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Anaerobic digestion as an option of the end-of-life phase of bio-based products in the light of the EU regulations

Abstract
A distinguishing feature of the sustainable bioeconomy is multi-product biomass processing in the form of a closed circulation of matter and energy, in addition to a life cycle assessment that includes end-of-life options of a product and restitution of the environment. This approach is in-line with the good practice principles of sustainable development. However, the market of bio-based products grows faster than its legal regulation. Gaps in the regulations pertaining to standardisation, certification and labelling mean that bio-based products and their processing technologies may not adhere to the guidelines of sustainable development ("greenwashing"). In the European Union, the only standard addressing criteria of sustainable development with respect to bio-based products is the standard CEN-TC411 EN 16751:2016. In the context of anaerobic fermentation and its products as an option of the end-of-life phase of a bio-base product, the applicable regulations are contained in the technical report CEN-TC411 TR 16957:2016, Waste Framework Directive 2008/98/EC, and several intermediate regulations concerning the utilisation of water, energy efficiency, agricultural production and processing, circulation of nitrogen in the environment, storage and disposal, and others.

Keywords: anaerobic digestion, sustainable bioeconomy, standardisation.

1. Introduction

Changes which occur in the contemporary world, including the global demographic trend towards the growth of human population, estimated to reach about a billion in the following decade, with the middle class population expected to treble, induce changes in the world's economic system and pro-environmental measures, needed for a number of unquestionable reasons. Firstly, there is a steady increase in the emission of greenhouse gases. Secondly, fossil resources of matter and energy are rapidly reaching their physical limits. Thirdly, generated waste products reach their critical amounts. A question therefore arises how to change the global economic system most sustainably while considering the above environmental threats. When raising the question of systemic changes in the world's economy, what we have in mind is not only the technical and technological improvements oriented towards new resources and more efficient production and services, but also social changes. Hence, the concurrent challenge is to transform today's society of mass consumption, uncontrolled generation of waste and excessive use of non-renewable natural resources into a society making a rational use of resources, implementing new models of production and consumption,

minimising amounts of generated waste and maximising its re-cycling and re-using. This transformation requires that the current model of so-called linear economy be changed into circular economy. Another element of this transformation would require stepping outside the framework of technical and technological innovations by including social and institutional changes.

The attainment of sustainable socio-economic development will depend on products generated from biomass[1], that is bio-based products[2] (food, animal feed, bioenergy, biomaterials, biochemicals). Hence, the key word today, driving changes in the socio-economic sphere of the European Union, is bioeconomy, which is a natural response to the contemporary environmental challenges, arising from climate change, limited natural resources and environmental pollution. It is assumed that the growth in bioeconomy will weaken the dependence of economy on natural resources, biomass processing sectors will be transformed and the acquisition of renewable resources and their conversion to bio-based products will gain the dimension of sustainability. Another assumption is that these changes will translate into new jobs and new sectors on the market of bio-based products. Consequently, the growth of the market of bio-based products will integrate three major determinants of the sustainable socio-economic development: (i) decoupling of the economic growth and the consumption of natural resources as well as its impact on the environment, (ii) ensuring wealth for all people, and (iii) securing constant supply of eco-system services. While these issues raise no doubt regarding the social perception, the relevant political decisions are less obvious and need to be based on reliable indicators/standards worded in legal regulations. In general, the principles of sustainable development on a global scale are well-defined today. Let me characterise four such guidelines which may determine political actions:

1. Compiled relationship between social development indicator (Human Development Index, HDI) and a measure of the ecological assets that a population requires to produce the natural resources it consumes (Ecological Footprint, EF).
2. Safe operational space for mankind (so-called planetary boundaries) as an initial condition for sustainable development.
3. Circular economy (in a closed loop).
4. Global aims of sustainable development (Sustainable Development Goals, SDG).

The starting measures applied to sustainable development are the Human Development Index (HDI), which assumes values about 0.7 and Ecological Footprint (EF) which should be below 1.7 gha. Across the world, depending on a country, the HDI ranges between 0.35 and 0.95 (in Poland the HDI is 0.85), while the EF is within the range of 0.49 and 15.82 (the Polish EF is 4.44 gha).

