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The Challenge of Utilising Bio–Resources: A Regional Perspective

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Abstract

Although it is still not warranted to speak about the end of the fossil age, we certainly witness a trend towards renewable sources for energy and material. Properties of bio-resources however differ vastly from fossil as well as other renewable resources. They are storable, mainly de-central in their provision, have usually weak logistic properties and face severe competition from various sectors, in particular from the vital food sector. A stronger reliance on bio-resources to support the European energy system as well as to provide raw materials for conversion to material products therefore raises technical, societal and environmental issues that have to be resolved if a bio-economy is to become a viable development pathway.

One major challenge is that regional technology networks become important as transport becomes a considerable concern for bio-resources. On top of that, the necessary high resource efficiency calls for strong interlinks between technologies. Particularly interesting will be the implementation of grid-overarching technologies that exploit the one big advantage of bio-resources, namely their storability, in order to stabilise energy grids. Another important question concerns the support of energy demands from industries.

This paper is based on the "discourse book" of the European Sustainable Energy Innovation Alliance on the rational utilisation of bio-resources (2014) [1]. It will in particular address the regional challenges of a sustainable European Bio-Economy.

Keywords:	Bio–economy, Bio–resource utilisation, Strong sustainability

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1. Introduction

The current discourse about ecological sustainability is heavily influenced by the concurrent discussions about the ecological threat global warming and the economic impact of diminishing fossil resources [2]. As a consequence an energy turn-around towards renewable resource based energy provision (as well as increased energy efficiency) is seen as a win-win-win option, at once relieving the burden on limited fossil resources, working against climate change and bringing society closer to sustainability. Besides this there are numerous voices such as Daniel Yergin (2011) [3] linking development and implementation of renewable energies to technological innovation and economic growth, adding to the sustainability credentials of an energy turn-around. This has led to the formulation of political goals (e.g. the European Union 20-20-20 Goals (2007a) [4] and plans (e.g. the European Union SET Plan (2007b) [5] to lay the foundation for a change to renewable energies within the 21st century.

Although this increase in renewable energy provision will be shouldered by technologies drawing on different renewable resources such as hydro power, wind, direct solar energy, geothermal energy, wave and tidal energy, bioenergy will play an important role in the future energy mix.

This increased demand however meets an already contested resource. By 2050 the world population will increase to more than 9 billion people (from its current 7,2 billion), requiring over 1016 kcal of food per year, an increase of over 40% from a current value of 7*1015 kcal/y (see e.g. Taste of Sustainability, FAO (2014) [6]). Besides, well entrenched industrial sectors, most notable pulp and paper production and construction, already use large amounts of biomass. According to the FAO (2014) [7] the world consumption for industrial round wood will reach 2.436 * 109 m^3/y wood raw material equivalent (WRME), 45% up from the 2005 consumption of 1.682 * 109 m³/y WRME.

This paper will discuss why a stronger reliance on bio-resources will fundamentally change the structure of industry as well as energy provision, making the regional context more important. It will also provide guidelines on how regional utilisation of bio-resources should be organised in order to exploit maximum benefit from these resources while maintaining sustainability of their use. This will be specifically explored from the viewpoint of energy systems.

2. Bio–resources — versatile, contested and demanding base for human society

There seems to be no other group of resources that can fulfil such a wide variety of demands as bio-resources. There is however no other group of resources that entail so direct and large scale impact on society and the environment for its provision and that so clearly highlight the general conundrum of sustainable development, namely living within "limited infinity". Bio-resources require as a basic production factor area, which is limited as our planet has a limited surface. Besides that it requires other ingredients, namely fertile environmental compartments, be they soil or water bodies.

Seen from the vantage point of converting solar energy into energy embodied in materials, the generation of bio-resources by the process of photosynthesis is not a particularly efficient process. Maximum theoretical conversion rates of solar radiation into bio-resources are between 4.6 for C-3 plants and 6 % for C-4 plants [8]. Practical conversion rates are around 50 % of these theoretical values.

