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Waste and residue availability for advanced biofuel production in the European Union and the United Kingdom

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Introduction

To achieve the goals of the European Climate Law and meet the commitment of net zero greenhouse gas (GHG) emissions by 2050, in July 2021, the European Union (EU) released a package called "Fit for 55." The package aims to decarbonize European GHG emissions by 55% relative to 1990 by 2030. Several proposals in this package incorporate targets or incentives for renewable fuels: a proposal to revise the Renewable Energy Directive (RED II), a regulation for the aviation sector called ReFuelEU, and a regulation for the marine sector called Fuel EU Maritime. These proposed changes are summarized in Searle (2021).

Both the ReFuelEU and the RED II revision proposals include ambitious targets for advanced biofuels made from cellulosic material and biogenic wastes. The regulation for aviation proposes a 5% share for sustainable aviation fuels (SAF) by 2030 (increasing to 63% in 2050) made only from wastes and residues defined in Annex IX of the RED II. Feedstocks defined in Annex IX, list A of the RED II include cellulosic wastes and residues that can deliver substantial GHG reductions. Annex IX also includes used cooking oil and inedible animal fats in list B. At the same time, the proposal to revise the RED II sets a target of 2.2% for advanced biofuels for 2030 made from Annex IX, list A.

In the United Kingdom (UK), the Renewable Transport Fuels Obligation (RTFO) currently establishes a renewable fuel share of 9.6% which they are proposing to increase to 14.6% by 2032 (GOV.UK, 2021). There is a subtarget for "development fuels" rising to 2.6% in 2031 (including double counting). The list of approved development fuels pathways is similar to Annex IX, list A, with the addition of renewable hydrogen and e-fuels (GOV.UK, 2021). In July 2021, the Department for Transportation launched a consultation for a SAF mandate. This would require annual jet fuel production of at least 10% by 2030, rising to 75% by 2050 (GOV.UK, 2021). The listed feedstocks for the SAF production

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include ligno-cellulosic material, material from biowaste, and residues from agriculture and forestry.

Fuels made from cellulosic materials and biogenic wastes are deemed "advanced" because they require more complex technology to convert them to biofuel compared to conventional, food and feed-based fuels (Baldino, 2019). However, despite the benefit of using these fuels to displace fossil fuel, these resources are limited. Thus, in this study we assess the availability of these feedstocks in each member state and the United Kingdom to help them understand the extent to which they can rely on domestically available low-carbon biofuels to decarbonize their transport sector.

This study updates Searle and Malins (2016), which assessed the 2009–2014 availability of key Annex 9A waste and residues in Europe (EU-28), and made projections for the years 2020 and 2030. Here, we present current (2020) feedstock availability in the EU-27 and UK separately and provide projections for 2030 and 2050. The three groups of waste and residues we consider are agricultural residues, forestry residues, and biogenic waste. The study considers as available only the feedstock that can be collected with no harm on the environment; thus, we take into consideration the protection of soil quality and agricultural, forestry, and waste management. We also consider how much of the feedstock is currently used or combusted for energy, since displacing a feedstock from its current use can lead to indirect increases in greenhouse gas emissions if the replacement for that material is resource-intensive or fossil fuel.

Methodology

We use the same methodology and assumptions as Searle and Malins, calculating the sustainable availability of agricultural and forestry residues and biogenic waste by subtracting from the total production the quantities already in use and the amounts left on site for soil preservation. Current uses include heat and power generation and animal feeding, for example. Changes in data sources and assumptions we have made compared to Searle and Malins are described below.

Estimating agricultural residue availability

In assessing the availability of agricultural residues, we take into account the following crops: barley, maize, oat, olives, rapeseed, rice (paddy), rye, soybeans, sunflower, triticale, and wheat. Searle and Malins, included sugar beet residues but we decided to omit it because of the likely difficulty in its collection.

Current year calculations of residue availability for the EU-27 and UK are based on data from FAOSTAT (2021). As in Searle and Malins, crop residue production per hectare is based on the yield of the main crop. We use crop production and yield averaged over the period 2015–2019 for the present-day calculation. The projections for crop production and yield in 2030 are taken from European Commission (2020). We extrapolate these values linearly to 2050, assuming that changes in crop production and yield from 2030 to 2050 will be equal to the rate of change in these parameters between 2020 to 2030; in other words, we assume half the annual rate of change from 2030 to 2050 as the European Commission projects for the period 2020 to 2030.