Planetary boundaries as a scientific concept were developed by an international team of researchers (Rockström, et al. 2009; Steffen et al. 2015) and they represent

[1] Material of biological origin, except the material embedded in geological formations and/or fossilised, e.g. whole plants or parts of plants, trees, algae, marine organisms, microorganisms, animals, etc. (CEN/TC 411 2014).

[2] A bio-based product is raw material, semi-raw material or final product produced partly or completely from biomass by means of physical, chemical or biological processing. (EN 16575:2014, European Committee for Standardisation, Technical Committee 411 (CEN TC/411): Bio-based products — Vocabulary, Mandate M/492, August 2014.)

boundaries for systemic processes on the Earth, perceived as a preliminary condition in an assessment of sustainable growth. Safe boundaries for nine processes have been determined, within which humanity can continue to develop. The nine areas for which the boundaries were set include: climate change, ocean acidification, stratospheric ozone depletion, nitrogen and phosphorus biogeochemical flow, freshwater use, deforestation and other land-use changes, biosphere diversity, atmospheric aerosol loading and chemical pollution. For each of the above processes, certain critical threshold levels for the survival of human race have been established.

Circular economy has now become an obvious concept, promulgated in the Ellen MacArthur Foundation report (2012). It was the first document implicating a possibility of building business models in compliance with the sustainable development principles. The report described a self-regenerating model in which the use of resources and generated environmental loads are minimised by the slowing down, closing or narrowing the circulation of matter and energy. In the context of circular economy, the key measures are the ones implemented at the end of a life cycle of products, that is reuse, revamping or recycling.

A sustainable product, i.e. a product made in agreement with the sustainable development principles, is now an outcome of the strategy developed by a number of companies. Numerous domestic and international companies build their strategies on the basis of 17 global sustainable development goals proclaimed by the United Nations (UN, 2015).

When designing the sustainable development of bio-based products, it is significant to minimise unfavourable environmental effects in the whole chain of values, including the supply of the production processes with renewable energy sources. The process of anaerobic fermentation, being one of the possible solutions for using biomass or recycle waste, can lead to the final energy product, such as electric/thermal power or transportation fuel, or it can be a potential option for the end-of-life phase of a bio-based product. Either way, we obtain a bio-based product (biogas/methane), which in a process of multi-product biorefinery processing can become either an additional market product or a fuel powering the plant's own processes. A by-product of the anaerobic fermentation process is digestate, which is still an unrecognized fully source of raw materials for new bio-based products.

Technologies of using biomass for energy purposes, including production of biogas, are relatively well known and widespread. The EU RED Directive and legal regulations arising from this directive are normalised. However, in the developmental approach to the sphere of bioenergy, it is justified to minimise the use of original sources of biomass and to redirect bio-based technologies towards utilisation of waste products, including ones which appear in the end-of-life phase of bio-based products or noxious waste. The dynamic growth of new bio-based products and problems posed by the necessity to employ "new" types of waste for energy generation require solutions which would take into account harmonisation of legal regulation and development of universal standardisation procedures that would cover the whole supply chain and waste recycling. This in turn requires analyses of biogas technologies not only in terms of their engineering side (technical and technological aspects) but also from the point of

view of the environment, economic and social issues; so, to be able to elaborate unified standardisation guidelines and to develop framework programmes for certification procedures and eco-labelling in the whole life cycle of a bio-based product.

Recapitulating, it should be noted that the bioeconomy is growing faster than its standardisation. Gaps in regulations concerning the standardisation, certification and labelling of bio-based products mean that such products and their manufacturing processes may fail to satisfy the objectives of sustainable development ("greenwashing"). Therefore, the aim of this study has been to analyse the European Union regulations regarding the sustainable development of the bio-based market in the context of using anaerobic fermentation processes.

