Biomass in the Context of Industrial Ecology

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Abstract—**Biomass is a resource that economically stands out from other types of resources. Implementation of bioeconomies based on more efficient and more versatile utilisation of biomass is in the focus of European and national agendas. At the same time, industrial ecology has emerged as central discipline aiming towards transferring sustainability ideas and sustainability principles into practice. In this context, non-biogenic resources are covered with priority, while the topic biomass is more rarely covered as an explicit issue. This paper highlights elements that are central to understand the role of biomass in the context of industrial ecology, and in particular basic differences that exist compared to other material resources.**

Keywords- biomass; biorefineries; bioeconomy; industrial ecology; decoupling

I. Introduction

Adoption of green economy principles concentrating on the intersection between environment and economy, has been and is the guiding element on the pathway to international recognition and implementation of sustainable development. Green economy was central to the Rio+20 (2012) agreement by UN member states to launch a process (currently in progress) to establish universal Sustainable Development Goals in order to translate developmental potentials into feasible goals at a practical level.

Sustainability has become a central although not static paradigm of all human activity. While conservation issues have been regarded as central for around three decades in the sustainability context, the last decade has seen a shift to issues such as:

- resilience (in the primary definition of the capabilities of systems to be able to cope with changes and to pro-actively reorganise themselves according to new needs while still maintaining essentially the same function and identity)
- industrial ecology as the discipline to put sustainability into practical applications (see Section II)
- systemic approaches (acceptance of a high degree of how one element of a system interacts with the other constituents of the system along with adoption of holistic multi-level perspectives and abandonment of linear causation analysis/ solution choices)

At the heart of all transition to more sustainable systems is an efficient management of resources with creation of optimum economic values under respect of boundaries framed by limited ecosystem capacities (in this context the concept of Planetary Boundaries as proposed by Rockström et al. [1] has become central during the last few years).

Resource consumption is still steeply increasing worldwide. A range of countries have elaborated policy frameworks for improved resource efficiencies, in general with a focus on increasing resource productivity (increased quantity of good or service obtained through the expenditure of one unit of resource, e.g. fossil fuels, rare earth elements, water).

Bioeconomy based on efficient and diversified use of biomass is one pillar e.g. in the European but also in national perspectives on resources strategies. Biomass stands out from other resources (non-biogenic resources) under various aspects (see Section III). This publication discusses major issues relevant in the context of biomass and industrial ecology, with the main aim to frame the topic and to advocate for more detailed studies designed to reveal the full potentials and the specific challenges of biogenic resources.

II. Industrial Ecology

Industrial ecology as an academic discipline and even more as an applied discipline is relatively new. It has evolved mainly during the last thirty years, although central elements existed earlier (in particular there is a close relationship with environmental engineering, which can be understood as a precursor and today still central sub-discipline). The field of science of industrial ecology has rapidly developed, but it still remains an emerging field today.

A brief review of literature (orientating research without defined standards) along with a brief study of online self-descriptions of around ten European university professorships in the field was carried out in April 2014. The overview was elaborated in preparation of an academic course to be taught to students of environmental engineering – the results provided in the following do in no way claim to be statistically based or to be complete, as they had been generated mainly to provide a tangible and up-to-date working definition of the discipline industrial ecology and its current focus areas. The results of the orientating research indicate a range of often-used keywords and incorporated conceptual elements that can be used to characterise the basic disciplinary framework:

- an oxymoron (seemingly self-contradictory, a composition of elements that do not normally occur in one context)
- a field with not yet set goals and boundaries; an emerging field with clusters of concepts, tools, objectives and strategies that integrates multiple dimensions

- a discipline to put elements together to a larger whole, driven by awareness of manifold human impacts on the biophysical environment
- an intellectual architecture connecting aspects of which some have well-defined relationships and others are only loosely grouped together
- the discipline to advance from diagnostically studying industrial metabolism (quantitative studies of flows of materials and energy in an environment influenced by human activity) to sustainable development

Industrial ecology marks the change from looking at unit process levels (inside a company or entity) to interrelations between entities, to a district or sector level, and ultimately to a regional, national and global level. In consequence, the focus leaves individual processes and sites and shifts to a broader view that can encompass clusters of companies, industrial zones or whole regions.

While the word industrial suggests that industry is addressed in some form, the scope of industrial ecology is generally understood to go well beyond and to implement socioeconomic perspectives. The word industrial in this context refers to all human activities occurring within modern technological society (including tourism, housing, medical services, transportation, agriculture) [2, 3]. The word ecology in the context of industrial ecology refers to the science of ecosystems as communities of living organisms interacting as a system with each other and with non-living elements of their environments.

