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Review

A review of biomass potential and current utilisation – Status quo for 93 biogenic wastes and residues in Germany

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ABSTRACT

The efficient use of biogenic by-products, residues and waste offers an extensive range of advantages. As well as fulfilling requirements of public services, intelligent "cascading" can tap alternative sources of carbon and play a key part in a system using renewable sources of energy. However, a comprehensive overview of existing resources and their current use is required as a sufficient basis for decision-making. Accordingly, this article studies the development and application of a four-stage categorisation of relevant biomasses and a consistent comparison of existing findings in form of a literature review. Taking the case example of Germany, 30 studies were evaluated with regard to their information on the theoretical and technical potential of biomass and its current use as a material and source of energy. The compiled results offer a detailed, consistent overview of the status quo in Germany for a total of 93 individual biomass types. The findings show a technical biomass potential between 92.7 and 122.1 million Mg (DM) that means up to 1,500 kg per capita. A share of 62.7–71.2 million Mg (DM) is already in established use. 26.9–46.9 million Mg (DM) are still unused. Currently, however, there is no guaranteed, unified reference year for cross-sectoral reporting on the potential and use of biomass. Also, the handling of sustainability criteria is regulated insufficiently. Thus, long-term monitoring is required to manage the efficient, sustainable use of resources in a future-proof manner. Looking forward, up to 7% of Germany's current primary energy consumption, and at least 13% of the target consumption, could be met using residual matter and waste.

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1. Introduction

Biogenic residual matter and waste accumulate in many fields of business and society. The spectrum extends from agriculture and forestry to industrial manufacturing and municipal waste. Bioeconomy opens up some interesting options to elevate the efficiency of already established utilisations and for the use of material that hitherto has been regarded as waste. These include, for example, the production of basic chemicals [1,2] and the generation of sustainable energy with the potential to save large amounts of greenhouse gases [3]. The far-reaching use of residual matter and waste to support a circular economy is receiving increasing levels of international funding [4–8] and support [9,10].

In this context, a biomass potential is defined as a resource which is generally being tapped and sometimes unused [11,12]. There is, however, no comprehensive quantitative estimate of the potential of biomass as a raw material and a source of energy. Reviews such as those by Searle & Malins [13], Bentsen & Felby [14], Batidzirai et al. [15], Smeets et al. [16], Stecher et al. [17] and Berndes et al. [18] show that results cover a wide range both nationally and internationally. There are currently no quality specifications or minimum requirements for calculating biomass potential [11,14,15,19,20]. Numerous authors [11,13–15,19,21] have suggested that methods should be harmonised, but these recommendations have yet to be applied consistently. Two of the most important factors affecting biomass potential are land availability (e.g. potential energy crops) and population distribution (residual materials). These are closely related to production- and process-related contexts [22]. To estimate potential, various assumptions have to be made which strongly affect the results. Kaltschmitt et al. [12] distinguish between theoretical, technical, economic and realisable potential. Thrän & Pfeiffer [11] also describe a sustainable potential. The restrictions involved in each case affect the degree of biomass potential in different ways. Among others, Hennig et al. [4], Thrän & Pfeiffer [11], Stecher et al. [17], Brosowski & Majer [20], Offermann et al. [22], Brosowski & Adler [23] and Vis et al. [19] point to the large number of basic parameters in studies on biomass potential. The lack of standards leads to uncertainties caused by differing definitions and interpretations of the contexts taken into consideration. This includes, for example, biomasses being allocated to higher-order groups. Table 1 shows an example of the range of different definitions and categorisations.

Table 1
Example descriptions of biomass.

Reference	Biomass categorisation for residues
Berndes et al. [18]	Primary residues (agricultural crop harvest residues, forest residues), secondary residues (food processing residues, wood and other processing residues, animal dung), tertiary residues (e.g. non-food organic wastes) and others
Smeets et al. [16]	Harvest residues, process residues, waste
Haberl et al. [24]	Residues on cropland
Yamamoto et al. [25]	Woody biomass residues, food biomass residues
Fischer and Schrattenholzer [26]	Crop residues, wood from forests, forest residues, animal waste, municipal waste
Thrän et al. [27]	Residual materials (straw, logging residues, excrement from livestock, municipal waste, production specific residuals)

It is not clear what individual forms of biomass are actually meant by, for example, “residues on cropland”, “woody biomass residues”, “excrements from livestock” or “animal waste”. As well as such heterogeneous descriptions, different source data (e.g. statistics, geodata, expert opinions), temporal references (e.g. present, future), spatial references (e.g. rural district, federal state, nation, continent) and physical units (e.g. Mg (FM), Mg (DM), GWh, PJ etc.) lead to considerable structural differences in the way that findings are presented [20]. Ultimately, the combination of all these parameters means that findings on biomass potential from different studies cannot be compared [4,17,20]. This situation is not satisfactory.

Biogenic by-products, residual matter and waste occur at different points along the production and processing chains. Until now, most higher-level summaries of different forms of biomass have been made in a legal context. The European Waste Catalogue, for example, defines individual types of waste using a six-figure number [29]. These waste types are collected, recycled or disposed of as public services [30]. However, bioeconomic use includes other resources which do not have to be collected. As yet, there is no binding regulation requiring these biomasses to be categorised on a large scale. In view of the highly uncertain data, on one hand, and the increasing importance of biogenic residual matter and waste for the transition to renewable energy, on the other, it is becoming increasingly important to be able to describe the availability and use of these material flows in a comprehensive, transparent and reproducible manner.

In Europe, Germany plays a key role in the use of biomass as an energy source. In 2015, 8.0% of total primary energy consumption (TPEC) in Germany was covered by bioenergy [31], making the absolute sum higher than in any other European country [32]. For this reason, the aim was to compile a large-scale review of the occurrence and use of biogenic residual matter and waste for the case example of Germany. This requires data to be classified and structured for the wide range of material fractions and a comprehensive point-in-time analysis to be carried out for the different types of biomass, which also need to be merged in a summary.

2. Methods and materials

The methodical approach contains three parts. The first part (Chapter 2.1) describes the development of a scheme for biomass categorisation. The second part is focused on characteristics for a consistent database (Chapter 2.2) and the third part outlines the proceeding for data collection (Chapter 2.3).

2.1. Biomass residue categorisation

It was necessary to describe the different biomasses with sufficient precision based on their origin. The aim was to bring together these different types of biomass transparently to form an extensive overall picture of existing resources. In the authors' opinion, this requires a schematic with at least four levels (Table 2).

The first level describes the individual biomasses. As well as the name, they can also be identified accurately using a free-text definition. For their further categorisation, two aggregation levels (Levels 2 and 3) allow individual biomasses to be integrated into groups based on content. At Level 4 they are categorised in higher-order groups by origin. The following groups were established for this purpose:

- Agricultural by-products
- Residues of forestry and wood industries
- Municipal waste
- Industrial residues
- Residues from other areas

2.2. Specifying demands for a consistent data base

The data availability differs depending on where each biomass comes from. In order to keep the data on potential comparable, the review took into account a total of three characteristics for each biomass, comparing the type and range of biomass potential (Chapter 2.2.1), the current biomass use (Chapter 2.2.2) and the time referred to in the sources (Chapter 2.2.3). The following paragraphs describe how the selected characteristics for comparison were dealt with.

2.2.1. Type and range of biomass potentials

The review is focused on the theoretical and technical biomass potential. According to Thrän & Pfeiffer [11] and Batidzirai et al. [15] the theoretical biomass potential quantifies the maximum productivity of biomass under optimal management. The technical biomass potential includes biomass-specific restrictions which could limit its use as a raw material or source of energy. These include, for example, technical limits on biomass collection or conversion as well as competing uses and legal regulations. In the case of some types of waste and residual materials, the theoretical and technical biomass potential can be considered as identical if the potential is directly linked to the production process for the primary product (e.g. molasses in sugar production).

As highlighted in the introduction, the absence of binding methodical standards in the field of biomass potentials makes it challenging to compare relevant findings. For instance, it is not clear which restrictions exactly define a technical potential. Also, the handling of sustainability criteria is regulated insufficiently. Batidzirai et al. [15] describe an ecologically sustainable potential as part of a technical potential. Weiser et al. [3] present a sustainable potential. However, it remains open which and how many sustainability criteria have to be taken into account. In literature the definitions and its combinations are not consistent [15].