2. Legal regulations governing the sustainability of bio-based products

Bio-based products are fundamental to bioeconomy. With respect to sustainability, it is assumed that all stages of the life cycle of bio-based products will be linked, starting from the extraction of nutrients[3] from the soil, which are essential for photosynthesis, until their return to the environment at the end of a product's life. Based on this assumption, it is an economic process with a closed loop of circulation, which necessitates efficient use of natural resources and waste management that enables constant renewal of the environment.

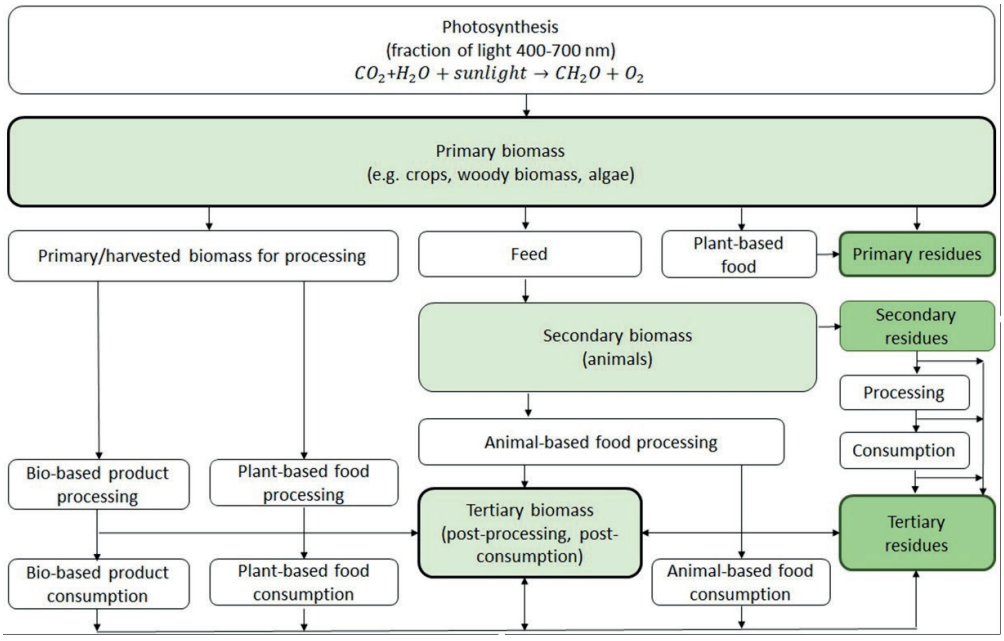

Fig. 1. A diagram illustrating division of biomass and post-production and post-consumption residues relative to the initial photosynthesis process

[3] So-called nutrients include macronutrients absorbed by plants in large quantities, e.g. N, P, K, Ca, Mg, and micronutrients, taken up by plants in relatively small amounts, e.g. Fe, Mn, Zn, Cu, B, Mo.

The market raw material for bio-based products is biomass, which — depending on the initial photosynthetic process — can be divided into primary biomass, i.e. produced in the process of photosynthesis (by photosynthesising organisms), secondary — conversion of primary biomass to animal products, and tertiary post-production and post-consumption biomass. Analogously, residues generated during the production/processing of biomass as well as bio-based post-consumption waste can be divided into primary, secondary and tertiary one (Fig. 1). Primary and secondary biomass itself can be a market product (e.g. firewood, fruit, milk), or else it can be raw material for further processing (e.g. cereal grain, seeds of oil plants). The notion of post-production or post-consumption residue does not exist in regulations pertaining to bio-based products. Hence, legally speaking any bio-residue is waste and is regulated by the law connected with the handling of waste.

At present, there are no legal regulations addressing the question of bio-based products that would include the three pillars of sustainability, i.e. environmental, economic and social issues, in addition to the question of circular economy. However, the process of developing law with respect to the sustainability of bio-based products is in progress, and among the international standardisation organisations which develop sustainability standards for bio-based products the following should be mentioned: the International Organization for Standardisation (ISO), European Committee for Standardisation (CEN) and American ASTM International (ASTM). Noteworthy are some other organisations, such as national normalisation institutions, which in respect of the EU, manage the TC411 secretariat (the Netherlands Standardization Institute, NEN), issue opinions for standards developed by the CEN and elaborate regulations for own markets of bio-based products (e.g. the German DIN, the Dutch NEN, the Swedish SIS, the French AFNOR, or the Polish PKN).