We updated a few other inputs to the agricultural residue analysis compared to Searle and Malins. In the analysis of the amount of residues necessary to leave in the field to protect soil quality, we updated tillage values with EUROSTAT (2021). We also updated data on other uses of agricultural residues in mushrooms cultivation, horticulture, and livestock, as in Searle and Malins, using FAOSTAT (2021) and EUROSTAT (2021).

One change we make in assumptions in the present study is to assume the same use of agricultural residues for heat and power in 2020, 2030, and 2050 as in 2012, whereas

Searle and Malins assumed an increase in use of this material for heat and power based on projections of increasing use of bioenergy in the National Renewable Energy Action Plans (NREAPs) for each country. We were unable to update the 2012 data on "other vegetable materials and residues" used in total primary production of energy by country because this product is no longer reported by EUROSTAT.

Estimating forestry residue availability

We calculate forestry residues based on data on total roundwood harvests from FAOSTAT (2021), and updated this for 2015 to 2019. We assumed it is considered as constant up to 2050 following Searle and Malins.

As in the case of agricultural residue, we assume the use of residues for energy will stay the same up to 2050, unlike Searle and Malins, who assumed an increase for 2020 and 2030. Searle and Malins estimated current use of forestry residues for heat and power based on statistics on bioenergy use from EUROSTAT, except for national biopower demand for Finland, Poland, and Sweden, for which estimates were taken from national statistics. For this study, we found updated values for Finland (Sevola, 2000) and Sweden (Natural Resources Institute Finland, 2021).

Estimating biogenic waste residues availability

Biogenic waste includes the following subgroups: paper and cardboard, wood waste, animal and mixed food waste, household and similar wastes, and common sludges. Unlike Searle and Malins, we exclude manure and animal feces. This is because we have published a separate analysis of biogas potential from livestock manure in Baldino et al. (2018). The waste current availability for EU-27 and UK is obtained through EUROSTAT data (2021) averaged over the years 2014, 2016, and 2018 since other intermittent years were not available.

EUROSTAT reports waste treatment by type: landfill, incineration, incineration for energy recovery, recycling, and backfilling. As in Searle and Malins, the waste that is recovered for any useful purpose is not considered available; this includes recycling and backfilling. The amounts considered available for biofuel production come from three types of treatment: disposal through landfill, incineration, and incineration for energy recovery. This is different from Searle and Malins, where only the disposal from landfill and incineration were considered available. The reason for now considering waste incinerated for energy recovery as available is the poor energy efficiency of waste incinerators (Grosso et al., 2010).

We base our estimate of the waste that is recycled and therefore not available on the targets in the Waste Framework Directive 2008 (European Commission, 2008). Its recent revision includes new and ambitious targets for re-use and recycling of waste residues: 55% to be achieved by 2025, 60% by 2030 and 65% by 2035. For the year 2050, we assume 80% recycling. In projecting the availability for 2030 and 2050, we assume waste generation will increase proportionally with the population of each member state, taking population projections from (UN, 2021). We then subtracted the amount that will be recycled (60% in 2030 and 80% in 2050).

Results

Results for the updated analysis on sustainable availability of agricultural residues, forestry residues, and biogenic wastes are presented below. Table 1 shows the results for agricultural residues for EU-27 and the UK. France, Germany, and Romania have by far the largest sustainable availability due to their large agricultural sector. We see an increase in sustainable availability of agricultural residues over time in all countries except Finland. The increase is due to expectations of increasing crop yields, which would also increase residue production. The reduction in residue availability in Finland is because that country disproportionately grows crops that the European Commission expect to decline in production or yield over time.

Table 1. Current agricultural residue production, sustainable field retention for soil quality, consumption in heat, power, biogas, and other uses, and final sustainable availability for biofuel production in million tonnes per year (dry basis).

