opaque system with little transparency for donors have led to a loss of credibility and insecure raw material supply for the processing industry.

The separate collection of drop ins like bioPE und bioPET is well established in the bioplastics sector because the total flow yields market volumes relevant for recovery. Although there are no technological constraints precluding the recycling of novel biobased plastics such as PLA, these materials are usually subject to thermal recovery only. Separate collection is not economically viable for current quantities. Simple collection systems are pivotal for broad consumer acceptance.

Market-specific barriers also play a fundamental role. Subsidy cuts for competing uses of biomass for energy purposes represent a key element to extend biomass use and alleviate policy-induced raw material shortages. Instead, equality is needed between material and energy use of biomass, both through cuts of existing unilateral subsidies and indirect distortion (e.g. sustainability criteria applicable to biomass but not to petrochemical products).

Many stakeholders from the economic sector have identified lack of cooperation, comprehension and understanding of later-stage processes and products along the value chain as major impediments and detrimental for the overall cascade. Effective cooperation across the entire value chain is often complex and non-transparent due to the multitude of stakeholders including municipalities, the corporate sector, non-profit collectors, as well as international competition. Better networking and interlinkage of stakeholders in a value chain helps to promote and optimise cascading use. Technological constraints limiting or preventing cascading use are generally considered negligible.

There are a number of approaches for the promotion of improved cooperation across entire value chains, e.g.

- "Ecodesign", i.e. product design that enables and facilitates recovery and reuse of raw materials, thus supporting cascading principles in both material quality and quantity ,

- Introduction of European standards for the classification and recovery of recyclable materials, e.g. a uniform waste wood regulation across all EU Member States, as well as analytic standards for quality assurance, thus supporting and safeguarding cascading use.

The combination of different measures (both specifically designed for cascading use and in general) represents a success factor governing the stability and extension of existing and future concepts for cascading use.

5 Environmental assessment of cascading use

A number of Life Cycle Assessment (LCA) studies on cascading use are available in the literature. In consequence, a subset of cascading pathways promising additional insights was selected for the present study. The following systems were included:

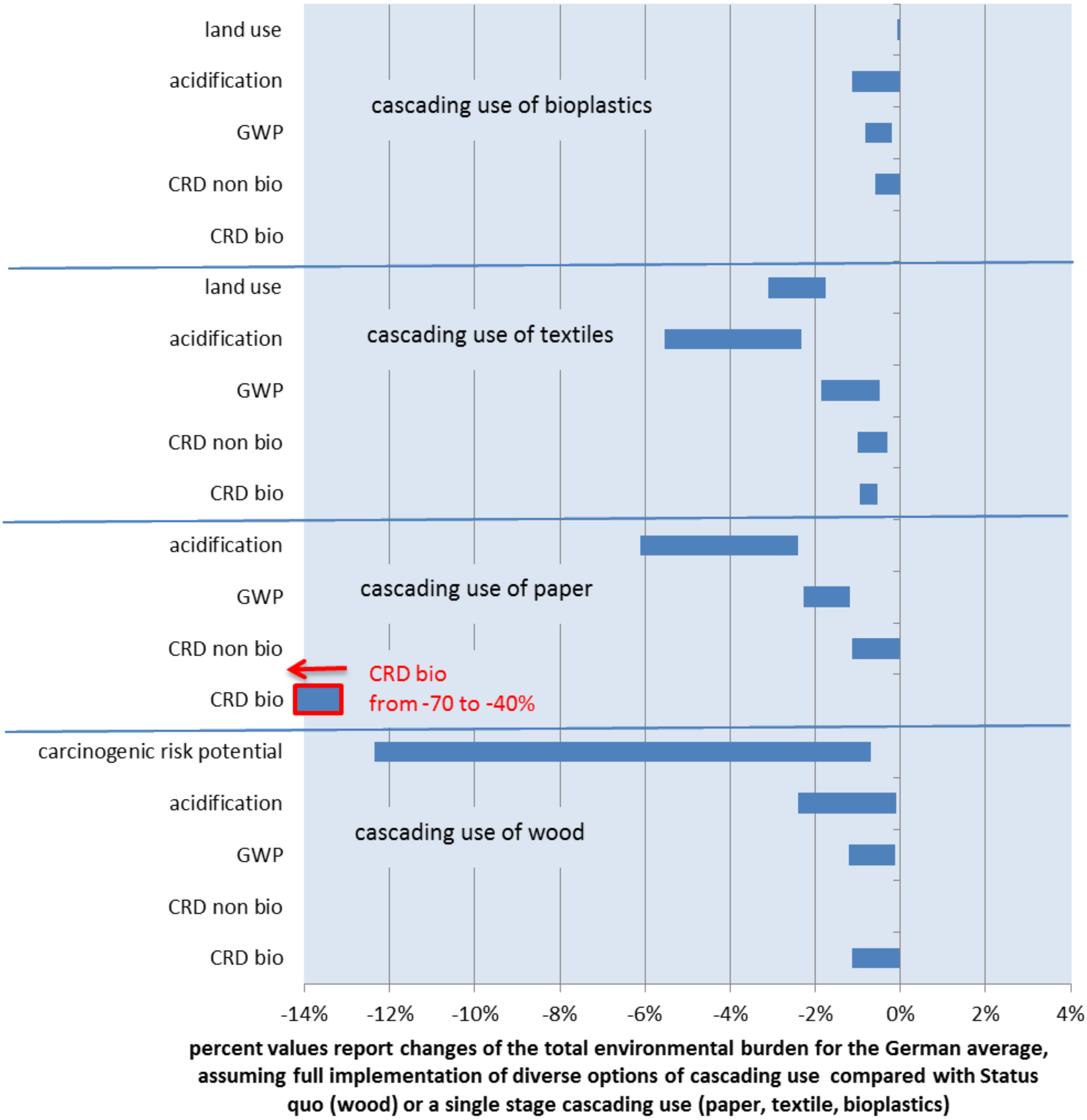
- **Wood**: Modelling of several cascading use scenarios for a comprehensive material flow balance for the entire wood sector, e.g.
  a) Partial redistribution of waste wood for increased material use in wood-based materials (particle board)
  b) Partial redistribution of forest energy wood for increased material use in wood-based materials (particle board)
  c) Partial redistribution of forest energy wood as input for chemical synthesis (as chemical feedstock or secondary biofuels)
  d) Complete redistribution of forest energy wood for increased material use (primarily for building and construction), thus overall increase of cascading use in the wood sector
- **Paper**: Modelling of regular consumption quantities of primary pulp paper in a screening LCA to explore the effects of single-stage and multi-stage cascading use in contrast with direct energy use of used paper, with goal to reduce primary pulp paper consumption
- **Textiles**: Modelling of regular consumption quantities of cotton textiles in a screening LCA to explore different options for the use of used textiles, with goal to reduce consumption of the raw material cotton
- **Bioplastics:** Modelling of a reference cultivation area for biomass in several LCAs analysing single-stage and multi-stage cascades for polylactid (PLA) and biobased polyethylene (bioPE) product systems in comparison with biomass use for biofuel application (ethanol).

The overall results are rather clear and unambiguous: **Intelligent pathways for cascading use are environmentally superior and preferable to single use in virtually all cases**. The benefits in most cases are not overwhelmingly large; however, they are constant (see Figure 1).

One explanation for the often narrow benefits may be found in the applied LCA methodology, which is based on the principle of equal benefits and models very extended systems. The resulting difference are therefore often minor. Moreover, the substitution of both fossil raw materials and other energy carriers with biomass for energy use is associated with considerable emission reductions or resource savings. This effect is constant for both direct and cascading use.