In order to compile a status quo for theoretical and technical biomass potentials, the review was focused on a data collection. The first step was to examine the studies considered to find information about the theoretical potential for each biomass. Next, the information provided on the technical biomass potential was collected. In some cases the presentation of findings covers a wide range because of differences in the calculation or estimation of the biomass potentials. For this reason, the minimum and maximum values were recorded. For the further quantitative analysis of the findings both values were processed. To compare the findings consistently, "metric tons of dry matter" [Mg (DM)] was selected as a reference unit in the review.

2.2.2. Current utilisation

Another part of the review involved recording the current utilisation of each biomass and comparing it with the technical biomass potential (Chapter 2.2.1). When the studies investigated contained relevant information, overall utilisation was divided into use as a raw material and use as a fuel. The difference between the technical biomass potential and actual use produces the unused biomass potential. The information collected was also recorded as Mg (DM).

2.2.3. Time reference

One important quality factor is that the resource information is up to date. In this context, however, the year in which a study was published does not offer any information about the recency of the source data used. For this reason, both pieces of information were recorded for evaluation in this review. To do so, the literature and data sources in the studies investigated were checked and the year of the source data determined.

2.3. Data collection

In all, 30 studies were evaluated for the case example of Germany. The references used are listed in Table 3 according to the origin of the biomass (Chapter 2.1).

The biomass-specific findings were combined in a data table that can be found in Appendix A–D. Appendix A contains the Level 4 categorisation of all 93 biomasses. Remarks on consideration and data for the theoretical and technical potential are part of Appendix B. Appendix C includes data of current utilisation. Appendix D contains the unused potential, time reference and biomass specific references for information on potentials and utilisation. To make the findings clearer, the merged biomass-specific individual results were summarised in Level 4 categories and also summed up across all the categories.

Table 2
Scheme for categorisation.

Level	Description	Remarks	Example
1.	Name	Description of each biomass	Molasses
	Definition	Free description of each biomass to identify it uniquely	Molasses, by-product of sugar production
2.	Aggregation level I	Multi-level summary of each biomass by content. Not	Beet sugar production
3.	Aggregation level II	relevant for every type of biomass	Residues from food industry
4.	Aggregation level III	Higher-order area of origin, by content	Industrial residues

Table 3
Overview of considered references for potentials and utilisation.

Biomass level 4 category	References for potentials	References for utilisation
Agricultural by-products	[3]; [27]; [33]; [34]; [35]; [36]	[37]; [38]
Residues of forestry and wood industries	[35]; [39]; [40]; [41]; [42]; [43]; [44]	[41]; [42]; [43]; [44]
Municipal waste	[23]; [35]; [45]; [46]; [47]; [48]; [49]	[47]; [48]; [50]
Industrial residues	[51]; [52]	[53]
Residues from other areas	[35]; [40]; [46]; [54]; [55]; [56]; [57]; [58]; [59]	[41]

3. Results

3.1. Biomass categorisation

For the review, a total of 93 biomasses were identified and included in the data collection. The biomasses studied are listed in Table 4.

The Level 4 schematic was used to structure and summarise the biomasses (Table 5). The 93 individual biomasses (Level 1) were sorted into 67 biomasses/categories at the first stage of aggregation (Level 2). At the second stage of aggregation (Level 3), 24 labels were established. At the third and last stage of aggregation (Level 4), the five categories of origin were determined. The full set of biomass categories (Levels 1 to 4) are found in Appendix A.

3.2. Consistent database

Using the three comparators (Chapter 2.2), relevant findings were consistently combined for a total of 77 out of 93 individual biomasses. For these biomasses information on theoretical biomass potential is available, while for 70 biomasses also data on the technical potential were found. 49 data records contain information on current utilisation. Details in the literature are available for 23 biomasses while 26 data records are based on assumptions. Relating biomasses (industrial residues and biogenic fraction of household waste) are subject to German disposal and recycling requirements [30]. Althougt no information on current utilisation was found in the literature and statistics, it must be assumed that 100% are in use.

With regard to the time reference, information for all consistent data records is available. Table 6 summarises the explanations and the appendix contains corresponding information on each individual biomass.

Table 5
Number of categorised biomasses in the 4-level schematic.

Level 1	Level 2	Level 3	Level 4	
18	11	3	1	Agricultural by-products
8	7	3	1	Residues of forestry and wood industries
17	13	3	1	Municipal waste
21	18	5	1	Industrial waste
29	18	10	1	Residues from other areas
∑93	∑67	∑24	∑5	

Merging the 77 consistent datasets leads to the results shown in Table 7. For the case example of Germany, a theoretical biomass residual material potential of 151.0–152.7 million Mg (DM) was summarised based on this data. Due to restrictions, 30.6 to 58.3 million Mg (DM) of the theoretical potential cannot be used. This is mainly residual matter from the wood industry and forestry, or agricultural by-products. One key driving force behind this is maintaining soil function. The data situation is unclear for at least another 9.8 million Mg (DM), which includes biomasses such as used cooking oils, wooden landscape management materials and sewage sludge.

The identifiable technical biomass potential is thus between 92.7 and 122.1 million Mg (DM) in all. It stands for up to 1500 kg per capita. The vast majority (68–75%) of this potential comes from residual matter from the wood industry and forestry and from agricultural by-products. 11–15% is from industrial residual matter, almost 10–12% from municipal waste and a good 5–6% from

Table 4
Overview of biomasses studied by 4-level categorisation.

Level 4 category	Level 1 category
Agricultural by-products (n = 18)	1: Winter catch crop; 2: Summer catch crop (spring grain); 3: Residues from vegetable gardening, esp. field vegetable residues; 4: Beet leaves; 5: Cereal straw (wheat, rye, barley, oats, triticale); 6: Rape straw; 7: Grain corn straw; 8: Sunflower straw; 9: Grain legumes straw; 10: Cattle slurry; 11: Pig slurry; 12: Chicken slurry; 13: Cattle manure; 14: Pig manure; 15: Chicken manure; 16: Horse manure; 17: Sheep and goat manure; 18: Poultry manure (others)
Residues of forestry and wood industries (n = 8)	19: Logging residues (coniferous); 20: Logging residues (deciduous); 21: Bark; 22: Sawmill By-products (sawdust, wood chips, slabs and splinters); 23: Wood shavings; 24: Black liquor; 25: Other industrial waste wood; 26: Waste wood,
Municipal waste (n = 17)	27: Biowaste; 28: Biogenic fraction of household waste; 29: Green waste; 30: Waste fabrics; 31: Mixed packaging/recyclable and reusable material; 32: Biodegradable waste from kitchens and canteens; 33: Waste from weekly markets; 34:, Commercial food waste (not waste management); 35: Used cooking oil from municipal waste; 36: Oils from separators in waste and water treatment; 37: Faecal sludge; 38: Waste from sewage cleaning; 39: Sewage sludge from food industry; 40: Sewage sludge from pulp/paper/cardboard/paperboard; 41: Sewage sludge from others (leather and fur industry, from organic chemical processes, from thermal processes); 42. Sewage sludge from public wastewater treatment plants; 43: Sewage sludge from public water treatment plants
Industrial residues (n = 29)	44: Epizootic animals, fallen animals, blood, heart, lungs; Bristles, skin, hooves, heads, horns, bones, stomach, intestines; 45: By-catch; 46: Fruit remnants, pomace; 47: Vegetable remnants; 48: Potato peelings; 49: Peel, press cake, extraction meal; 50: Milk processing; 51: Bran & flour-dust; 52: Adhesive proteins; 53: Returned bread; 54: Spent grains/yeast residues from breweries; 55: Malt culms, sorting grain from malting; 56: Residues from distilleries; 57: Residues from winemaking, 58: Molasses; 59: Molasses pulp; 60: Pressed pulp; 61: Dried pulp; 62: Wet pulp; 63: Pre production cleaning residues; 64: Residues of confectionery production; 65: Production of ready-made meals, condiment & sauces; 66: Coffee and tea production; 67: Nutshells; 68: Production of compound feed; 69: Tobacco residues; 70: Vinasse, cell residues; 71: Vinasse, brewer grains; 72: Glycerol from biodiesel production
Residues from other areas (n = 21)	Stalks/woody biomass from 73/74: Biomass from communal green areas; 75/76: Cemeteries; 77/78: Heath areas; 79/80: Orchards; 81/82: Vineyards; 83/84: Peatland; 85/86: Roadside greenery; 87/88: Greenery along waterways; 89/90: Greenery along railways; 91: Driftwood; 92: Aquatic plants; 93: Wooden landscape management materials

Table 6
Overview about datasets.