	Heat, power and biogas	Other uses (livestock, mushrooms and horticulture)	Retained for soil quality	Current (2020)		2030		2050	
				Agricultural residue production	Sustainable availability	Agricultural residue production	Sustainable availability	Agricultural residue production	Sustainable availability
Austria	0.32	0.34	3.05	4.86	1.15	5.05	1.35	5.24	1.58
Belgium	0.16	0.57	0.97	1.97	0.27	2.00	0.32	2.03	0.36
Bulgaria	0.00	0.23	9.21	12.69	3.25	13.02	3.59	13.33	3.94
Croatia	0.00	0.11	2.27	3.63	1.25	3.89	1.44	4.16	1.64
Cyprus	0.00	0.03	0.04	0.05	0.00	0.05	0.00	0.05	0.00
Czech Republic	0.15	0.24	5.65	8.06	2.02	8.12	2.16	8.18	2.30
Denmark	0.54	0.51	4.73	7.76	1.98	7.59	1.99	7.42	2.00
Estonia	0.27	0.04	0.82	1.38	0.25	1.37	0.26	1.35	0.27
Finland	0.02	0.15	2.00	3.32	1.15	3.17	1.09	3.02	1.03
France	0.37	3.38	39.92	59.78	16.11	60.80	17.77	61.77	19.39
Germany	0.00	2.85	20.44	39.07	15.77	38.90	15.99	38.71	16.20
Greece	0.26	0.41	2.71	3.94	0.56	4.03	0.63	4.11	0.71
Hungary	0.40	0.36	9.58	17.35	7.01	17.90	7.73	18.45	8.40
Ireland	0.00	1.32	0.69	1.62	0.00	1.55	0.00	1.48	0.00
Italy	0.24	1.56	11.56	19.08	5.71	20.26	6.58	21.42	7.38
Latvia	0.00	0.08	1.89	2.86	0.89	2.88	0.94	2.89	0.98
Lithuania	0.01	0.20	3.63	5.25	1.41	5.28	1.51	5.32	1.60
Luxembourg	0.01	0.03	0.11	0.14	0.00	0.14	0.00	0.14	0.00
Malta	0.00	0.01	0.01	0.01	0.00	0.01	0.00	0.01	0.00
Netherlands	0.34	1.89	0.40	1.04	0.00	1.05	0.00	1.06	0.00
Poland	2.69	2.44	18.65	27.49	3.71	27.20	4.13	26.88	4.34
Portugal	0.41	0.40	0.68	1.22	0.00	1.24	0.00	1.27	0.00
Romania	0.00	1.23	19.56	30.89	10.11	32.09	11.22	33.26	12.26
Slovakia	0.03	0.10	3.24	4.63	1.27	4.79	1.40	4.94	1.55
Slovenia	0.01	0.08	0.33	0.53	0.11	0.55	0.12	0.56	0.14
Spain	0.96	2.80	16.92	23.01	2.33	22.88	2.44	22.74	2.59
Sweden	1.30	0.24	2.51	4.74	0.69	4.66	0.69	4.58	0.69
EU 27	8.48	21.61	181.55	286.37	77.01	290.45	83.34	294.36	89.35
United Kingdom	1.32	2.59	9.60	19.44	5.93	19.30	6.05	19.15	6.16

Table 2 show the results for forestry residues for all member state in EU-27 and UK. According to the data sources and assumptions described in the methodology, the availability is the same in the current year, 2020, in 2030 and 2050. As in Searle and Malins, we find the countries with the highest availability are Finland and Sweden.

Table 2. Forestry residue production, sustainable field retention, consumption in heat and power, and final sustainable availability for biofuel production, in million tonnes per year (dry basis), for the current year (2020), 2030, and 2050. Values are the same in all years.

	Forestry residue production	Retained for soil quality	Heat and power	Sustainable availability
Austria	1.77	1.37	0.40	0.00
Belgium	0.64	0.49	0.13	0.02
Bulgaria	0.89	0.69	0.11	0.10
Croatia	1.01	0.81	0.07	0.12
Cyprus	0.00	0.00	0.00	0.00
Czech Republic	2.00	1.53	0.18	0.30
Denmark	0.42	0.31	0.11	0.00
Estonia	1.46	0.88	0.08	0.50
Finland	13.15	7.24	1.02	4.89
France	8.23	6.57	0.90	0.76
Germany	7.90	5.78	1.14	0.98
Greece	0.28	0.20	0.08	0.00
Hungary	1.11	0.82	0.11	0.18
Ireland	0.23	0.15	0.02	0.06
Italy	2.53	2.11	0.42	0.00
Latvia	1.60	1.12	0.20	0.29
Lithuania	0.92	0.66	0.10	0.15
Luxembourg	0.05	0.04	0.00	0.01
Malta	0.00	0.00	0.00	0.00
Netherlands	0.42	0.26	0.09	0.08
Poland	4.77	2.70	2.07	0.00
Portugal	2.28	1.96	0.11	0.21
Romania	2.49	1.93	0.40	0.17
Slovakia	1.22	0.95	0.04	0.22
Slovenia	0.61	0.53	0.06	0.02
Spain	2.50	2.01	0.35	0.14
Sweden	16.22	10.34	3.87	2.00
EU 27	74.69	51.43	12.06	11.20
United Kingdom	0.90	0.62	0.08	0.20

Table 3 shows the available biogenic waste in EU-27 and UK per waste category derived from landfill, incineration, and incineration for energy recovery disposal. The highest availability is found in France and Germany which are the largest waste producers due to a high amount of waste generation per inhabitant and population size.