Accurate system definition is essential for result structure in several ways. For instance, the different scenarios for cascading wood use assume constant consumption of forest wood. Arising mass flows are simply diverted and redistributed. The different options do not result in land use reduction or decreased biogenic resource consumption. However, the analysis balances these effects with savings for fossil and mineral resources. In the case of paper and textiles, the agricultural raw materials that are saved by cascading use remain the same (wood / pulp or cotton). Considerable potentials to alleviate land use and biogenic raw material consumption may be realised here. Similar to wood, the model assumption for bioplastics is constant biomass production and access. Ultimately, cascading use cannot substitute biomass production for direct energy use (in principle, ethanol can be derived from bioplastics waste—however, no current practical relevance), yet it may an alternative to other fossil systems.

Figure 1: Overview of all LCA results, presented as ranges of different cascade options in comparison with the status quo (wood), or rather consequences of abandoning cascading use (paper, textiles, plastics); percent values report changes of the total environmental burden for the German average, assuming full implementation of cascading use



Relevant factors that render cascading biomass use environmentally favourable are

a) high quality of products substituted for material use
b) safeguarding against material loss along the cascade, so that energy use as the final cascade step may be carried out efficiently and with high yield

Overall LCA results are less dependent on logistics and process-related expenditure. As long as additional transport demand resulting from cascading use does not exceed distances of a few hundred kilometres, environmental burdens from logistics remain as negligible as elaborate sorting techniques required for waste wood separation.

6 Cascading use in context of an overall concept for biomass use

Questions of sustainability and superior resource efficiency for specific cases of cascading use are often difficult to answer. The concept presented here proposes a tool that may act as an early-warning system monitoring the plausibility of sustainability assessments for specific biomass cascades.

For this purpose, the present research project analysed and tested several different approaches. The level of detail or simplification of the assessment concept was the key question. Requirements for the concept included

- compatibility with existing methodology
- comprehensibility, suitability for communication, and transparency
- multi-criterial decision support in one consistent model
- assessment options at two different levels: (a) Cascading use in the overall system (macrooptimisation) or (b) comparison of alternatives (microoptimisation)
- applicability both at sector level and for case studies

Due to the complex nature of the query (sustainability assessment per se, cascading use systems add complexity layer), the selected approach provides a comprehensive overview with careful indicator selection ensuring a sound representation of environmental and socio-economic key aspects. At the same time, efforts for successful application are relatively minor. Due to the relatively early stage of implementation of the cascading use principle, the tool was developed for scientific consulting services for the guidance of policy development. The target audience is the science sector.

Thus, a certain level of reflection and consideration may be expected from prospective users. Due to the complexity of the task, a high level of automated assessment would be counter-productive, as it would obscure the assessment process. In consequence, plausible results could not be guaranteed. On the contrary, active involvement and detailed knowledge of the matters at hand is essential (e.g. research of LCA results or own brief screening LCAs, plausible reasoning behind the selection of socio-economic indicators).

All cascades explored in the present project were evaluated with the newly developed evaluation grid. This preliminary task may serve as a general introduction, particularly as a guideline for the application to other examples of cascading use. Figure 2 illustrates the method for the wood cascade example (see Section 0). Thus, the selection of underlying environmental and socio-economic indicators is inferred.

The key principle is based on a ranking of the cascade option in reference to another option for biomass use. This reference option may represent either the status quo or a defined case of non-cascading use. For instance, bioplastics cascades were compared with the use of agricultural biomass for bioethanol production for fuel purposes. The wood cascade was modelled in reference to the present status quo for use of woody biomass. The classification is carried out with a five-tier ranking scale defined as follows:

"In comparison with the reference case (no cascading use), the option under investigation is associated with

▸ a strongly positive effect	2
▸ a positive effect	1
▸ a neutral effect, neither positive nor negative	0
▸ a negative effect	-1
▸ a strongly negative effect	-2

Transparent decisions and sound rationale during classification are of paramount importance. A user guideline to illustrate plausible application and support decision-making has been included. It demonstrates ranking, e.g. in which cases "rank 2" is appropriate, or which aspects merit "rank -1". A certain personal scope of action for the individual user remains, as they have to make a case for each individual rank.

The example illustrated in Figure 2 reveals that solely the "extreme option 4" is associated with extreme values. This implies a strongly positive effect in association with almost insurmountable implementation barriers in light of the underlying policy framework.