Number of data record	Remark	Comparator
93	**Biomasses were taken into account**	
16 of 93	Biomasses with no data	
77 of 93	**Biomasses were consistently combined with information on theoretical biomass potential at least**	Biomass potential
70 of 77	Biomasses with information on technical biomass potential	
49 of 77	Biomasses with information on current utilisation	Current utilization
23 of 49	Biomasses with information on current utilisation based on literature	
26 of 49	Biomasses with information on current utilisation based on assumptions	
77 of 77	Biomasses with information on time reference	Time reference

Table 7
Biomass potential of residual matter and waste and their current use – status quo in Germany in million Mg (DM) and Level-4-categories (deviations because of rounding).

	Agricultural by-products	Residues of forestry and wood industries	Municipal waste	Industrial residues	Residues from other areas	Total
Theoretical biomass potential	44.6	65.5–66.8	18.5–18.8	13.5	8.8	151.0 –152.7
Technical biomass potential	24.7–29.3	37.9–61.8	11.0–11.7	13.5	5.6–5.8	92.7–122.1
Utilisation	8.8	28.4–36.9	9.5	13.5	2.5	62.7–71.2
Material use	*4.2*	*8.3–9.1*	*8.5*	*8.6*	*No data*	*29.6–30.4*
Energetic use	*4.6*	*17.7–25.2*	*1.0*	*0.1*	*2.5*	*25.8–33.4*
Material or energetic use	*0.0*	*2.4–2.6*	*0.0*	*4.9*	*No data*	*7.3–7.5*
Use unclear	0.0	0.0	1.2–1.9	0.0	1.9–2.1	3.1–4.0
Not used	15.9–20.5	9.5–24.9	0.3	0.0	1.2	26.9–46.9

biomass from other areas. Altogether, 62.7–71.2 million Mg (DM) of the technical potential is being used. Due to disposal and recycling requirements [30], use is almost 100% in the case of municipal waste and industrial residual matter. Use is also high (up to 75%) in the case of residual matter from the wood industry and forestry. By contrast, as of now only one third of agricultural by-products are used. Across the entire range, it can be said that 29.6–30.4 million Mg (DM) of biomass are used as a raw material. 25.8–33.4 million Mg (DM) are used as a fuel. Another 7.3–7.5 million Mg (DM) have been identified as being used, though without any information on whether this is as a raw material or as a fuel. Proof of use is uncertain for at least 3.1–4.0 million Mg (DM).

Altogether, 26.9–46.9 million Mg (DM) of the identified technical potential is not used or not known to be used. Up to 97% of the unused potential is determined to come from the three biomasses of logging residues (about 9.5–24.9 million Mg (DM)), animal excrement (9.1 million Mg (DM)) and cereal straw (6.8–11.4 million Mg (DM)). Another 1.2 million Mg (DM) are from wooden landscape management materials.

The appendix contains a complete overview of biomass-specific findings.

With regard to the recency of the evaluated and finally considered biomasses, a wide range was found for the year of publication and the time which the source data for potentials and utilisation are from. In the case of publication, the range extended from 2006 to 2016. The source data used for biomass potentials goes from 2000 to 2013. Fig. 1 shows an evaluation of the findings.

For 2016 the evaluation shows that more than 70% of the sources from the literature are no more than three years old. Only one percent of the biomass potentials evaluated are based on source data from the last three years. Almost half the source data used are more than four years old. Another 18% are more than five years old, and roughly a third of the source data are six years old, or older. For a total of 23 biomasses (Table 6) data on utilisation is available in the literature. In 15 cases information on potentials and its use refer to the same year. For the other biomasses information on utilisation is between two and eight years newer than the corresponding information on biomass potential. To summarise, it can be said that across all the data evaluated, it is not possible to find one standard reference year either for the year of publication or for the year of the source data employed.

4. Discussion

For the case example of Germany, this review presents an extensive, transparent collection of data on the potential of residual biomass and its use. Using a four level schematic it was possible to structure the 93 biomasses studied by content and to consistently merge the findings for 77 biomass types. With up to 1,500 kg per capita the amount of biogenic residues and wastes is remarkable in Germany.

With regard to data consistency, the information basis for agricultural by-products, forest residues of forest and wood industries and industrial residues is well defined, while for municipal waste and biomass from other areas some overlapping and inconsistencies can be noticed. Municipal waste such as green waste (e.g. from public green) is collected as a public service, but only the total quantity removed is recorded in the statistics. It is well known that these materials are only collected particularly and an unknown share is left behind in situ to save costs. However, estimations for theoretical and technical biomass potential can be found in some studies [23,45–47,54,55] evaluated. It is not yet possible to distinguish clearly between the amount already in the municipal disposal system and the amount which remains unused in situ. In the case of materials from landscape management (e.g. Refs. [40,56,59]), it is also not possible to identify beyond all doubt which reference areas and which yields are included in the calculations. As the parameters used for calculation (e.g. the yield, water content, recovery rate, etc.) are very sensitive, this field is subject to a relatively high level of uncertainty. Compared with the total quantities of all biomass, however, the resulting influence is low, meaning that analysing local material flows could lead to an improvement in the regional circular economy.

Merging the data allows the status quo to be presented in detail, though it is not yet possible to compare the quality of the potential findings recorded. Though the data on the technical potential

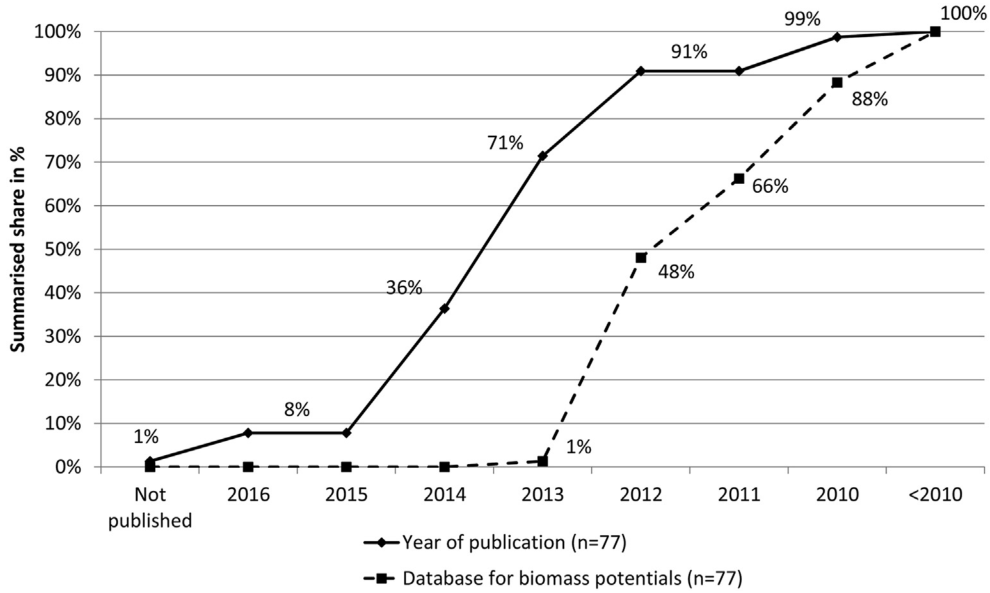

Fig. 1. Age of the presented data in relation to the year of data generation or publication.

include biomass-specific restrictions, the calculations do not have to meet the same quality standards. Initial evaluations of the recency of publications and source data reveal a wide range of figures. Currently, it is not possible to present findings with a single reference year. Furthermore, the findings present a large bandwidth especially for the technical potentials of agricultural by-products and residues of forestry and wood industries. At the same time the related individual biomasses (especially logging residues and straw) stand for the most important unused biomasses. To achieve the target of sustainability, in the next step the findings need to be evaluated using sustainability criteria, such as the 24 sustainability indicators proposed by the Global Biomass Partnership (GBEP) in 2011 [60]. Among other things, this would address the topics of lifecycle green house gas emissions, soil quality, biodiversity, employment in the bioenergy sector and the efficiency of technological processes. This could be used firstly to judge how informative published results were, and secondly to improve the data in a calculated manner if it did not meet the targets required by research. It would elevate the transparency in the field of biomass potentials and could be a basis to identify priorities for further research.