It is this low efficiency of converting solar radiation into useful energy from bio-resources (regardless if used for nutrition or technical purposes) that makes "living in limited infinity" particularly obvious: bio-resource generation rate is limited by the limitation of the production factors, most notably arable land and forest area. This rate may however be sustained over (practically) infinite time if human society learns to manage these production factors cleverly.

Human society is already a strong contender for this limited form of natural income. Beer et al. (2007) [9] estimate Global Net Primary Production (NPP, the rate at which sunlight is converted into useful chemical energy, measured in t of carbon fixed by photosynthesis per year) to roughly 105 Gt/y, of which 53.8% are allotted to terrestrial systems. Haberl et al. (2007) [10] show that from the terrestrial NPP 23.8% are already appropriated by man, be it by harvesting (53% of this appropriation) or land use change (amounting to 40% of the appropriation) or human-induced fires. They also point out that the overall impact of human activities reduces the NPP by almost 10%. According to these authors it is far from certain that the current rate of appropriation is sustainable.

Limited generation rates are one aspect that makes bio-resources inherently contested commodities. Their versatility is another. From the vantage point of the energy sector and the chemical industry as well, bio-resources can fulfil every demand currently covered by various fossil (and nuclear) technologies: they may be converted in heat or electricity, fuel or any chemical compound demanded by the market. In a time when fossil oil, the key resource for synthetic materials and transport fuels faces its production maximum and, together with all other fossil resources, comes under increasing environmental scrutiny as a culprit of global climate change, the versatility of bio-resources translates into increased demand from various sectors. This adds to the already strong competition for bio-resources between traditional users, in particular the food sector, firewood use and pulp and paper industry, to name the most important ones. This means that any competition for bio-resources will inherently end up as a competition for land. As a consequence there is a direct competition between sectors, such as the food sector and bio-fuel industry, for particular crops. On top that there is however an indirect competition between different forms of land use as forests providing resources for energy provision or pulp&paper industry may compete with fields that provide crops for food or bio-fuel. Following this argumentation the growing demand for food and energy will end up in exceeding the limits of fertile land. This influences the eco-chains interrelated to these land conversions which can lead to further climate change ending up in less productivity and volatility of bio resources production [11].

3. Differences between bio–resources and fossil resources

One of the major differences to other (in particular fossil) resources is the wide variety of bio-resources. This does not only concern the wide variety of plants and animals that man has domesticated for his purposes. It also applies to by-products and wastes from industrial and societal processes using primary bio-resources.

The intense competition for bio-resources (and hence for fertile land) applies in particular to the relative small number of primary agricultural crops and wood from forestry, leaving the oceanic fish resources mainly used for food out of consideration for a moment.

There is however another kind of bio-resources that is outside the current pattern of competition: secondary bio-resources that are by-products or wastes from agricultural, industrial or societal processes. Their use does in general not add to the direct competition for land although it may influence the fertility of land. In general their use is either in the form of a cascade (prolonging the value chain of a primary resource within society) or parallel to a valuable crop (using parts of plants that are usually not entering the markets such as straw and corn cobs) or additional (using land that is underutilised or otherwise not cultivated).

The most obvious dissimilarities between bio-resources and fossil resources are however their different logistical parameters. If bio-resources have to play a more prominent role in energy provision and industry, this means a radically changed economic and logistical structure of resource provision. Table 1 shows a comparison of humidity, transport density and energy content for some example resources.

The table lists two kinds of bio-resources, relatively dry material for which the energy content is calculated as the calorific value generated by incineration. For wet materials the energy content is defined by the energy content of biogas if these materials are subjected to an anaerobic fermentation.