The highest amount of biogenic waste available for biofuel production in the EU-27 comes from households and sorting residues, which mainly go to energy recovery. In general, we see a higher quantity of sustainable available waste compared to Searle and Malins. This is due to the fact that we consider waste incinerated for energy recovery treatment as available.

For some countries the availability for 2030 (or 2050) is stable respect to the current (or 2020) availability. The reason for this is these countries are already able to recycle more than the target of the Waste Framework Directive.

Table 3. Current (2020) generation of waste by category in thousand tonnes per year, and total sustainable availability in the current year (2020), 2030, and 2050 in million tonnes per year (biogenic fraction; dry basis).

	Paper and cardboard wastes	Wood wastes	Animal and mixed food waste	Vegetal wastes	Household and similar wastes	Sorting residues	Common sludges	2020 sustainable availability	2030 sustainable availability	2050 sustainable availability
Austria	0.00	0.00	0.00	0.00	8.78	31.37	6.73	0.05	0.05	0.05
Belgium	1.16	828.82	24.67	9.73	1567.48	407.44	89.36	2.93	2.93	2.59
Bulgaria	23.18	172.13	13.70	100.54	620.80	252.70	33.87	1.22	0.76	0.32
Croatia	0.11	20.24	0.87	6.51	509.25	30.04	8.57	0.58	0.36	0.15
Cyprus	0.01	5.49	1.29	3.55	161.54	37.44	11.73	0.22	0.10	0.04
Czech Republic	10.05	19.10	7.95	21.57	1257.89	74.47	14.48	1.41	1.30	0.64
Denmark	1.01	42.65	1.65	40.29	988.75	102.53	91.79	1.27	1.27	0.66
Estonia	0.07	137.75	0.31	0.23	122.10	24.98	0.49	0.29	0.25	0.11
Finland	38.08	2635.79	15.23	45.10	511.20	90.33	245.08	3.58	2.40	1.18
France	164.36	2106.37	221.42	133.82	8745.95	1859.29	925.02	14.16	11.54	5.85
Germany	58.43	6886.49	187.55	478.42	6133.11	2835.93	1299.86	17.88	14.91	7.18
Greece	1.24	17.56	15.57	33.25	1705.87	219.47	78.46	2.07	1.08	0.49
Hungary	1.55	12.79	16.38	12.17	785.11	175.24	29.30	1.03	0.96	0.43
Ireland	0.01	40.97	10.99	3.94	292.04	122.15	2.01	0.47	0.47	0.47
Italy	1.47	673.88	26.86	27.12	1707.47	3093.43	545.56	6.08	6.08	4.95
Latvia	0.10	10.20	0.27	7.99	103.41	97.85	0.66	0.22	0.17	0.07
Lithuania	0.05	22.19	0.41	1.91	96.80	105.57	4.27	0.23	0.23	0.15
Luxembourg	0.00	35.58	0.00	1.71	58.35	12.70	0.97	0.11	0.11	0.08
Malta	0.01	5.20	2.00	2.17	59.50	19.73	9.93	0.10	0.06	0.03
Netherlands	1.25	1188.24	113.40	82.25	2170.97	658.47	394.23	4.61	4.61	2.53
Poland	2.60	1314.27	24.66	10.27	3092.92	747.80	103.56	5.30	4.66	2.10
Portugal	0.30	9.73	3.88	3.90	903.29	71.43	73.49	1.07	1.07	0.71
Romania	4.50	1321.98	13.88	113.71	1447.68	183.47	97.65	3.18	2.15	0.96
Slovakia	1.69	147.31	13.21	9.68	572.89	29.60	29.42	0.80	0.68	0.31
Slovenia	0.07	78.79	0.31	0.03	43.51	28.27	6.54	0.16	0.16	0.13
Spain	3.34	111.35	35.10	27.50	3165.89	2667.45	363.13	6.37	6.37	3.33
Sweden	1.11	1757.13	7.16	20.24	1019.14	192.41	37.11	3.03	2.11	1.13
EU 27	315.74	19602.04	758.71	1197.59	37851.68	14171.55	4503.26	78.40	66.83	36.66
United Kingdom	11.14	1351.98	196.20	52.68	5782.33	2457.96	223.81	10.08	10.08	8.03