The future use of previously unused biomasses as a raw material or fuel, and the adjustment of current material flows, are subject to economic and legal conditions. To mobilise unused biomasses regional and competitive biomass supply concepts are required. In case of straw, for example, steady prices for raw material are an essential precondition to establish regional value chains. Established material flows like waste streams and industrial residues are subject to legal frameworks. Biowaste, for instance, is well integrated into German public disposal system and detailed data is available from public statistics. In contrast, a detailed utilisation of industrial residues remains unclear. These biomasses are part of private companies and it can merely be assumed that 100% are in use. There are no public statistics available. The question to be considered is where and in which extent smart cascades can increase efficiency of these material flows.

Towards 2020 and 2030 it can be assumed that the annual amount of residues and wastes will remain at a similar level in Germany. However, consumer behaviour and production methods are interrelated to the amount of wastes and residues. Decreasing meat consumption for example affects the animal population and finally the amount of excrements. Breeding methods can increase or decrease the proportion of straw in the crop production and higher standards in biodiversity can limit the use of logging residues and materials from landscape management.

Currently, residual materials and waste used as a fuel make up 541 PJ of the German energy system [61]. If the currently unused potential for energy production were added this would provide another 390–680 PJ. In relation to the German total primary energy consumption of 13,306 PJ in 2015 [62], at least 7% could be covered by the identified technical biomass potential of residues and wastes. This share could be raised significantly if the federal government's targets for reduction 7190 PJ in 2050 [63] were achieved. Assuming that the amount of residual material and waste remained at the same level, according to this calculation the future percentage could be at least 13%. In other words, the efficient use of residual materials and waste as a raw material and a fuel could play an important role in lastingly reducing Germany's dependency on imported energy.

5. Conclusion

In the case example of Germany, the findings offer an initial, extensive overall view of current known resources and their use. As studies on biomass potential are generally individual projects, the merged results do not share a reference year. Biomass use is comparatively well recorded thanks to constant market observation. However, there have only been occasional comparisons with national biomass potential including flows of imports and exports, and the results are very incomplete, especially in the field of biogenic residual materials. It is currently possible to evaluate the temporal development of individual biomasses and their use in occasional cases, but no overview is possible. In view of the fact that there is increasing demand for residual materials to be used and for cascading recycling systems, information on the potential of residual material is gaining in importance.

With a potential share of up to 13% of the future primary energy consumption in Germany, the identified potential is significant for the energy transition and needs specific consideration. For regular statements to be made on biomass potential and current use, continuous and more precise reporting is required. On this point, corresponding national and international requirements need to be discussed, bindingly established and constantly applied. At present, there is a lack of suitable organisational systems and data structures for this purpose, or of clear responsibilities among the institutions providing and receiving the data. In the long term, monitoring biogenic resources will allow resources to be evaluated with data of sufficient quality and over time. A database of this kind could be used to support decision-making as policy on the bioeconomy is further adapted.

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Appendix A. Biomass categorisation

Seq. no.	Level-4-Biomass-Categorisation				
	Level 1		Level 2	Level 3	Level 4
	Name	Definition	Aggregation I	Aggregation II	Aggregation III
1	Catch crop, winter	Additional biomass from catch crops	–	Catch crops	Agricultural by-products
2	Catch crop, summer (spring grain)	Additional biomass from catch crops	–	Catch crops	Agricultural by-products
3	Residues from vegetable gardening, esp. field vegetable residues	Residues from olericulture	–	–	Agricultural by-products
4	Beet leaves	By-products from beet harvesting	–	–	Agricultural by-products
5	Cereal Straw (Wheat, rye, barley, oats, triticale)	By-products of cereal cultivation	–	Straw	Agricultural by-products
6	Rape straw	By-products of rape cultivation	–	Straw	Agricultural by-products
7	Grain corn straw	By-products of grain corn cultivation	–	Straw	Agricultural by-products
8	Sunflower straw	By-products of sunflower cultivation	–	Straw	Agricultural by-products
9	Grain legumes straw	By-products of grain legume cultivation	–	Straw	Agricultural by-products
10	Cattle slurry	Liquid manure from cattle farming	Slurry	Livestock manure	Agricultural by-products
11	Pig slurry	Liquid manure from pig farming	Slurry	Livestock manure	Agricultural by-products
12	Chicken slurry	Liquid manure from chicken farming	Slurry	Livestock manure	Agricultural by-products
13	Cattle manure	Manure (solid) from cattle farming	Manure	Livestock manure	Agricultural by-products
14	Pig manure	Manure (solid) from pig farming	Manure	Livestock manure	Agricultural by-products
15	Chicken manure	Manure (solid) from chicken farming	Manure	Livestock manure	Agricultural by-products
16	Horse manure	Manure (solid) from horse keeping	Manure	Livestock manure	Agricultural by-products
17	Sheep and goat manure	Manure (solid) from sheep and goat farming	Manure	Livestock manure	Agricultural by-products
18	Poultry manure (others)	Manure (solid) from poultry farming (ducks, geese, etc.)	Manure	Livestock manure	Agricultural by-products
19	Logging residues coniferous	Logging residues combine wood < 7 cm in diameter and merchantable wood that remains in stock. It thus consists of stem wood including bark, branches and twigs, crop residues, roots and rhizomes and possibly adhering needles and leaves.	Logging residues	By-products from forest wood	Residues of forestry and wood industries
20	Logging residues deciduous	Logging residues combine wood < 7 cm in diameter and merchantable wood that remains in stock. It thus consists of stem wood including bark, branches and twigs, crop residues, roots and rhizomes and possibly adhering needles and leaves.	Logging residues	By-products from forest wood	Residues of forestry and wood industries
21	Bark	All trunk and branch portions outside of the cambium (cell-forming layer). Bark consists of the inner bark (bast) and the outer bark	–	By-products from forest wood	Residues of forestry and wood industries
22	Sawdust, wood chips, slabs and splinters	Sawdust: Co-product of wood cutting, flat cuboid and pin-like shape. Chips: by-product of the chopping process in lumber production. Solid wood parts cut diagonal to the	Sawmill By-products	Industrial waste wood	Residues of forestry and wood industries

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(*continued*)

Seq. no.	Level-4-Biomass-Categorisation				
	Level 1		Level 2	Level 3	Level 4
	Name	Definition	Aggregation I	Aggregation II	Aggregation III
		fiber direction. Slabs & splinters: co-products of the trimming of logwood (slabs) and board (splinters)			
23	Wood shavings	Wood chips (thin and flat chips) are a co-product of wood processing in sawmills or affiliated value-added processes (carpenters, wood moldings manufacturer)	–	Industrial waste wood	Residues of forestry and wood industries
24	Black liquor	Black liquor is a byproduct of pulp production. It results in the separation of lignin and cellulose, and is a mixture of lignin, water and the chemicals that are used for the extraction.	–	Industrial waste wood	Residues of forestry and wood industries
25	Other industrial waste wood	Other industrial waste wood accumulates during the processing of wood products. It does not include sawmill By-products and wood shavings.	–	Industrial waste wood	Residues of forestry and wood industries
26	Waste wood	Industrial waste wood and used wood, if these are wastes in the meaning of §3 para. 1 of the current German recycling and waste legislation. Waste Wood Ordinance, §2, section 1 (2007).	–	Recycling materials	Residues of forestry and wood industries
27	Biowaste	Biogenic share in household waste, collected and reported separately.	–	Collected by municipal waste management	Municipal waste
28	Biogenic fraction of household waste	Biogenic share in household waste, not collected and reported separately.	–	Collected by municipal waste management	Municipal waste
29	Green waste	Green waste, collected and reported by municipal waste management	–	Collected by municipal waste management	Municipal waste
30	Biodegradable waste from kitchens and canteens	Biodegradable kitchen and canteen waste, collected and reported by municipal waste management	–	Collected by municipal waste management	Municipal waste
31	Waste from weekly markets	Waste from weekly markets, collected and reported by municipal waste management	–	Collected by municipal waste management	Municipal waste
32	Oils from separators in waste and water treatment	Oils from separators, collected and reported by municipal waste management	–	Collected by municipal waste management	Municipal waste
33	Waste fabrics	Waste fabrics, collected and reported by municipal waste management	–	Collected by municipal waste management	Municipal waste
34	Mixed packaging/recyclable and reusable material	Mixed packaging/recyclable and reusable material, collected and reported by municipal waste management	–	Collected by municipal waste management	Municipal waste
35	Commercial food waste, not waste management	Commercial food waste, not collected and reported by municipal waste management	–	Not collected by municipal waste management	Municipal waste
36	Used cooking oil	Used cooking oil, not collected and reported by municipal waste management	–	Not collected by municipal waste management	Municipal waste
37	Faecal sludge	Faecal sludge, reported by official waste statistics	Sewage sludge from municipal waste	Sewage sludge	Municipal waste
38	Waste from sewage cleaning	Waste from sewage cleaning, reported by official waste statistics	Sewage sludge from municipal waste	Sewage sludge	Municipal waste
39	Sewage sludge from food industry	Sewage sludge from in-house waste water treatment, reported by official waste statistics	Sewage sludge from in-house waste water treatment	Sewage sludge	Municipal waste
40	Sewage sludge from pulp/paper/cardboard/paperboard	Sewage sludge from in-house waste water treatment of pulp, paper, cardboard, paperboard industry, reported by official waste statistics	Sewage sludge from in-house waste water treatment	Sewage sludge	Municipal waste
41	Sewage sludge from other industries (leather and fur industry, from organic chemical processes, from thermal processes)	Sewage sludge from in-house waste water treatment of leather and fur industry, reported by official waste statistics	Sewage sludge from in-house waste water treatment	Sewage sludge	Municipal waste
42	Sewage sludge from public wastewater treatment plants	Sewage sludge from public wastewater treatment plants, reported by official waste statistics	Sewage sludge from waste water treatment and drinking water treatment	Sewage sludge	Municipal waste
43	Sewage sludge from public water treatment plants	Sewage sludge from water treatment plants, reported by official waste statistics	Sewage sludge from waste water treatment and drinking water treatment	Sewage sludge	Municipal waste