Figure 2: Evaluation concept applied to wood cascade results

Indicator		Information from …	Option 1	Option 2	Option 3	Option 4
Environmental						
Resource efficiency	Value chain/ cascade effect	Increase of cascade stages (BUF)	1	1	0	2
Resource efficiency	Non/renewable energy carriers	LCA result: CED $_{fossil/mineral}$	1	1	-1	2
Resource efficiency	Resource conservation: biomass	LCA result: cumulative biogenic raw material demand, CRD_{bio}	0	0	0	0
Climate protection: greenhouse gas emissions		LCA result	1	1	1	2
Eutrophication		LCA result	1	1	1	2
Biodiversity: natural space		LCA result	0	0	0	0
Socio-economic		**Central questions**				
Product quality		Pollutant accumulation in products?	-1	0	0	0
Food security		Existing conflicts that may be resolved with the option?	0	0	0	0
Societal acceptance		Is there public interest in the option? If so, perception positive?	0	0	0	1
Policy framework		Is the required policy framework for the option in place?	1	1	-1	-2

Detailed description of the options for wood cascades under investigation:

Option 1: Partial redistribution of waste wood for increased material use in wood-based materials (particle board)

Option 2: Partial redistribution of forest energy wood for increased material use in wood-based materials (particle board)

Option 3: Partial redistribution of forest energy wood as input for chemical synthesis (as chemical feedstock or secondary biofuels)

Option 4: Complete redistribution of forest energy wood for increased material use (primarily for building and construction), thus overall increase of cascading use in the wood sector

7 Key points of an implementation strategy for cascading use of biomass

7.1 How do existing policy strategies address cascading use?

The term cascading use features in a number of relevant strategy and position papers on both German and European policies. References to cascading use invariably occur in context with **biomass use** and the goal of **increased resource efficiency**. The present project analysed key strategy and position papers for specifics cascading use and proposed approaches for implementation. Table 1 lists key statements from these documents on cascading use, and the strategic context of each publication.

The different interpretations and definitions of cascading use in the papers have been discussed in Section 0. The revised edition of the German Sustainability Strategy 2016 (*Deutsche Nachhaltigkeitsstrategie)* and the German Resource Efficiency Programme (*Deutsches Ressourceneffizienzprogramm* (*ProgRess II)* both promote cascading use in a **close strategic link with the goals of the circular economy**, particularly in Germany.

The analysis of the strategy and position papers revealed a general lack of detail on specific measures and fields of action for the implementation of cascading use principles. All publications remain rather broad in their overall statements. Key points for the establishment of strategic areas of action include

- certification and product labelling, as both consumer and producer perspectives are equally important (Sustainability Strategy 2016)
- management of renewable resources for increased material use (ProgRess II)
- interlinkage of value chains (BioEconomy Strategy)
- promotion of multidisciplinary and cross-sectoral research (DG Research)
- specific guidelines for the promotion of successful cascading use approaches (DG Environment)
- consistent implementation of circular economy principles, i.e. waste hierarchy, and systematic efforts for sustainable ecodesign of products (EEA)

The National Biodiversity Strategy of the Federal Government (*Nationale Strategie zur biologischen Vielfalt*, Bundesregierung 2007) predates the term cascading use. However, a number of proposed measures for biodiversity protection include elements in line with several of the concepts listed above („*… maximum resource conservation through economical and efficient resource use, increased use of recycling products and renewable raw materials…*“.

The most important issue in environmental policy is climate protection and mitigation of climate change. The relevant national strategy paper addressing these matters is the Climate Action Plan 2020 (*Aktionsprogramm Klimaschutz 2020)* of the Federal Government (BMUB 2014). Cascading use is not explicitly referenced in this document; however, it is implied in context of calls for resource efficiency, increased recycling and reuse as essential measures for climate action. The Federal Government is currently developing a National Climate Action Plan 2050 in response to the recent Paris agreement. The resolution is expected to pass by autumn 2016. The measures required to meet the reduction target of 80 to 95% by 2050 are developed and mapped out in a broad national dialogue. For this purpose, a catalogue of measures has recently been published. It includes cascading use in context with recycling and carbon storage in products as measures for climate protection (Wuppertal Institut et al. 2016). The Federal Environment Agency also published a position paper (UBA 2016) identifying necessary key measures for the Climate Action Plan 2050. Its primary focus is on efficient use of residues with high carbon content.