The current total sustainable availability for the EU-27 and the UK and the projections for 2030 and 2050 are shown in Figure 1. We find that while forestry residues are kept constant according to our assumption, and the availability for biogenic waste is decreasing over time due to the Waste Framework Directive targets and decreasing population, agricultural residues are slighting increasing from 2020 to 2030 (8.2%), and from 2030 to 2050 (7.2%). The combined effect of these three trends is a general decrease in waste and residue availability across EU member states and the UK in 2030 and 2050. This is particularly true for those countries where biogenic waste makes up a large share compared to the countries that have higher agricultural production (Figure 2 and Figure 3).

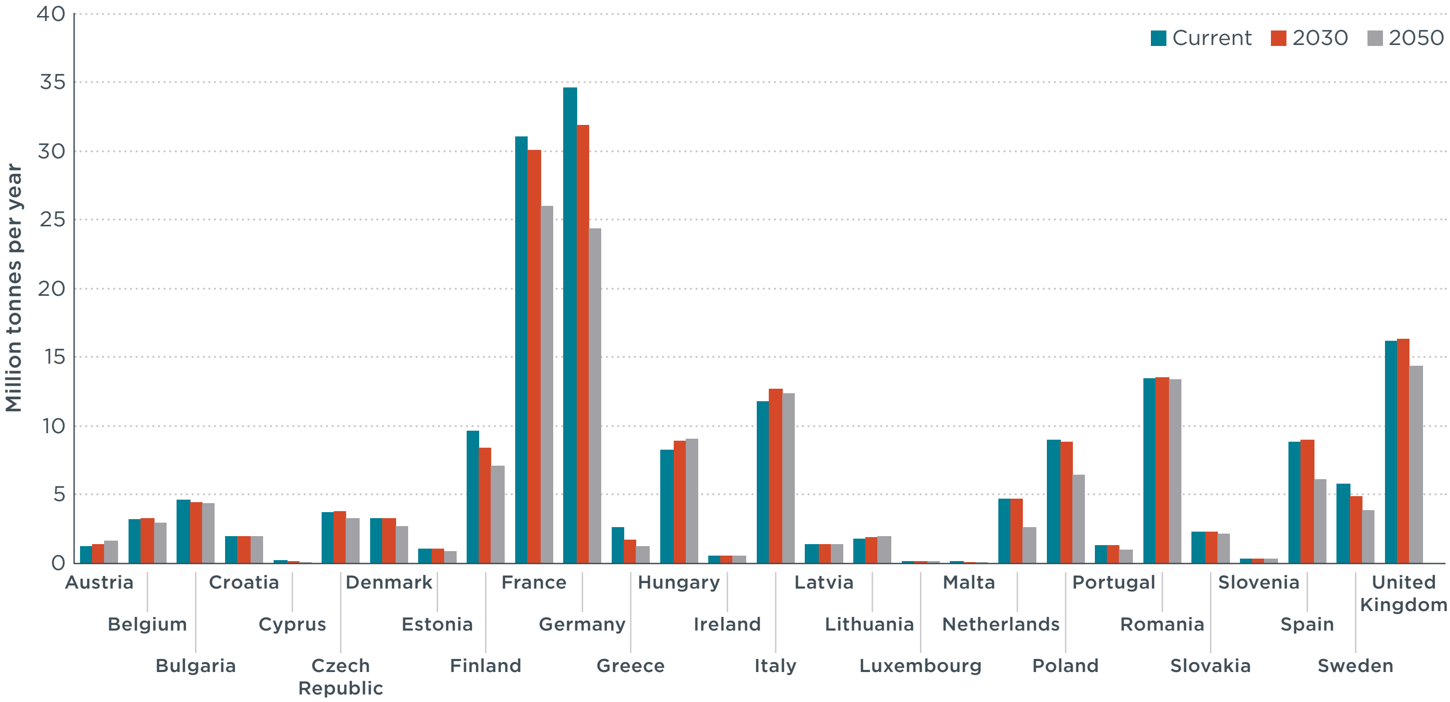

Figure 1. Total sustainable availability of waste and residues in the EU-27 and the UK (million tonnes per year)

Figure 2. 2030 share of waste and residues in EU-27 and UK (percentage)

Figure 3. 2050 share of waste and residues in EU-27 and UK (percentage)

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