There exists no standard definition of industrial ecology, but generally it can be understood as being a practical approach to sustainability, aiming to transfer the concept of sustainable development into practice in an economically feasible way. It builds on the idea that industrial activities should not be considered in isolation from the natural world but as part of the natural system, and that industrial systems should be viewed as industrial ecosystems that function within the natural ecosystem or biosphere and in a similar way consist of flows of material, energy and information [3]. A common misunderstanding is the interpretation that industrial ecology understands nature as mature cyclical no waste economy to be used as blueprint for designing industrial systems – but actually industrial ecology regards nature as a hypothetical model that can be used by humans in part with its strategies and principles in order to restructure various forms of human-influenced interactions [4]. Main elements of the general strategy towards a mode of operation of human activities that will be compatible with the natural ecosystems and that will therefore be sustainable over long-term are as follows:

- optimisation of resources use, in particular by closing material cycles and increasing efficiencies
- minimisation of emissions and other negative impacts on ecosystems
- ensuring long-term functionality and high-performance of systems under special consideration of acceptable quality of life for human beings (anthropocentric perspective) and maintenance of economic viability of systems for industry, trade and commerce

Central first step remains the examination of flows of resources through a socioeconomic system (industrial metabolism). Key diagnostic tools in this context are material flow analysis (MFA), substance flow analysis (SFA) and life cycle analysis (LCA). Based on the diagnosis, specific strategic elements of industrial ecology can be:

- various options to maximise the degree of valorisation of a resource and thereby increasing the productivity of the resource – including cascaded use of resources, circular economy with recycling of wastes
- decoupling strategies (mainly decoupling resources use from economic growth, impact decoupling)
- substitution strategies – including use of alternative resources that perform the same function but have reduced environmental impacts, use of materials that have better efficiencies, substitution with renewable resources
- product-oriented environmental policies ("product stewardship"), e.g. extended producer responsibilities
- implementation of life-cycle thinking
- fostering of technological change and innovation with view to aspects such as dematerialisation, decarbonisation, elimination/ management of critical resources, cleaner production, improved eco-efficiency, design for environment
- fostering of systems thinking and integrative approaches to create diversified benefits and win-win solutions (integrative participation of stakeholders and experts such as environmental planners, engineers, companies, public entities)
- fostering of industrial symbiosis, in particular in the form of industrial parks

It is further interesting to note that the orientating study mentioned above suggests that the majority of stakeholders in the field of industrial ecology have a background related to resources management. However, non-biogenic expertise and working fields seem to be dominant. In particular there appears to be a strong correlation between expertise in material flow analysis and subsequent adoption of a broader perspective via the discipline industrial ecology. Biogenic expertise and working knowledge in fields specifically related to the resource biomass seem to be less well represented within the current spectrum of the discipline industrial ecology.

III. Biomass as a Resource

A. *Biomass: A Conditionally Renewable Resource*

From an anthropocentric perspective, a resource is anything that satisfies human needs and wants. If the availability of the resource is limited, allocation through resource management is required (assignment of available resources among a set of possible options). Biomass belongs to the so-called 'conditionally renewable resources' – a category that is either seen as subcategory of 'renewable resources' or as a third main category next to 'non-renewable resources' and 'renewable resources'. Main criteria of non-renewable resources (e.g. fossil energy carriers, minerals) is that they have been formed at very slow rates over long time periods and are not replenished after depletion. Renewable resources are either available at a continuous rate that might be limited but which is not influenced by human consumption (such perpetual resources are wind and sunlight) or they can be replenished or reproduced at a rate that is at least equal to their consumption rate, thus maintaining a flow. If conditionally renewable resources are subject to excessive consumption, depletion or destruction of the resource is possible (examples are forest biomass, agricultural production, fish, healthy water). The conditionally renewable resource biomass further belongs to the category of 'reproducible resources' which can be renewed through human activities as result of planned actions. The heart of management strategies therefore are implementation of efficient allocation procedures under consideration of long-term perspectives.