Table 1: Overview of a selection of relevant strategy and position papers addressing cascading use

Strategic paper	Author	Role of cascading use	Implementation via
German Sustainability Strategy, Edition 2016	Federal Government (2016)	In reference to SDG #12: "*Sustainable products should be durable in design, resource-efficient and fit for recycling after use (**cascading use**)*"	Certification and product labelling
German Resource Efficiency Programme II (ProgRess II)	Federal Government (BMUB 2015)	*It is essential to "optimise both material efficiency of renewable raw materials and efficiency of technological processes by dedicated research and fully realise potentials. Increased **cascading use** supports both principles"*	management of renewable resources for increased material use
National Research Strategy Bio-Economy 2030	BMBF (2010)	*"Products with higher added value potential are preferred... Favour **cascading and coupled use** of biomass wherever possible and recommended."*	Biorefineries, intelligent interlinkage of value chains
Catalogue of measures – Outcome of the dialogue on the Climate Action Plan 2050 of the Federal Government	BMUB (Wuppertal Institut, ifeu, Öko-Institut, ISI, IRESS, IFOK 2016)	Mention of cascading use among proposed measures: *Promotion of sustainable, multifunctional forestry (KSP-L-09)* *High-quality use and recovery of materials, parts and modules, application of sustainable materials for building and construction (KSP-G-02)*	Promotion of material reuse / recycling Long-life wood products as carbon sinks, innovative approaches
UBA Position on the Climate Action Plan	UBA (2016)	*"Carbon residues of producers … should be used for energy purposes wherever possible, after realisation of high-quality use or recovery in accordance with **biomass cascade principles**."*	Efficient use of residues with high carbon content
Forest Strategy 2020	Federal Government (BMEL 2011)	*"Waste prevention and closed waste material loops promoting re-entry into the economic cycle are essential for increased recourse efficiency. Intelligent **cascading use** of scarce resources in the wood and paper sector in general should be increased. There are additional reserves that should be accessed in combination with research measures"*	Development of innovative wood products and efficient production techniques
Innovating for Sustainable Growth a Bioeconomy for Europe	EU Commission DG Research and Innovation (2012)	*„Promote the setting up of networks … including the necessary logistics and supply chains for a **cascading use** of biomass and waste streams."*	multi-disciplinary and cross-sectoral research
Closing the loop – EU Action Plan for a Circular Economy	EU Commission DG Environment (2015)	*„… circular economy with a focus on value retention of products, materials and resources for as long as possible, and on waste minimisation".*	Development of guidelines and the promotion of successful approaches to cascading use

Strategic paper	Author	Role of cascading use	Implementation via
Circular economy in Europe — Developing the knowledge base	EEA (2015)	*… biomass is best used in a **cascade** in which energy generation is the last step rather than the first."* Interpretation : cascading use = low-level recycling	Ecodesign, funding initiatives, business models, eco-innovation
Resource efficiency: moving towards a circular economy (2014/2208(INI))	European Parliament (2015)	*"This includes fully implementing a **cascading use** of resources, sustainable sourcing, a waste hierarchy, creating a closed loop on non-renewable resources, using renewables within the limits of their renewability and phasing out toxic substances"* Cascading use as a building block of an economy with optimised resource efficiency	Diverse measure across the value chain
Policy briefing: Cascading use of biomass: opportunities and obstacles in EU policies	EEB, BirdLife Europe (2015)	Cascading use defined as consistent observance of waste hierarchy	Economic reward of waste hierarchy observance
Cascading of woody biomass: definitions, policies and effects on international trade	IEA Bioenergy Task 40 (Olsson et al. 2016)	*"cascading" … could be among the appropriate policy tools, but for a vital debate, it is important <u>not to assume that cascading is the silver bullet"</u>*	Warning against legislature regulating the implementation of cascading use