(*continued*)

Seq. no.	Level-4-Biomass-Categorisation				
	Level 1		Level 2	Level 3	Level 4
	Name	Definition	Aggregation I	Aggregation II	Aggregation III
44	Epizootic animals, fallen animals, blood, heart, lungs; Bristles, skin, hooves, heads, horns, bones, stomach, intestines	Residues from slaughter, not meat processing. Different Categories for By-products from slaughter. (Cat.1: Epizootic animals. Cat.2: fallen animals. Cat. 3 (usable for human alimentation: blood, heart, lung) In addition: bristles, skin, hooves, heads, horns, bones, stomach, intestines	Offal & meat processing	Food industry	Industrial residues
45	By-catch (possibly overboard), fish remains (bones heads, tails, entrails)	Only disembarked fish residues are recorded; nor recorded are fish residues and bycatch processed directly on board	Fish processing	Food industry	Industrial residues
46	Fruit remnants, pomace	Rejected fruits & vegetables, peels, pits, press cake, pomace	Fruit- & vegetable processing	Food industry	Industrial residues
47	Vegetable remnants	Rejected vegetables stalks, shells, seeds	Fruit- & vegetable processing	Food industry	Industrial residues
48	Potato peelings	Residues generated by producing products such as potato chips, frozen products and other potato products	Fruit- & vegetable processing	Food industry	Industrial residues
49	Peel, press cake, extraction meal	Peel, press cake, extraction meal	Production of vegetable & animal oils & fats	Food industry	Industrial residues
50	TS, primarily whey	Whey is a quantitatively relevant by-product; in addition small amounts of rinsing milk used for washing pprocessing units	Milk processing	Food industry	Industrial residues
51	Bran & flour-dust	Bran & flour-dust generated by producing cereal flours	Hulling & grinding mills, production of starch & starch products	Food industry	Industrial residues
52	Adhesive proteins	Production of starch products: potato protein, corn gluten, etc.	Hulling & grinding mills, production of starch & starch products	Food industry	Industrial residues
53	Returned bread	Returned bread and offcuts	Production of bakery and farinaceous products	Food industry	Industrial residues
54	Spent grains/yeast residues from breweries	Largest proportion: spent grains (ca. 75%); in addition: malt dust, hot and cold trub (10%), yeast residues (10%) and diatomaceous earth	Production of beverages	Food industry	Industrial residues
55	Malt culms, sorting grain from malting	In the production of malt from cereals different percentages (DM) of the collected grain is turned into residues (depending on the quality): 0.8% sorting grain (DM: 85%) and 5% Malt culms (DM: 92%) (interview data)	Production of beverages	Food industry	Industrial residues
56	Residues from distilleries	Pomace, ingredients of vinasse, "Vorlauf", (lipids, minerals, proteins and phenolic components)	Production of beverages	Food industry	Industrial residues
57	Residues from winemaking	Not considered here: Green cuttings (see agricultural waste)	Production of beverages	Food industry	Industrial residues
58	Molasses	Molasses, by-product of sugar production	Beet sugar production	Food industry	Industrial residues
59	Molasses pulp	Molasses pulp, which arise as residue/by-product of sugar production	Beet sugar production	Food industry	Industrial residues
60	Pressed pulp	Pressed pulp, by-product of sugar production	Beet sugar production	Food industry	Industrial residues
61	Dried pulp	Dried pulp, by-product of sugar production	Beet sugar production	Food industry	Industrial residues
62	Wet pulp	Wet pulp, by-product of sugar production	Beet sugar production	Food industry	Industrial residues
63	Pre production cleaning residues	Residues produced by cleaning beets before processing, by-product of sugar production	Beet sugar production	Food industry	Industrial residues
64	Residues of confectionery production	The quantitatively largest waste streams are produced by manufacturing chocolate products and raw products: Cocoa shells, skin of almond and other nuts, fat fractions, additives for filled chocolates	–	Food industry	Industrial residues
65	Residues of production of ready-made meals, condiment & sauces	For "convenience products" (egg) shells, seeds, offcuts, faulty batches. Condiment production: pomace of spice plants	–	Food industry	Industrial residues
66	Residues of coffee and tee production	Largest proportion: Coffee grounds (production of coffee extract); Coffee skins (from roasting); Dusts, faulty batches, run-up batches	–	Food industry	Industrial residues
67	Nutshells	Nutshells (Walnut, peanut, hazelnut; cashew nut, pistachio, almond, chestnut, macadamia), not generated in the confectionery production	–	Food industry	Industrial residues
68	Residues of production of compound feed	When receiving grain from agricultural production: husks (mass fraction), "Schmachtgetreide", straw, weed seeds, faulty raw materials, faulty and cleaning batches	–	Feed production for livestock & pets	Industrial residues
69	Tobacco residues	Tobacco residues from the tobacco industry	–	Cigarette- & tobacco industry	Industrial residues

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(*continued*)

Seq. no.	Level-4-Biomass-Categorisation				
	Level 1		Level 2	Level 3	Level 4
	Name	Definition	Aggregation I	Aggregation II	Aggregation III
70	Vinasse, cell residues	Mainly fermentation residues, especially molasses residues (=vinasse) and cell residues. In addition: Faulty batches (e.g. drugs)	Chemical-, pharmaceutical-, yeast industry	Biotech industries	Industrial residues
71	Vinasse, brewer grains	Mainly fermentation residues, especially from the fermentation of molasses or starch	Bioethanol production	Biotech industries	Industrial residues
72	Glycerin from biodiesel production	Glycerin, which is generated during the production of biodiesel	–	–	Industrial residues
73	Stalks from public green area	Stalks from parks, zoos, amusement parks, recreational areas, allotments etc.)	–	Biomass from public green area	Residues from other areas
74	Woody biomass from public green area	Ligneous content of biomass from parks, zoos, amusement parks, recreational areas, allotments etc.)	–	Biomass from public green area	Residues from other areas
75	Stalks from cementries	Stalks from cemeteries	–	Biomass from cemeteries	Residues from other areas
76	Woody biomass from cementries	Ligneous content of biomass from cemeteries	–	Biomass from cemeteries	Residues from other areas
77	Stalks from heath areas	Stalks from heath areas	–	Biomass from heath areas	Residues from other areas
78	Woody biomass from heath areas	Ligneous content of biomass from heath areas	–	Biomass from heath areas	Residues from other areas
79	Stalks from orchards	Stalks from orchards	–	Biomass from orchards	Residues from other areas
80	Woody biomass from orchards	Ligneous content of biomass from orchards	–	Biomass from orchards	Residues from other areas
81	Stalks from vineyards	Stalks from vineyards	–	Biomass from vineyards	Residues from other areas
82	Woody biomass from vineyards	Ligneous content of biomass from vineyards	–	Biomass from vineyards	Residues from other areas
83	Stalks from peatland	Stalks from peatland	–	Biomass from peatland	Residues from other areas
84	Woody biomass from peatland	Ligneous content of biomass from peatland	–	Biomass from peatland	Residues from other areas
85	Stalks from roadside greenery	Herbaceous content of biomass cut alongside roads	Roadside greenery	Biomass from traffic areas	Residues from other areas
86	Woody biomass from roadside greenary	Ligneous content of biomass cut alongside roads	Roadside greenery	Biomass from traffic areas	Residues from other areas
87	Stalks along waterways	Herbaceous content of biomass cut alongside waterways	Greenery along waterways	Biomass from traffic areas	Residues from other areas
88	Woody biomass along waterways	Ligneous content of biomass cut alongside waterways	Greenery along waterways	Biomass from traffic areas	Residues from other areas
89	Stalks along railways	Herbaceous content of biomass cut alongside railways	Greenery along railways	Biomass from traffic areas	Residues from other areas
90	Woody biomass aloong railways	Ligneous content of biomass cut alongside railways	Greenery along railways	Biomass from traffic areas	Residues from other areas
91	Driftwood	Fluvial transported woody debris	–	–	Residues from other areas
92	Aquatic plants	Biomass from waters	–	–	Residues from other areas
93	Wooden landscape management materials	Resulting from actions that predominantly serve objectives of nature and landscape conservation and are not cultivated specifically. Accordingly waste from gardens and parks is excluded	–	–	Residues from other areas