B. Optimised Utilisation as Primary and Secondary Resource

While some resources can be recycled (e.g. metals) others can only be used once (e.g. fossil energy carriers). Due to the nature of the majority of its applications (food, fuel), biomass is mainly used as primary resource (natural resource made available and used for the first time in economic activities). In this context, biorefinery concepts that aim at complete valorisation of the biomass to cover various needs in parallel by producing multiple products at the same time are central strategic elements of bioeconomies. A biorefinery can be understood as a facility or a processing network of facilities (including equipment and infrastructures) that integrates biomass utilisation and conversion processes in a way that takes advantage of the versatility of usable biomass components and of intermediates in order to maximise the overall value derived from the feedstock. The possible range of products will depend on the main type of biorefinery and the actual processes applied, and includes food, fodder, fuels, energy in the form of power and/or heat, various forms of value-added chemicals.

Nevertheless, utilisation of biomass as secondary resource (a resource made available through recycling, e.g. plant fibres from recycling) is an issue of significant relevance. This includes various forms of valorisation of food wastes or other biogenic residues, and more advanced cascade approaches in order to maximise overall productivity through creation of a value chain that often includes a combination of material use, chemical use and energy use. One example is the cascaded use of wood by first maximising material use via e.g. timber products, paper, then followed by using the same biomass for chemical use via e.g. fibre and/ or constituents extraction for various chemically based products, and only finally using remaining biomass that is unsuitable for other applications for energy use.

C. Global Long-term Trends in Use of Natural Resources – Overview since 1900 with a Focus on Biomass

When looking at the four major material classes biomass, fossil energy carriers, ores and industrial minerals, and construction minerals, it becomes evident that biomass has developed differently throughout the last century compared to the other three major classes. Total material extraction increased by a factor of 8 in the 20th century (from about 7 Gt in 1900 to about 55 Gt in 2000), with the strongest increase for construction minerals (growth factor 34), followed by an increased consumption of ores and industrial minerals (factor of 27), and of fossil energy carriers (factor of 12), while biomass extraction increased only 3.6-fold [5, 6]. During this period, world population had increased by a factor 4. This reveals that the average global metabolic rates (average consumption of resources per capita and year) have around doubled overall during the course of the 20th century (sum of the four material classes mentioned above), while for biomass the average consumption rate per capita has remained at similar level.

For much of the 20th century, biomass had dominated among the four material types. In 1900, biomass accounted for almost three quarters of total material use. One century later, its share had declined to only one third. Thus on top of using more biotic renewable resources, the global socio-economic metabolism has increasingly turned towards mineral resources. A central shift therefore was from renewable biotic resources to non-renewable mineral ones [6].

Nevertheless, most renewable energy worldwide today still comes from biomass: around three quarters of renewables are produced by using biomass. Most of this is traditional biomass, mainly fuel wood gathered in traditional societies for household cooking and heating, often without regard for sustainable replacement [7].

In industrialised countries, biomass is seen as a central and versatile high-potential resource towards establishing a high-value bioeconomy as one element of green economy, which explains the high current and future priority given to biomass.

D. Decoupling Resources Use from Economic Development: Fundamental Differences between Biomass and other Resources

Breaking the link between resource consumption and economic growth is one central challenge towards increased sustainability. Decoupling strategies comprise all means to break the dependencies between economic development and requirement of resources. However, it is important to be aware of the fact that biomass stands out from other resources in the way of how individual resources are linked to economic growth and hence can be considered in decoupling strategies.

Several studies have confirmed that biomass is characterised by economic inelasticity – which means that its consumption is not related to economic development. A study on resources use in China with a focus on identifying interlinks between resources use and economic developments revealed that consumption of metallic minerals, non-metallic minerals and fossil fuels grew within positive economic development, while biomass remained stable [8]. Similarly, Steinberger et al. [9] identified that when analysing material flow data and their links to economic factors, biomass stands significantly out from other main material groups such as ores/industrial minerals, construction minerals, fossil energy carriers – all of which are correlated to each other and to economic activity, but of which none is correlated to biomass. This pattern appears to be further confirmed when looking at the economic analyses of a decoupling study conducted by Mattila et al. [10] for the high-income country Finland, which revealed that the increase in GDP and the ecological footprint related to consumption of biological resources are separated subsystems of the economy.

Based on the knowledge that biomass is to be regarded as being economically inelastic and considering further the patterns of use of biomass throughout the last century as described above (part III C), it can be concluded that consumption of biomass is strongly related to population growth but not to economic growth – and that this pattern is irrespective of the economic development stage of a country. Decoupling strategies – today considered to be central elements to advance towards more sustainable use of natural resources [11] – therefore appear to be unsuitable to address biomass management issues in this context.