7.2 Position of cascading use among the three "core strategies"

The objectives of the present project include the reflection of cascading biomass use in context with the three core strategies for decreased resource consumption:

- **Efficiency** (ratio between benefit and required resource consumption).
- **Consistency** (simplified: substitution of fossil with renewable resources; → bioeconomy)
- **Sufficiency** (decrease of goods and services demand)

Cascading use of biomass should contribute to **resource efficiency**. The limited resource agricultural land for the cultivation of biomass, or biomass itself, may be used more efficiently with the help of cascading approaches. Thus, competition may be alleviated, particularly in context with food security. Simultaneously, cascading use can make considerable contributions to climate protection, biodiversity conservation, and a number of additional environmental matters.

The results of the present project confirm these expectations for the majority of case scenarios.

Consistency and **sufficiency**, however, may be associated with contrary expectations for the implementation of cascading use. The positive influence of cascading use on resource efficiency may be used, depending on which overall environmental goal is the first priority:

- Cascading use enables **reduced land use** and thus, **reduced resource consumption**, with equal quantities of biomass available (with a temporal delay) for material and energy economy purposes.

Under the assumption that all agricultural land is under cultivation, and that agricultural production levels should not be increased with area expansion, but rather be curbed in the future, cascading use could support policies pursuing the sufficiency principle.
- Cascading use may also provide the economy with **more biobased raw materials** while keeping raw material consumption, and thus land use, constant.
  Under the premise that complete substitution of fossil raw materials (consistency) is not feasible without a surplus of raw material biomass, cascading use would free up agricultural land and make it available for the expansion of biomass for material products. Thus, raw material biomass is redistributed for material use, and becomes available for energy use with a temporal delay depending on duration of use in each cascade stage.

Prioritisation is clearly required at a higher policy level to clarify and define which direction to pursue with the introduction of cascading use. What appears like two "either / or" approaches may in practice be combined, so that both strategies could boost presently low levels of cascade implementation. It is a fact that high shares of biomass are currently used for direct energy purposes. At present, 44% of wood biomass are incinerated without any prior material use.

In addition to the expected environmental benefits, a retreat in part from primary energy use of biomass and the resulting redistribution of available primary raw materials for material use could promote the following goals of action:

- pressure release on land use
- increased material use of available biomass
  a.) by redistribution of the high shares of biomass used for energy purposes
  b.) for the shift to a bioeconomy (defined as the departure from a fossil-based material industry towards a biobased economy)

The key question in this process is the extent to which the shift from a crude oil-based economy to a biobased economy is intended (BMBF 2010). It is a fact that a complete substitution of fossil raw materials with biogenic raw materials would require considerable resource quantities, which would add to the same conflicts that have been debated for bioenergy / biofuel policy over the past decade. Cascading use could contribute to alleviate some of the pressure, but it is unlikely to solve all potential conflicts and offset all consequences of a complete bioeconomy shift.

7.3 Role of cascading use in resource policy

The analysis above illustrates that cascading use of biomass as an independent strategy in isolation is unlikely to be rewarding. There are already strong and complex links with existing methodology and policy strategies (resource efficiency, bioeconomy, circular economy). Moreover, the following practical reasons apply:

- The implementation of cascading use as a generalised requirement in the complex world of production requires great effort. This was revealed in the individual analyses of this research project that explored relevant barriers and success factors of existing cascade concepts. Practical examples demonstrating successful implementation are very rare.
- Cascading use takes place within the tightly woven network of supply chains and depends on perfectly closed loops and complete quality assurance. In consequence, practical application has been largely restricted to niche products and markets, with the exception of the paper industry and parts of the wood industry.

Instead of an example for an alternative, independent strategy, cascading use represents a **principle for the support of the overarching goals and associated strategies**. Cascading use may be particularly well suited to

- increase resource efficiency per se (e.g. in context with the resource strategy)
- support a resource-efficient shift towards a biobased material industry. Use cascades are a key component of the bioeconomy.