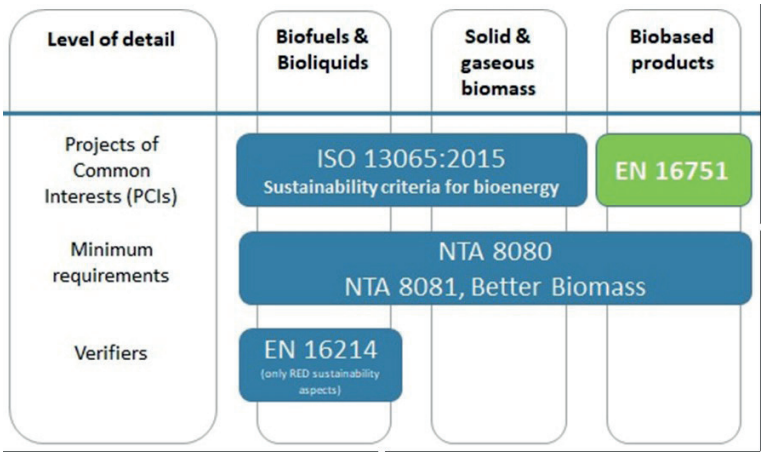

Fig. 2. Initial regulations connected with the sustainable development of bio-based products

It is justified to claim that the spheres of food, biofuels and bioenergy are well regulated. But the legislation regulates only products in which the content of a bio-component equals 100% and only certain aspects of raw material for production and

the quality of market products. The specification of basic regulations related to the sustainable development of bio-based products (excluding food) is shown in Figure 2. The compiled data show that with respect to biofuels and biocomponents as well as solid and gas energy products produced from biomass the ISO 13065:2015 standard regulates their markets in terms of sustainability criteria, while the Dutch standard NTA 8080:2015 as well as the certification system NTA 8081, based on the mentioned standard, as well as the certification system Better Biomass pertains to the sustainability of biomass used for both energy purposes and manufacture of bio-based products; finally, a group of European standards designated as EN 16214:2012 determines the criteria of sustainability in the field of production of biofuels and biocomponents. The only standard which today addresses the criteria of sustainable development applied to all bio-based products having a bio-component, but excluding food, feeds and bioenergy, is the EU standard EN 16751:2016. This is a horizontal standard, i.e. one which defines a general framework for the management of questions of sustainable development within the profile of the whole chain of supplies, but does not provide the ground for stating whether a specific product or process is sustainable, although the standard can be used in communication between companies (B2B) or serve as the foundation for developing specific standards for bio-based products or certification systems.

2.1. Standard EN 16751:2016

Standard EN 16751:2016 is one of the documents developed by the Technical Committee (TC) CEN-TC411 based on the mandates issued by the European Commission in 2008 and 2011: EC Mandates M/429 (2008), M/491 & M/492 (2011). There are five working groups (WG) operating within the Technical Committee, which develop complementary regulations:

- WG1: Terminology:
  - » EN 16575:2014 Bio-based products — Vocabulary.
- WG2: Bio-solvents:
  - » CEN/TS 16766: 2015 Bio-based solvents — Requirements and test methods.
- WG3: Bio-based content:
  - » CEN/TC 16721:2014 Bio-based products — Overview of methods to determine the bio-based content.
  - » EN 16640:2017 Bio-based products — Bio-based carbon content — Determination of the bio-based carbon content using the radiocarbon method.
  - » EN 16640:2017/AC:2017 Bio-based products — Bio-based carbon content — Determination of the bio-based carbon content using the radiocarbon method.
  - » EN 16785-1:2015 Bio-based products — Bio-based content — Part 1: Determination of the bio-based content using the radiocarbon analysis and elemental analysis.
- WG4: Sustainability criteria, life cycle analysis and related issue:
  - » Technical Report: CEN/TR 16957:2016 Bio-based products — Guidelines for Life Cycle Inventory (LCI) for the End-of-life phase.
  - » Standards: EN 16751:2016 Bio-based products — Sustainability criteria; EN 16760:2015 Bio-based products — Life Cycle Assessment.
- WG5: Certification and declaration tools:

» EN 16848:2016 Bio-based products — Requirements for Business to Business communication of characteristics using a Data Sheet.
» EN 16935:2017 Bio-based products — Requirements for Business-to-Consumer communication and claims.

The standards developed to date pertain to the questions of sustainability of bio-based products based on Life Cycle Assessment (LCA). Majer et al. (2018) have reviewed the current regulations concerning the sustainable development of bio-based products and demonstrated that apart from certain flaws in these regulations regarding the form and structure of standards, such as the adopted sustainability criteria, the set of indicators, harmonization and operationalisation of regulations as well as questions related to risk management: e.g. an indirect land use change (iLUC), carbon leakage, food security risk, caused by specific political decisions (e.g. leakage effects), there are gaps in the regulations connected with the origin of biomass, new inter-sector products (e.g. containing only a small percentage of a bio-component) and end-of-life questions. The authors conclude that in practice the above gaps in the law may lead to differences in the quality of bio-based products and differences in the costs of existing certification systems, which might result in various influences on the social approval of political decisions associated with the sustainable development of bio-based products and bioeconomy. For example, if a given product contains only a few per cent of a bio-component, and the inputs into its production engage the use of non-renewable resources, then legally speaking this product can be named as a bio-based product, although an LCA analysis will demonstrate that the carbon footprint connected with CO_2 emissions is just as large as induced by making an analogous product not having any bio-based content.

Gołaszewski (2017) and Olba-Zięty et al. (2018) maintain that the technical and economic analysis related to product development (known as the Techno-Economic Analysis, TEA), which nowadays is the basis for a life-cycle inventory (LCI) and an analysis of environmental impacts (LCA), is insufficient for making an assessment of the sustainability of a bio-based product. Complementary estimation of the Life Cycle Costs (LCC) and social impacts (Social LCA, S-LCA) is in order.

3. Anaerobic fermentation process in the life cycle of a bio-based product

In terms of the sustainable development of bio-based products and the circular character of bioeconomy, the key issue with respect to the supply chain and environmental restitution is the end-of-life phase of a bio-based product. This is a shared point between the regulations being developed by the TC411 and the Waste Framework Directive 2008/98/WE. The end-of-life options in the Directive 2008/98/WE are based on life cycle assessment and estimates of environmental impacts, although they do not distinguish between bio-based and other products. Hence, the technical report CEN-TC411 CEN/TR 16957:2016 contains a compilation and gradation of selected end-of-life options which can apply to bio-based products (Fig. 2). It needs to be noticed that the report does not deal with details concerning the collection of waste, its transport and sorting because these are comprised in the regulations connected with the LCA. Instead, the report focuses on the characterisation of waste from a bio-based product and inclusion

of the end-of-life option of a product to the process of making an inventory of significant inputs and outputs in the system of a product, i.e. the Life Cycle Inventory (LCI). A set of potential end-of-life options takes into account possible reuse, mechanical and biological recycling, recovery of valuable chemical substances, incineration, including an alternative with energy recovery, storage, including biogas production, wastewater treatment under aerobic or anaerobic conditions as well as discharge of the waste to the environment in its natural form.