Steinberger et al. [9] have highlighted that their results (mentioned above) underline the unique status of biomass as the most basic material. They further pointed out that tendency to use biomass as commercial energy carrier may lead to a closer coupling of biomass use and economic wealth, which could result in increased global inequality.

IV. Conclusions

Two main reasons can be identified why consideration of biomass is underrepresented within the current spectrum of the discipline industrial ecology. First, there is a dominance of non-biogenic resource management expertise and academic backgrounds among the main actors and key stakeholders in the discipline. Furthermore, the resource biomass stands out from other material resources in various aspects, with the consequence that management of biogenic resources necessarily needs to be different from other resources:

(1) Biomass is characterised by economic inelasticity, which makes application of resource decoupling strategies unsuitable.

(2) Significant fluctuations of amounts and qualities of the resource occur, among others due to seasonal influences, which poses specific challenges to resource supply for various applications and for scheduling valorisation options.

(3) As a conditionally renewable resource (which further belongs to the reproducible resources) its management is very different from management of other material resources, and there needs to be a focus on ensuring long-term supply under changing conditions. This includes consideration of effects of climate change (e.g. on biomass yields, soil fertility, weather conditions, seasonal shifts) and changing patterns of demand in particular for food (key factors: the rising world population will increase demand for amounts of food; shift of diets will become relevant as they typically occur along economic development of various countries; losses/ efficiencies in food supply chains require attention [12]).

Optimised utilisation of biomass is in general targeted through specific strategies and programmes, e.g. implementation of biorefineries and various other bioeconomy elements. Industrial ecology as a discipline that necessarily has to be integrative if it is to succeed in advancing towards more sustainable human activities would benefit from identifying and unlocking possible synergies.

References

[1] J. Rockström, W. Steffen, K. Noone, Å. Persson, F.S. III Chapin, E. Lambin, T.M. Lenton, M. Scheffer, C. Folke, H.J. Schellnhuber, B. Nykvist, C.A. de Wit, T. Hughes, S. van der Leeuw, H. Rodhe, S. Sörlin, P.K. Snyder, R. Costanza, U. Svedin, M. Falkenmark, L. Karlberg, R.W. Corell, V.J. Fabry, J. Hansen, B. Walker, D. Liverman, K. Richardson, P. Crutzen, and J. Foley, "Planetary boundaries: exploring the safe operating space for humanity," Ecology and Society 14(2), 2009, art. 32.

[2] R. White, "The greening of industrial ecosystems", 1994.

[3] Resource Optimization Initiative, information material, compiled 2005-2014.

[4] R. Isenmann, "Management "inspired by nature" – Misunderstanding the basic tenet of industrial ecology and how to avoid popular shortcomings," presentation at International Course "Industrial Ecology", Univesity of Bremen, 2005.

[5] F. Krausmann, S. Gingrich, N. Eisenmenger, K.H. Erb, H. Haberl, and M. Fischer-Kowalski "Growth in global materials use, GDP and population during the 20th century," Ecological Economics, 68(10), 2009, pp. 2696-2705. – here from: UNEP-Report "Decoupling natural resource use and environmental impacts from economic growth", 2011

[6] UNEP-Report "Decoupling natural resource use and environmental impacts from economic growth", 2011.

[7] T. Theis, and J. Tomkin. (edts.), "Sustainability: A Comprehensive Foundation. Online-Resource," Rice University, Houston, Texas, 2013.

[8] H. Wang, S. Hashimoto, Y. Moriguchi, Q. Yue, and Z. Lu, "Resource use in growing China – Past trends, influence factors, and future demand," Journal of Industrial Ecology 16 (4), 2012, pp. 481-492.

[9] J.K. Steinberger, F. Krausmann, and N. Eisenmenger, "Global patterns of material use: A socioeconomic and geophysical analysis," Ecological Economics 69, 2010, pp. 1148-1158.

[10] T. Mattila, "Any sustainable decoupling in the Finnish economy? A comparison of the pathways and sensitivities of GDP and ecological footprint 2002-2005," Ecological Indicators 16, 2012, pp. 128-134.

[11] M. Alsheyab, and S. Kusch, "Decoupling resources use from economic growth – chances and challenges of recycling electronic communication devices," Journal of Economy, Business and Financing 1(1), 2013, pp. 99-107.

[12] S. Kusch, and C.J. Evoh, "Meeting the growing demand for food and bioenergy in the 21st century: synergies through efficient waste management," Biofuels 4(5), 2013, pp. 479-483