Table 1: Comparison of logistic parameters for fossil and bio-resources (adapted from Gwehenberger et al. (2008) [12])

Conversion	**Material**	**Humidity [%w/w]**	**Energy content [MJ/kg][1]**	**Density [kg/m³][1]**	**Energy density [MJ/m³][1]**
Incineration	Straw (grey)	15	15	100-135	1.500–2.025
	Wheat (grains)	15	15	670-750	10.050–11.250
	Rape seed	9	24.6	700	17.220
	Wood chips	40	10.4	235	2.440
	Split logs (beech)	20	14.7	400–450	5.880–6.615
	Wood pellets	6	14.4	660	9.500
Biogas production	Grass silage	60–70	3.7	600–700	2.220–2.590
	Corn silage	65–72	4.2	770	3.230
	Organic municipal waste	70	2.4	750	1.800
	Manure	95	0.7	1000	700
	Light fuel oil	*0*	*42.7*	*840*	*36.000*
	Anthracite	*0*	*35.3*	*800-930*	*28.000–33.000*

[1] All numbers related to fresh material

Table 2: Transport distance with different means of transportation, using 1% of the energy contained in the payload

Resource	Means of transportation	Transport distance per % of energy contained in payload [km]
Manure	Tractor	5.7
Straw	Tractor	12
Corn silage	Tractor	18
Wood chips	Truck	40
Split logs	Truck	100
Wood pellets	Train	475
Corn	Train	525
Crude oil	Ocean going ship	7800

Table 1 shows that bio-resources are characterised by high humidity and/or low transport density and generally lower energy content. In many practical cases therefore transport volume will become limiting for the collection logistic of these resources. The differences between fossil resources (represented here by light heating oil) and bio-resources are poignant: there is a factor of 24 between the energy density of straw and light heating oil with regard to their energy density. The disadvantage of wet resources must be put in perspective – biogas has a much broader range of applications than heat generated by incineration.

The logistical challenge becomes even more visible if different means of transportations are factored in. According to their energy efficiency (and strongly influenced by their particular ratio of empty weight to load capacity) transport systems require different amounts of energy to transport a load a certain distance. If we set the limit of the energy used to transport a resource to its utilisation site arbitrarily to 1% of the contained energy, we obtain the results summarised in Table 2.

This table clearly points to the increased importance of regional supply in the case of bio-resources: different resource quality conditions have different energy consumption per transported material load. For low density goods like manure, straw, corn silage and wood chips a sustainable transport is still possible within a range of 50 kilometres. Following these assumptions bio-resources with higher density can be even transported across distances over 500 kilometres per % of energy contained in payload kilometre.

Whereas it is fully rational to establish a global fossil economy as transport from source to utilisation plays almost no role, the use of lower quality bio-resources must become regional and possibly even local.

4. Defining sustainable energy services for bio–resources

Any attempt to balance the utilisation of bio-resources sustainably must take the social, economic and environmental services that bio-resources may provide into account. It requires to analyse which of them can or cannot be performed by other resources or what the restrictions on other resources are to provide them in a sustainable way.

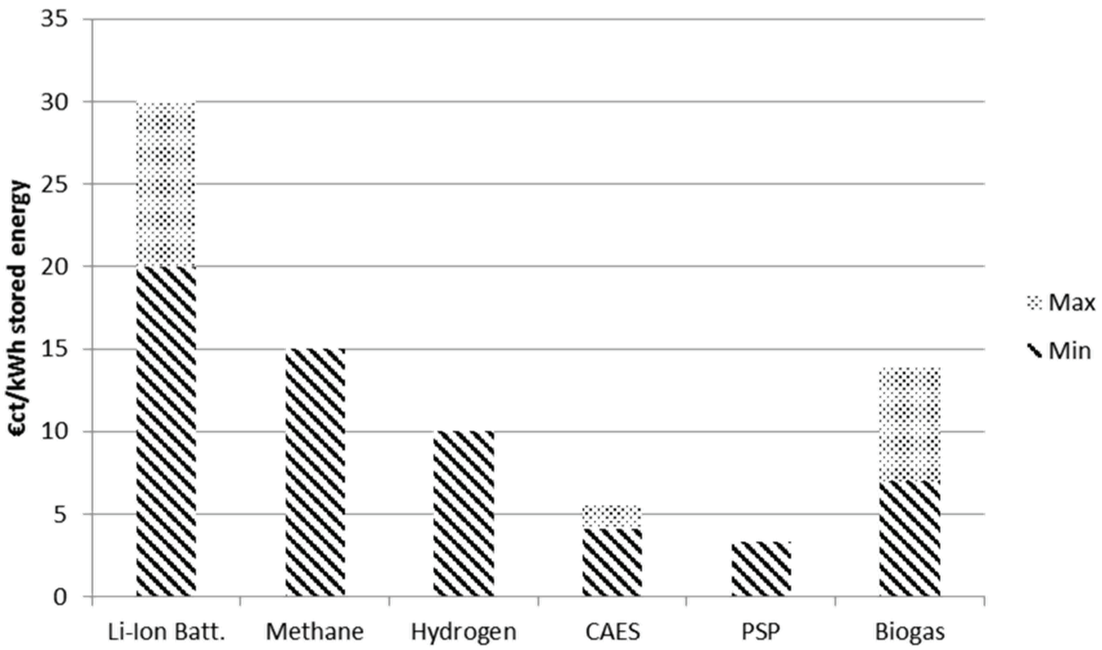
There is no doubt that the main societal service of bio-resources is to provide food for the global population. Bio-resources currently have a monopoly on this service although there have been numerous research attempts to generate food from fossil hydrocarbons (e.g. Gosh et al. (1984) [13]) via biotechnological pathways. Providing food from limited fossil resources, which are themselves highly contested, is however not an alternative.