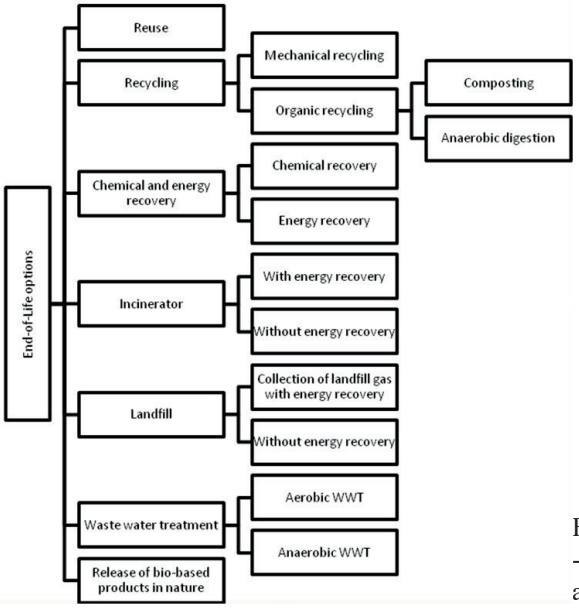

Fig. 3. Options of end-of-life of a bio-based product (developed by the author, according to SIS-CEN/TR 16957:2017)

Each option for the end-of-life phase of a bio-based product generates different impacts on the environment. Two options, that is mechanical or biological recycling and chemical recovery, can lead to the production of secondary material which can be used to make another product. This type of a cascade of products from the same raw material enhances the effect of sustainability by saving on the consumption of primary biomass and other resources (nutrients), which results in the reduction of carbon footprint.

Table 1. The EU regulations related to anaerobic digestion

Directive/Commission decision	Regulations versus anaerobic fermentation
2009/28/EC: Promotion and production of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC	It establishes aims to get 20% of energy from renewable sources by 2020. Legislative framework includes: national targets and measures, national renewable energy action plans, cooperation between Member States, guarantee of origin, access to and operation of the grids
2008/98/EC: Waste Framework Directive	Requirement for waste manager to obtain a permit for recovery and valorisation of wastes (the amount and type of waste treated, the method used, activities for monitoring and control process)

(Waste-associated) Commission Regulations	
2000/532/EC	List of wastes
1069/2009	Rules for animal by-products and derived products not intended for human consumption
1774/2002	Animal by-product regulation
142/2011	Implementing Regulation No. 1069/2009
92/2005	Implementing Regulation No. 1774/2002 plus Annex VI associated with biogas transformation and processing rendered fats
185/2007	Amending regulation No. 809/2003 as regards extension of the validity of the transitional measures for composting and biogas plants under Regulation No. 1774/2002
208/2006	Amending Annexes VI and VIII to Regulation No. 1774/2002 as regards processing standards for biogas and composting plants and requirements for manure
1999/31/EC: Landfill	Biogas production as an alternative to control the pollution
2008/1/EC: Integrated pollution prevention and control	Obligations with which industrial and agricultural activities must comply
2009/73/EC: Common rules for the internal market in natural gas	For creating a competitive, secure and environmentally sustainable market in natural gas
2012/27/EC: Energy efficiency	To achieve the EU 20% target on energy efficiency by 2020
2000/60/EC: Water policy	Key instruments to protect waters against agricultural pressures related with nitrates

Source: the author, on the basis of BIOGAS[3] Consortium 2016.

The anaerobic process in a biogas plant as an option for the end-of-life phase of a bio-based product, like the process of aerobic composting, can be classified as organic recycling. The process of anaerobic fermentation in biogas production meets the criteria of sustainability by producing a sustainable renewable energy carrier, recycling of waste (digestate) and recovery of nutrients. The legislative framework for using energy from renewable resources, including biogas use, consists of the EU Directive 2009/28/EC, and some other regulations pertaining to biogas plants that are derivative laws connected with waste management (Waste Frame Directive 2008/98/EC), waste storage (1999/31/EC), integrated prevention and monitoring of pollutants (2008/1/EC), regulations of the natural gas market (Directive 2009/73/EC), energy efficiency (2012/27/EC) and water policy (2000/60/EC).