The goal of a strategy for the implementation of cascading use of biomass could be summed up as follows:

Due to strong constraints creating the need for sustainable and environmentally-sound use of biomass (land demand, competition, ILUC etc.), a consistent approach to biobased products according to bioeconomy principles has to rely on the implementation of **cascading use in principle**.

However, "in principle" also implies a demonstrated improvement of resource efficiency in each individual case. Indicators and metrics as proposed in this research project are required for this purpose. Individual analyses are indispensable, as there is no blanket case for cascading use under all circumstances. In addition to the criteria detailed in § 6 Section 2 Circular Economy Act, the following should be **avoided at all cost**:

- displacement of favourable reuse for higher-quality purposes,
- production of "useless" products that require creation of a viable market,
- pollutant accumulation and contamination of products.

What are the policy implications?

The first prerequisite is a clearer structuring of aims and goals for the so-called bioeconomy. Here, the integration of cascading use as a key instrument for resource use efficiency optimisation is essential.

7.4 Links with existing strategies

The analyses above provide two core strategies that are closely linked with cascading use, or are in the process of integration via application of cascading use principles:

- bioeconomy
- advanced circular economy

Both approaches share the overall goal of resource conservation with generally more efficient resource use. The bioeconomy approach has a distinct focus on biobased products and innovative production processes. Although current strategy papers apply different definitions of cascading use (BMBF 2010, EC DG Research and Innovation 2012), the broad goals and guidelines match up closely.

The waste hierarchy almost completely "harmonises" and reconciles the circular economy with use cascades, at least for the non-consumer sector. The processes of material-specific capture, collection, separation and maintained separation of post-consumer waste and its recycling (open-loop, closed-loop, up/down), and material and energy recovery signify the full application of cascading use for biogenic secondary raw materials.

Thus, the circular economy represents the principle of material flow management across entire value chains that applies to all kinds of material industries, whether biobased, fossil or mineral. The added value of the term biomass cascading use may be found in the integration of the (currently insufficiently realised) hierarchy principle into the bioeconomy strategy.

The cascade principle as defined in the present project integrates both key aspects, thus closing the gap between biomass use of main and by-products and the waste hierarchy (nova 2015).

7.5 Strategic key elements for the promotion of cascading use

The key elements are distinguished for different levels of action and decision-making. They chiefly address policy decision-makers, and are divided into areas of action

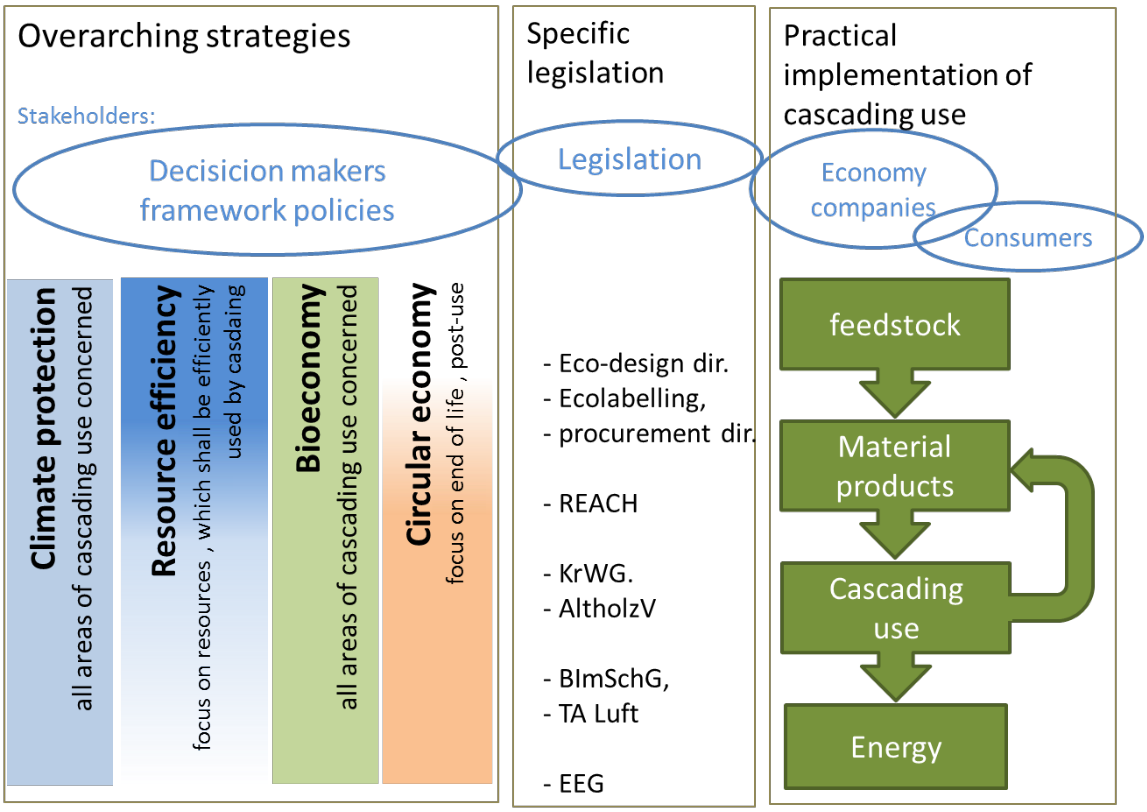
- for framework development,
- for development of specific legislation,
- for identification of research foci.