In contrast to food, there are plenty alternatives to bio-resources to provide energy. Wind power, solar thermal energy and photovoltaic will become major suppliers of electricity and electricity will become more prominent in any sustainable energy system (see e.g. The European SET Plan Roadmap (2007b) [5]). All these technologies convert solar energy much more efficiently into electricity than technologies based on bio-resources can do. The resources for these technologies are free of any cost for material energy carriers, giving them a key economic advantage over bio-resources (as well as over fossil and other resources). This economic advantage already becomes a change factor for the electricity system in Europe: the more wind power and PV enter the electricity market, the less room there is for conventional base load technologies like nuclear and large fossil based power plants. Moreover all mentioned renewable based energy technologies are having a considerably lower ecological impact compared to fossil based as Kettl (2012) [14] shows in his life cycle analysis.

All these renewable sources however are either periodically or intermittently available. This requires other approaches that stabilise the distribution grids, in particular for electricity. Besides management of power demand (by *smart grids*) the use of energy storage or material energy carriers (both fossil and bio-based) that pick up the gap between intermittent electricity provisions will become necessary. The challenge then is however not anymore the provision of a large amount of base load electricity but to power technologies that are nimble enough to stabilise the distribution grids, that operate only when “cheap and green” wind or PV power is in short supply.

Following this argument, the cost of energy and in particular electricity storage will become crucial for a future energy system. Analysing the cost of electricity storage as Figure 1 shows bio-resources are an economically viable non-fossil way to stabilise electricity grids. They become particularly interesting when factoring in that capacity for compressed air energy storage as well as for pumped storage plants are limited and in many cases geographically distant from the generation of cheap wind power, necessitating large investment in grid infrastructure.

While bio-resources may become too valuable for providing low temperature (residential) heat or even base load electricity, they may become an option with regard to stabilising the electricity grid. Providing just electricity however would run counter to the requirement of highest possible resource efficiency that is paramount when utilising limited and contested bio-resources, even in the form of secondary and tertiary



Li-Ion Batt. – Lithium-ion Battery
Methane – Refers to methane generated by power-to-gas processes
Hydrogen – Produced by electrolysis
CAES – Compressed Air Energy Storage
PSP – Pump Storage of Power
Biogas – Produced from grass silage

Figure 1: Cost of energy storage with data from Deutsche Bank (2012) [15]

resources. As a matter of fact bio-resources can only be converted to electricity by oxidation, generating heat as a by-product. Resource efficiency requires that this heat must be utilised. It is also a fact that heat may be stored much cheaper than electricity, as low temperature heat can be stored with costs as low as 0.1 € ct/kWh [16]. This allows a de-coupling between electricity provision to stabilise the electricity grid and heat demand.