Appendix B. Remarks on consideration and theoretical/technical biomass potential

Seq. no.	Consideration of dataset		Comparator 1			
			Theoretical biomass potential		Technical biomass potential	
			Min	Max	Min	Max
	yes/no	Remark	Mg (DM)	Mg (DM)	Mg (DM)	Mg (DM)
1	No	Insufficient data	No data	No data	No data	No data
2	No	Insufficient data	No data	No data	No data	No data
3	No	Insufficient data	No data	No data	No data	No data
4	No	Part of humus balance for straw potential. Not available as additional potential.	2,300,000	2,300,000	575,000	1,150,000
5	Yes	Full dataset	25,655,520	25,655,520	11,024,340	15,568,580
6	No	Part of humus balance for straw potential. Not available as additional potential.	7,637,000	7,637,000	1,527,400	1,527,400

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Seq. no.	Consideration of dataset		Comparator 1			
			Theoretical biomass potential		Technical biomass potential	
			Min	Max	Min	Max
	yes/no	Remark	Mg (DM)	Mg (DM)	Mg (DM)	Mg (DM)
7	No	Part of humus balance for straw potential. Not available as additional potential.	3,440,000	3,440,000	No data	No data
8	No	Insufficient data	No data	No data	No data	No data
9	No	Insufficient data	No data	No data	No data	No data
10	Yes	Full dataset	7,458,391	7,458,391	4,930,440	4,930,440
11	Yes	Full dataset	2,907,900	2,907,900	2,590,479	2,590,479
12	No	Insufficient data	No data	No data	No data	No data
13	Yes	Full dataset	5,594,538	5,594,538	3,570,426	3,570,426
14	Yes	Full dataset	2,424,258	2,424,258	2,052,557	2,052,557
15	Yes	Full dataset	582,148	582,148	562,876	562,876
16	No	Insufficient data	No data	No data	No data	No data
17	No	Insufficient data	No data	No data	No data	No data
18	No	Insufficient data	No data	No data	No data	No data
19	Yes	Full dataset	20,119,000	20,119,000	7,002,000	18,424,000
20	Yes	Full dataset	18,936,000	18,936,000	6,605,000	17,377,000
21	Yes	Full dataset	6,843,000	6,843,000	4,708,000	5,074,000
22	Yes	Full dataset	6,774,000	7,050,000	6,774,000	7,050,000
23	Yes	Full dataset	1,570,000	1,570,000	1,570,000	1,570,000
24	Yes	Full dataset	1,757,000	1,757,000	1,757,000	1,757,000
25	Yes	Full dataset	2,718,000	2,718,000	2,718,000	2,718,000
26	Yes	Full dataset	6,751,000	7,849,000	6,751,000	7,849,000
27	Yes	Full dataset	1,779,600	1,779,600	1,632,000	1,632,000
28	Yes	Information on potentials but no information on utilisation.	1,960,000	1,960,000	400,000	800,000
29	Yes	Full dataset	2,337,000	2,337,000	2,290,500	2,290,500
30	Yes	Full dataset	275,200	275,200	275,200	275,200
31	Yes	Full dataset	28,000	28,000	28,000	28,000
32	Yes	Information on potentials but no information on utilisation.	1235	1235	1235	1235
33	Yes	Full dataset	100,000	100,000	100,000	100,000
34	Yes	Full dataset	5,462,000	5,462,000	5,462,000	5,462,000
35	Yes	Information on potentials but no information on utilisation.	728,800	728,800	721,600	721,600
36	Yes	Information on technical potentials but no information on utilisation or theoretical potential.	41,705	380,000	41,705	380,000
37	Yes	Information on theoretical potential only.	16,300	16,300	No data	No data
38	Yes	Information on theoretical potential only.	54,700	54,700	No data	No data
39	Yes	Information on theoretical potential only.	720,900	720,900	No data	No data
40	Yes	Information on theoretical potential only.	120,300	120,300	No data	No data
41	Yes	Information on theoretical potential only.	14,600	14,600	No data	No data
42	Yes	Information on theoretical potential only.	4,703,700	4,703,700	No data	No data
43	Yes	Information on theoretical potential only.	158,200	158,200	No data	No data
44	Yes	Information on potentials and total utilisation.	390,000	390,000	390,000	390,000
45	Yes	Full dataset	25,000	25,000	25,000	25,000
46	Yes	Information on potentials and total utilisation.	45,000	45,000	45,000	45,000
47	Yes	Information on potentials and total utilisation.	37,000	37,000	37,000	37,000
48	Yes	Information on potentials and total utilisation.	48,000	48,000	48,000	48,000
49	Yes	Full dataset	6,100,000	6,100,000	6,100,000	6,100,000
50	Yes	Full dataset	780,000	780,000	780,000	780,000
51	Yes	Full dataset	1,430,000	1,430,000	1,430,000	1,430,000
52	Yes	Full dataset	312,000	312,000	312,000	312,000
53	Yes	Information on potentials and total utilisation.	470,000	470,000	470,000	470,000
54	Yes	Information on potentials and total utilisation.	360,000	360,000	360,000	360,000
55	Yes	Information on potentials and total utilisation.	105,000	105,000	105,000	105,000
56	Yes	Full dataset	15,000	15,000	15,000	15,000
57	Yes	Information on potentials and total utilisation.	113,000	113,000	113,000	113,000
58	Yes	Information on potentials and total utilisation.	586,000	586,000	586,000	586,000
59	Yes	Information on potentials and total utilisation.	1,310,000	1,310,000	1,310,000	1,310,000
60	Yes	Information on potentials and total utilisation.	330,000	330,000	330,000	330,000
61	Yes	Information on potentials and total utilisation.	25,000	25,000	25,000	25,000
62	Yes	Information on potentials and total utilisation.	4400	4400	4400	4400
63	Yes	Information on potentials and total utilisation.	28,000	28,000	28,000	28,000
64	Yes	Information on potentials and total utilisation.	48,000	48,000	48,000	48,000
65	Yes	Information on potentials and total utilisation.	113,000	113,000	113,000	113,000
66	Yes	Information on potentials and total utilisation.	14,500	14,500	14,500	14,500
67	No	Insufficient data.	No data	No data	No data	No data
68	Yes	Information on potentials and total utilisation.	53,000	53,000	53,000	53,000
69	Yes	Information on potentials and total utilisation.	6600	6600	6600	6600
70	Yes	Information on potentials and total utilisation.	81,000	81,000	81,000	81,000
71	Yes	Information on potentials and total utilisation.	522,000	522,000	522,000	522,000
72	Yes	Information on potentials and total utilisation.	180,400	180,400	180,400	180,400
73	Yes	Information on potentials but no information on utilisation.	831,00	831,000	415,500	415,500
74	Yes	Information on potentials but no information on utilisation.	327,600	327,600	163,800	163,800