For the handling of digestate mass from biogas plants and the circulation of nutrients, Waste Framework Directive 2008/98/EC and Landfill Directive 1999/31/EC are significant. Whereas the definition of biowaste in the former directive does not take into account agricultural residue products (straw, manure, etc.), the latter one employs the notion of biodegradable waste, that is any type of waste which undergoes aerobic or anaerobic decomposition, and this definition includes industrial bio-based products, such as paper or textiles. Anaerobic methane fermentation is the process of biological decomposition of biodegradable waste leading to biogas and digestate. Waste Framework Directive 2008/98/EC sets out end-of-waste (EoW) criteria, i.e. when waste ceases to be waste and gains the status of a secondary product or raw material (Table 2).

Table 2. The principle, framework conditions and elements of EoW criteria

EoW principle	The framework conditions	Set of specific criteria for each stream
The waste ceases to be waste when a useful and safe product is placed on the market	• Commonly used • A market or demand exists • Meets technical requirements, legislation and standards • No overall adverse environmental or human health impacts	Product quality: • input materials • quality control procedures • provision of information • processes and techniques

Source: *End-of-waste criteria for biodegradable waste subjected to biological treatment (compost & digestate): Technical proposals*, H. Saveyn, E. Eder, 2014, Luxembourg: Publications Office of the European Union, DOI: 10.2791/6295.

Digestate is a waste material derived from the anaerobic digestion process. It is therefore subject to the regulations of Waste Framework Directive 2008/98/EC. In terms of potential end-of-life options, theoretically all options mentioned previously may apply. The simplest solution is to apply liquid digestate directly to soils under own land, provided that the feedstock supplied to a given biogas plant installation consists of plant residue, animal faeces or waste from agricultural and food processing industry, and the application of digestate complies with the regulations governing plant fertilisation, including the Nitrates Directive 91/676/EEC:1991, which limits the maximum dose of nitrogen to 170 kg N/ha of farmland. Any other situation of using digestate for making marketable product in the form of liquid or solid fertiliser, soil amendment, compost or biochar, requires the producer to satisfy specific certification procedures applicable to the end-of-life phase of products. Outside the EU regulations, to some extent, each member country implements own modifications.

4. Summary

A distinguishing feature of the sustainable bioeconomy development is the multi-product biomass processing approach in the form of a closed flow of matter and energy, in addition to a life cycle assessment which includes end-of-life options of a product and restitution of the environment. This approach complies with the good practice principles in the field of sustainable development. However, the bioeconomy sectors grows faster than its legal regulation. Gaps in the regulations pertaining to standardisation, certification and labelling mean that bio-based products and their processing technologies may not fulfil the guidelines of sustainable development. This may lead to so-called greenwashing, which in fact means cheating the consumer by claiming that a given bio-based product satisfies the criteria of sustainability. Currently, the chief regulations regarding anaerobic fermentation as an option of the end-of-life phase of a bio-based product are contained in the technical report CEN-TC411 CEN/TR 16957:2016 implementing the regulations arising from the Waste Framework Directive 2008/98/EC. Besides, many provisions can be found in regulations connected with relevant EU directives, governing such questions as waste landfill, water, promotion of renewable energy resources, energy efficiency, animal production, the flow of nitrogen in the environment, and other.

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- CEN/TC 16721:2014 Bio-based products — Overview of methods to determine the bio-based content;
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- *EN 16785-1:2015 Bio-based products — Bio-based content — Part 1: Determination of the bio-based content using the radiocarbon analysis and elemental analysis*;
- *Technical Report: CEN/TR 16957:2016 Bio-based products — Guidelines for Life Cycle Inventory (LCI) for the End-of-life phase*;
- *Standards: EN 16751:2016 Bio-based products- Sustainability criteria; EN 16760:2015 Bio-based products — Life Cycle Assessment*;
- *EN 16848:2016 Bio-based products — Requirements for Business to Business communication of characteristics using a Data Sheet*;
- *EN 16935:2017 Bio-based products — Requirements for Business-to-Consumer communication and claims*;
- *2008/98/EC: Waste Framework Directive*;
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- *1999/31/EC: Landfill of waste*;
- *2008/1/EC: Integrated pollution prevention and control*;
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