Heat may however not be transported via long distance grids. This means that heat consumer and electricity generation from bio-resources have to be within short distance. This in turn results in a basic principle for energy systems that utilise bio-resources: such systems must link at least the electricity grid and local heat use and/or heat distribution grids in order to achieve the necessary resource efficiency to be sustainable: bio-based energy technologies therefore should always be multivalent, meaning that they serve more than one energy form. The size of the installations is governed by transport limitations posed by resources and/or residues (like biogas manure) on the one hand and the quest for using all thermodynamically convertible energy on the other hand. In many cases this means that the size is limited by the heat demand that can be served by such an energy technology.

Resource efficiency of bio-energy systems can be even more augmented when they may serve an additional distribution system, namely the gas grid. Three-valent systems like biogas plants or Synthetic Natural Gas (SNG) plants may operate in continuous mode at optimum process conditions. Switching between different distribution systems allows them to stabilise grids while at the same time optimising economic revenue and using all energy contained in their resources up to thermodynamic limits.

The argument for providing bio-based transport fuel is also based on the possibility to provide material energy carriers that may easily be stored. Currently this service is overwhelmingly provided by fossil oil, with the global share of bio-fuels currently at about 3% [17]. In addition to the arguments given above, considerations of energy density, weight of the storage system and range have to be taken into account. As more and more people concentrate in cities (the WHO expects 70% of the world population living in cities by 2050 [18]) the overall pattern of transport may change considerably, with public transport, bicycles and electric vehicles providing mobility in urban regions. Dispersed settlements like in rural areas, long distance individual mobility, air traffic as well as ships will however require stored energy with high energy density, quick charge and low emissions.

There is no doubt that fossil fuel (oil as well as natural gas) will still provide a major share of this service for many decades to come. Besides that, synthetic fuel (hydrogen from electrolysis with surplus electricity as well as CO_2 converted to methane with this hydrogen) will possibly provide a share, too. Bio-fuels from secondary and tertiary resources may become a viable alternative for this service in the long run.

Still another service relevant for economic sustainability is the provision of heat. While low temperature residential heat can be provided sustainably by solar thermal units, ground heat pumps (using electricity for their operation) and off-heat from thermal electricity provision or industry (distributed via district heating grids in urban areas), the situation is however different for high temperature industrial heat. This service is currently covered by coal and natural gas, together with electricity for special applications (e.g. steel smelters). Alternatives on the base of renewable resources are however scarce. Although concentrated solar energy can reach high temperatures, this technology has considerable drawbacks. On the one hand it is only viable in places with high solar radiation and it shares periodic operation with all other direct solar technologies. On the other hand the large areas required directly at the site of energy production make this technology unwieldy for industrial applications. This opens the way for processed bio-resources like cleaned biogas and char coal that will have to contribute to the provision of high temperature industrial heat.

It is obvious that bio-resource based services in general have clear advantages on the count of greenhouse gas emissions compared with fossil based services and in particular that bio-energy has a much lower ecological footprint than either fossil or nuclear energy provision technologies [19]. Following the argument given above, bio-resources are, however, no general solution for a sustainable energy system. Kettl et al. (2011) [19] show that bio-energy systems trail other renewable energy forms (e.g. wind and hydro power) in ecological performance. This means that also from an ecological point of view the application of bio-resources should be restricted to the services that cannot be provided economically and ecologically sensibly by other renewable sources, e.g. stabilising energy distribution grids and providing transport fuel and high temperature industrial heat.

5. Developing a sustainable bio–resource utilisation system

Bio-resources are contextual resources. The generation of primary resources is dependent on a *concrete* ecosystem. Demand for resources as well as the generation of secondary resources is shaped by socio-economic context. The decision how to sustainably balance the use of bio-resources is therefore only possible if the context is taken into account. This means that rules that guide such decisions have to be context related.

5.1. Rules for sustainable regional bio–resource utilisation

Besides preserving or even improving ecological performance of land and providing nutrition, bio-resources are the fundament for creation of sustainable jobs and wealth in rural regions. These are services that may not be provided by other resources and must therefore be given priority (within the framework established by the limits posed by eco-systems and the provision of food) before fulfilling other requests to bio-resources.