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Seq. no.	Consideration of dataset		Comparator 1			
			Theoretical biomass potential		Technical biomass potential	
			Min	Max	Min	Max
	yes/no	Remark	Mg (DM)	Mg (DM)	Mg (DM)	Mg (DM)
75	Yes	Information on potentials but no information on utilisation.	200,250	200,250	100,500	100,500
76	Yes	Information on potentials but no information on utilisation.	26,650	26,650	13,325	13,325
77	Yes	Information on potentials but no information on utilisation.	231,000	231,000	115,500	115,500
78	Yes	Information on potentials but no information on utilisation.	200,200	200,200	100,100	100,100
79	Yes	Information on potentials but no information on utilisation.	381,000	381,000	190,500	190,500
80	Yes	Information on potentials but no information on utilisation.	165,100	165,100	165,100	165,100
81	Yes	Information on potentials but no information on utilisation.	89,250	89,250	45,000	45,000
82	Yes	Information on potentials but no information on utilisation.	232,700	232,700	232,700	232,700
83	Yes	Information on potentials but no information on utilisation.	600,000	600,000	59,400	59,400
84	Yes	Information on potentials but no information on utilisation.	232,050	232,050	46,150	46,150
85	Yes	Information on potentials but no information on utilisation.	545,500	545,500	50,000	75,000
86	Yes	Information on potentials but no information on utilisation.	575,250	575,250	162,500	357,500
87	No	Insufficient data	No data	No data	No data	No data
88	Yes	Information on potentials but no information on utilisation.	10,000	10,000	10,000	10,000
89	No	Insufficient data	No data	No data	No data	No data
90	Yes	Information on potentials but no information on utilisation.	500,000	500,000	25,000	40,000
91	Yes	Information on potentials but no information on utilisation.	20,000	20,000	10,000	10,000
92	No	Insufficient data	No data	No data	No data	No data
93	Yes	Information on technical potential and utilisation but no theoretical potential.	3,670,000	3,670,000	3,670,000	3,670,000

Appendix C. Use of biomass

Seq. no.	Comparator 2									
	Utilisation									
	Total		Material		Energetic		Material or energetic		Use unclear	
	Min	Max	M	Max	Min	Max	Min	Max	Min	Max
	Mg (DM)	Mg (DM)	Mg (DM)	Mg (DM)	Mg (DM)	Mg (DM)	Mg (DM)	Mg (DM)	Mg (DM)	Mg (DM)
1	No data	No data	No data	No data	No data	No data	No data	No data	No data	No data
2	No data	No data	No data	No data	No data	No data	No data	No data	No data	No data
3	No data	No data	No data	No data	No data	No data	No data	No data	No data	No data
4	No data	No data	No data	No data	No data	No data	No data	No data	No data	No data
5	4,208,928	4,208,928	4,173,928	4,173,928	35000	35000	–	–	–	–
6	No data	No data	No data	No data	No data	No data	No data	No data	No data	No data
7	No data	No data	No data	No data	No data	No data	No data	No data	No data	No data
8	No data	No data	No data	No data	No data	No data	No data	No data	No data	No data
9	No data	No data	No data	No data	No data	No data	No data	No data	No data	No data
10	2,958,264	2,958,264	0	0	2,958,264	2,958,264	–	–	–	–
11	466,286	466,286	0	0	466,286	466,286	–	–	–	–
12	No data	No data	No data	No data	No data	No data	No data	No data	No data	No data
13	785,494	785,494	0	0	785,494	785,494	–	–	–	–
14	20,526	20,526	0	0	20,526	20,526	–	–	–	–
15	371,498	371,498	0	0	371,498	371,498	–	–	–	–
16	No data	No data	No data	No data	No data	No data	No data	No data	No data	No data
17	No data	No data	No data	No data	No data	No data	No data	No data	No data	No data
18	No data	No data	No data	No data	No data	No data	No data	No data	No data	No data
19	1,435,410	3,776,920	119,139	313,484	1,316,271	3,463,436	–	–	–	–
20	2,694,840	7,089,816	26,948	70,898	2,667,892	7,018,918	–	–	–	–
21	4,708,000	5,074,000	832,271	896,972	1,752,421	1,888,654	2,123,308	2,288,374	–	–
22	6,774,000	7,050,000	5,446,296	5,668,200	1,327,704	1,381,800	–	–	–	–
23	1,570,000	1,570,000	593,460	593,460	976,540	976,540	–	–	–	–
24	1,757,000	1,757,000	0	0	1,757,000	1,757,000	–	–	–	–
25	2,718,000	2,718,000	40,770	40,770	2,677,230	2,677,230	–	–	–	–
26	6,751,000	7,849,000	1,268,945	1,475,329	5,205,264	6,051,862	276,791	321,809	–	–
27	1,632,000	1,632,000	1,615,680	1,615,680	16,320	16,320	–	–	–	–
28	No data	No data	No data	No data	No data	No data	No data	No data	400,000	800,000
29	2,274,467	2,274,467	2,160,743	2,160,743	113,723	113,723	–	–	–	–
30	272,448	272,448	248,473	248,473	23,975	23,975	–	–	–	–
31	23,800	23,800	23,015	23,015	785	785	–	–	–	–
32	No data	No data	No data	No data	No data	No data	No data	No data	1235	1235
33	99,500	99,500	99,003	99,003	497	497	–	–	–	–

(*continued*)

Seq. no.	Comparator 2									
	Utilisation									
	Total		Material		Energetic		Material or energetic		Use unclear	
	Min	Max	M	Max	Min	Max	Min	Max	Min	Max
	Mg (DM)	Mg (DM)	Mg (DM)	Mg (DM)	Mg (DM)	Mg (DM)	Mg (DM)	Mg (DM)	Mg (DM)	Mg (DM)
34	5,188,900	5,188,900	4,394,998	4,394,998	793,902	793,902	–	–	–	–
35	No data	No data	No data	No data	No data	No data	No data	No data	721,600	721,600
36	No data	No data	No data	No data	No data	No data	No data	No data	41,705	380,000
37	No data	No data	No data	No data	No data	No data	No data	No data	No data	No data
38	No data	No data	No data	No data	No data	No data	No data	No data	No data	No data
39	No data	No data	No data	No data	No data	No data	No data	No data	No data	No data
40	No data	No data	No data	No data	No data	No data	No data	No data	No data	No data
41	No data	No data	No data	No data	No data	No data	No data	No data	No data	No data
42	No data	No data	No data	No data	No data	No data	No data	No data	No data	No data
43	No data	No data	No data	No data	No data	No data	No data	No data	No data	No data
44	390,000	390,000	No data	No data	No data	No data	390,000	390000	–	–
45	25,000	25,000	25,000	25,000	0	0	–	–	–	–
46	45,000	45,000	No data	No data	No data	No data	45,000	45,000	–	–
47	37,000	37,000	No data	No data	No data	No data	37,000	37,000	–	–
48	48,000	48,000	No data	No data	No data	No data	48,000	48,000	–	–
49	6,100,000	6,100,000	6,100,000	6,100,000	0	0	–	–	–	–
50	780000	780000	780000	780000	0	0	–	–	–	–
51	1,430,000	1,430,000	1,349,920	1,349,920	80,080	80,080	–	–	–	–
52	312,000	312,000	312000	312000	0	0	–	–	–	–
53	470,000	470,000	No data	No data	No data	No data	470,000	470,000	–	–
54	360,000	360,000	No data	No data	No data	No data	360,000	360,000	–	–
55	105,000	105,000	No data	No data	No data	No data	105,000	105,000	–	–
56	15,000	15,000	13500	13500	1500	1500	–	–	–	–
57	113,000	113,000	No data	No data	No data	No data	113000	113000	–	–
58	586,000	586,000	No data	No data	No data	No data	586000	586000	–	–
59	1,310,000	1,310,000	No data	No data	No data	No data	1,310,000	1,310,000	–	–
60	330,000	330,000	No data	No data	No data	No data	330,000	330,000	–	–
61	25,000	25,000	No data	No data	No data	No data	25,000	25,000	–	–
62	4400	4400	No data	No data	No data	No data	4400	4400	–	–
63	28,000	28,000	No data	No data	No data	No data	28,000	28,000	–	–
64	48,000	48,000	No data	No data	No data	No data	48,000	48,000	–	–
65	113,000	113,000	No data	No data	No data	No data	113,000	113,000	–	–
66	14,500	14,500	No data	No data	No data	No data	14,500	14,500	–	–
67	No data	No data	No data	No data	No data	No data	No data	No data	No data	No data
68	53,000	53,000	No data	No data	No data	No data	53,000	53,000	–	–
69	6600	6600	No data	No data	No data	No data	6600	6600	–	–
70	81,000	81,000	No data	No data	No data	No data	81,000	81,000	–	–
71	522,000	522,000	No data	No data	No data	No data	522,000	522,000	–	–
72	180,400	180,400	No data	No data	No data	No data	180,400	180,400	–	–
73	No data	No data	No data	No data	No data	No data	No data	No data	415,500	415,500
74	No data	No data	No data	No data	No data	No data	No data	No data	163,800	163,800
75	No data	No data	No data	No data	No data	No data	No data	No data	100,500	100,500
76	No data	No data	No data	No data	No data	No data	No data	No data	13,325	13,325
77	No data	No data	No data	No data	No data	No data	No data	No data	115,500	115,500
78	No data	No data	No data	No data	No data	No data	No data	No data	100,100	100,100
79	No data	No data	No data	No data	No data	No data	No data	No data	190,500	190,500
80	No data	No data	No data	No data	No data	No data	No data	No data	165,100	165,100
81	No data	No data	No data	No data	No data	No data	No data	No data	45,000	45,000
82	No data	No data	No data	No data	No data	No data	No data	No data	232,700	232,700
83	No data	No data	No data	No data	No data	No data	No data	No data	59,400	59,400
84	No data	No data	No data	No data	No data	No data	No data	No data	46,150	46,150
85	No data	No data	No data	No data	No data	No data	No data	No data	50,000	75,000
86	No data	No data	No data	No data	No data	No data	No data	No data	162,500	357,500
87	No data	No data	No data	No data	No data	No data	No data	No data	No data	No data
88	No data	No data	No data	No data	No data	No data	No data	No data	10,000	10,000
89	No data	No data	No data	No data	No data	No data	No data	No data	No data	No data
90	No data	No data	No data	No data	No data	No data	No data	No data	25,000	40,000
91	No data	No data	No data	No data	No data	No data	No data	No data	10,000	10,000
92	No data	No data	No data	No data	No data	No data	No data	No data	No data	No data
93	2,495,600	2,495,600	0	0	2,495,600	2,495,600	–	–	–	–