Also included are

- corporate stakeholders that are responsible to implement cascading use and fill it with economic viability
- consumers that exert major influence through their purchase behaviour. The National Sustainability Strategy arrives at the conclusion (Bundesregierung 2016): „*Sustainable consumption and sustainable production are two sides of the same coin*‘“. Moreover, future progress on sufficiency matters distinctly relies on consumer involvement.

All relevant levels of fields of action (overarching strategies, legislation, implementation) and the stakeholders in question (politics, economy, consumers) are united in the “cascading chain” illustrated in Figure 3.

Figure 3: Integration of relevant levels of areas of action and stakeholder communities for the strategic key elements to boost cascading use



8 Recap

A range of environmental strategies and programmes have identified cascading use of biomass as a crucial element for increased resource efficiency. However, the term lacks a clear and consistent definition. The definition proposed in the present project allows transparent distinction between different terms and interpretations. In the early stages of the project, analysis of existing concepts for cascading use revealed a shortage of successful examples of use cascades in practice. Relevant examples include the wood sector, paper sector, textiles sector and plastics sector, which is a prime candidate for transformation towards biobased plastics.

After comprehensive analysis of agricultural and forestry raw material potentials provided a cascade origin, a number of detailed LCAs were carried out for each of the four sectors above. The results revealed distinct environmental benefits for the majority of cascading use options in comparison with the reference scenario, which included no or single-stage cascading use. However, individual analysis on a case-by-case basis is essential. The outcome of the complex LCA modelling was adapted and developed into the proposed evaluation concept. This concept may be used for the assessment of potential cascading use for a broad range of situations, but with a limited level of input data detail. Thus, it provides an early warning system, and may facilitate informed decisions on the sustainability and expected success of cascading use approaches for any given system.

The project further developed recommendations for key elements for a strategy promoting cascading use. These are distinctly in favour of integrating cascading use as a supporting principle for the achievement of overarching policy goals and strategies, as opposed to the establishment of an isolated policy strategy pursuing cascading use out of context.

The onus is not least on the consumer. Consumer awareness is key for the success of the most effective of all strategies targeting reduced resource consumption, the sufficiency strategy.

Sustainable resource use requires a blend of strategies, or rather a concerted integrative effort. Calls for increased cascading use alone are bound to fall short of the overall goal. Successful application has to be documented and quantified, which may be achieved with the evaluation concept proposed here. Cascading use has to be integrated with efficient production processes and product design. Thus, complex interactions and feedback loops between policy fields and economic and industrial sectors may be analysed and managed transparently.

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