There is no general rule for providing these services. The pathway towards achieving the goal of sustainable regional development is dependent on a range of contextual parameters such as the existing economic structure (e.g. the existence of conventional sectors of bio-resource utilisation), the existence of markets for particular products and services as well as education and qualification levels in the region, to name the most prominent. Sustainable development requires that the utilisation of bio-resources becomes a major factor for spatial planning which in turn must take over a strong co-ordinating role balancing resource provision and consumption in the spatial context [20].

5.2. Heuristic guidelines

The following paragraphs can be seen as heuristics guiding a regional discourse about utilising bio-resources based on the properties, technological aspects and service provision priorities presented earlier in this article. They are particularly focussed on energy aspects.

5.2.1. “Refinerize” conventional sectors

Bio-resources are the only possible basis for sectors that conventionally utilise wood and crops such as pulp & paper, timber or oils and fats industry but also the food sector. These sectors provide products that cannot easily be replaced by other goods or services and render decent profits along their value chain. Moreover such industries have established well organised logistical systems and provide jobs and income as well as skills and qualification for employees. Putting priority to serving these sectors is sensible and in the case of the food sector even obligatory.

The sectors themselves, however, have to evolve into flexible bio-refinery systems based on their main resource but accommodating other (secondary) bio-resources provided by their spatial and economic context. This strategy serves two objectives:

- Employing existing logistic systems as well as skills and technological infrastructure to realising the rule of fully utilising sustainably available bio-resources and
- Offering a broader portfolio of goods and energy services from available bio-resources thus adding to the necessary flexibility of markets, accommodating possible shifts in preferences of consumers in a sustainable bio-based economy.

This means that the function of conventional sector industrial sites in a bio-based economy will more and more resemble that of oil refineries in a fossil economy: transforming main resources into diverse products for many different markets.

5.2.2. Use intersections of distribution grids as means to fully utilise bio–resources

Technologies that treat secondary and tertiary bio-resources in a way that the major part of their material products are re-integrated into the ecosphere are “rear guard technologies” of societal utilisation of bio-resources. Such rear guard technologies like combustion and bio-gas have a narrow product portfolio: combustion provides heat, heat and power (in case of CHP) and biogas can be up-graded to bio-methane or used in a CHP to generate heat and power. All these products may be distributed via distribution grids. The optimum location for these technologies therefore is where these grids intersect [21].

5.2.3. Implement de-central bio–refineries

The necessary proximity of heat users to two- or trivalent bio-energy providers gives raise to another type of bio-refinery: de-central bio-refineries converting secondary or under-utilised bio-resources to intermediate “platform” materials, improving quality and transport properties of these bio-resources. This approach pursues three objectives:

- Technologies transforming bio-resources to platform products more often than not require large amounts of heat (for drying as well as process heat). This provides stable demand for heat as the low-end service of de-central bio-based energy systems thus utilising bio-resources fully.
- Many of these technologies separate large parts of the bio-resources that will not enter industrial life cycles (removing bark from timber, removing the press cake from silage in Green Bio-Refineries or oil presses, etc.) which may be utilised in the de-central energy systems themselves or returned to.
- These bio-refineries add considerable value to the bio-resources directly at the region of their emergence, thus providing jobs and social stability.

6. Conclusion

The arguments presented in this paper are based on the assumption that future global development will be oriented according to the concept of strong sustainability. This particular development pathway is however only one of possible ways human society may structure its future. Sustainable development in itself is not a mandatory continuation of our current economic system and requires without doubt political will and profound societal change on a global scale for its implementation.

The further human society moves towards sustainable development, however, the more important a bio-based economy will become. This calls for rational management of bio-resources as particularly valuable renewable resources. The approach offered in this paper proposes to balance the use of bio-resources taking their spatial, natural and economic context into account.

Transport matters much more for bio-resources than for fossil resources that compete with them in many industrial or energy applications. Moreover quality and quantity of bio-resources are dependent on the natural endowment in a region. This means that decisions about utilisation of bio-resources must always be taken within a concrete regional. Given the complex technological possibilities and logistical considerations this often requires the help of planning instruments like RegiOpt (2011) [22], which software is available from Fussabdrucksrechner (2014) [23]. Utilising bio-resources may not only be a chance to reduce ecological pressures but also to improve societal and economic development in many European regions.

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