Appendix D. Unused biomasses, time reference, biomass specific references

Seq. no.	Comparator 2		Comparator 3			Biomass specific references	
	Unused		Time reference			Biomass potentials	Utilisation
	Min	Max	Publication	Data			
	Mg (DM)	Mg (DM)		Potentials	Utilisation		
1	No data	No data	No data	No data	No data	No data	No data
2	No data	No data	No data	No data	No data	No data	No data
3	No data	No data	No data	No data	No data	No data	No data
4	No data	No data	2003	2000	No data	[33]	No data
5	6,815,412	11,359,652	2012	2007	2015	[3,34,35]	[37]
6	No data	No data	2010	2007	No data	[27]	No data
7	No data	No data	2011	2007	No data	[34]	No data
8	No data	No data	No data	No data	No data	No data	No data
9	No data	No data	No data	No data	No data	No data	No data
10	1,972,176	1,972,176	2016	2010	2013	[35,36]	[38]
11	2,124,193	2,124,193	2016	2010	2013	[35,36]	[38]
12	No data	No data	No data	No data	No data	No data	No data
13	2,784,932	2,784,932	2016	2010	2013	[35,36]	[38]
14	2,032,032	2,032,032	2016	2010	2013	[35,36]	[38]
15	191378	191378	2016	2010	2013	[35,36]	[38]
16	No data	No data	No data	No data	No data	No data	No data
17	No data	No data	No data	No data	No data	No data	No data
18	No data	No data	No data	No data	No data	No data	No data
19	5,566,590	14,647,080	2014	2012	2012	[35,39,40]	[41]
20	3,910,160	10,287,184	2014	2012	2012	[35,39,40]	[41]
21	0	0	2014	2012	2012	[35,41]	[41]
22	0	0	2012	2010	2010	[35,42]	[42]
23	0	0	2006	2006	2006	[43]	[43]
24	0	0	2012	2012	2012	[41]	[41]
25	0	0	2012	2012	2012	[41]	[41]
26	0	0	2012	2010	2010	[35,44]	[44]
27	0	0	2014	2011	2011	[23,35,45]	[50]
28	No data	No data	2012	2008	No data	[46]	No data
29	16034	16034	2014	2011	2011	[23,35,45]	[50]
30	2752	2752	2014	2012	2012	[47]	[47]
31	4200	4200	2014	2012	2012	[47]	[47]
32	No data	No data	2012	2010	No data	[48]	No data
33	500	500	2014	2012	2012	[47]	[47]
34	273100	273100	2014	2012	2012	[47]	[47]
35	No data	No data	2014	2000	No data	[46]	No Data
36	No data	No data	2012	2010	No Data	[48,49]	No Data
37	No data	No data	2012	2010	No Data	[48]	No Data
38	No data	No data	2012	2010	No Data	[48]	No Data
39	No data	No data	2012	2010	No Data	[48]	No Data
40	No data	No data	2012	2010	No Data	[48]	No Data
41	No data	No data	2012	2010	No Data	[48]	No Data
42	No data	No data	2012	2010	No Data	[48]	No Data
43	No data	No data	2012	2010	No Data	[48]	No Data
44	0	0	2013	2012	No Data	[51]	Assumption
45	0	0	2013	2012	No Data	[51]	Assumption
46	0	0	2013	2012	No Data	[51]	Assumption
47	0	0	2013	2012	No Data	[51]	Assumption
48	0	0	2013	2012	No Data	[51]	Assumption
49	0	0	2013	2012	No Data	[51]	Assumption
50	0	0	2013	2012	No Data	[51]	Assumption
51	0	0	2013	2012	No Data	[51]	Assumption
52	0	0	2013	2012	No Data	[51]	Assumption
53	0	0	2013	2012	No Data	[51]	Assumption
54	0	0	2013	2012	No Data	[51]	Assumption
55	0	0	2013	2012	No Data	[51]	Assumption
56	0	0	2013	2012	2014	[51]	[53]
57	0	0	2013	2012	No Data	[51]	Assumption
58	0	0	2013	2012	No Data	[51]	Assumption
59	0	0	2013	2012	No Data	[51]	Assumption
60	0	0	2013	2012	No Data	[51]	Assumption
61	0	0	2013	2012	No Data	[51]	Assumption
62	0	0	2013	2012	No Data	[51]	Assumption
63	0	0	2013	2012	No Data	[51]	Assumption
64	0	0	2013	2012	No Data	[51]	Assumption
65	0	0	2013	2012	No Data	[51]	Assumption

(*continued*)

Seq. no.	Comparator 2		Comparator 3			Biomass specific references	
	Unused		Time reference			Biomass potentials	Utilisation
	Min	Max	Publication	Data			
	Mg (DM)	Mg (DM)		Potentials	Utilisation		
66	0	0	2013	2012	No Data	[51]	Assumption
67	No data	No data	No data	No data	No Data	No data	No data
68	0	0	2013	2012	No Data	[51]	Assumption
69	0	0	2013	2012	No Data	[51]	Assumption
70	0	0	2013	2012	No Data	[51]	Assumption
71	0	0	2013	2012	2014	[51]	[53]
72	0	0	not published	2013	No data	[52]	Assumption
73	No data	No data	2014	2011	No Data	[54]	No data
74	No data	No data	2014	2011	No Data	[54]	No data
75	No data	No data	2014	2011	No Data	[55]	No data
76	No data	No data	2014	2011	No Data	[55]	No data
77	No data	No data	2014	2011	No Data	[56]	No data
78	No data	No data	2014	2011	No Data	[56]	No data
79	No data	No data	2014	2011	No Data	[57]	No data
80	No data	No data	2014	2011	No Data	[57]	No data
81	No data	No data	2014	2011	No Data	[35,58]	No data
82	No data	No data	2014	2011	No Data	[35,58]	No data
83	No data	No data	2014	2011	No Data	[59]	No data
84	No data	No data	2014	2011	No Data	[59]	No data
85	No data	No data	2010	2007	No Data	[46]	No data
86	No data	No data	2010	2007	No Data	[46]	No data
87	No data	No data	2010	2008	No Data	[46]	No data
88	No data	No data	2010	2008	No Data	[46]	No data
89	No data	No data	2010	2008	No Data	No data	No data
90	No data	No data	2010	2008	No Data	[46]	No data
91	No data	No data	2010	2008	No Data	[46]	No data
92	No data	No data	No data	No data	No Data	No data	No data
93	1,174,400	1,174,400	2010	2010	2010	[35,40]	[41]

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