Peat extraction, trade and use in Europe: a material flow analysis

Olivier Hirschler, Bernhard Osterburg

Thünen Institute, Coordination Unit Climate, Braunschweig, Germany

SUMMARY

Peat is a fossil material used as a component of horticultural growing media as well as fuel. In a context of climate debates, several European countries have decided to address greenhouse gas emissions from peat extraction and use. In this situation, reliable data on peat amounts are needed as a basis for public discussion and policy-making. However, the quantity and quality of the available data is generally considered insufficient. In this context, this article provides a reliable overview of the peat market in Europe for the period 2013–2017 based on the systematic collection, selection and combination of available data. The results show that around 20 million tons of peat are extracted yearly in Europe, including 62 % for energy and 38 % for non-energy purposes. Energy peat is consumed where it is produced, whereas non-energy peat is exported from Northern Europe to Western Europe on a massive scale. In some countries, the data combination reveals incompatibilities between extraction and trade data, with an evident case for Germany. The accuracy and the timeliness of the results could be improved with more up-to-date information on the composition of peat and growing media as well as an adaptation of the definition used in trade statistics.

KEY WORDS: energy, growing media, horticulture, peat market

INTRODUCTION

Peat is a heterogeneous mixture of more or less decomposed plant (humus) material that has accumulated in a water-saturated environment and in the absence of oxygen (GME 2020). Peat consists of dead biomass with a high carbon concentration and forms peatland soils. These peatlands cover 3 % of the world land area while constituting 30 % of the global terrestrial biomass (Parish *et al.* 2008). Peat extraction is the process of removing peat raw materials from a peatland and collecting them (GME 2020) and generally takes place on previously drained peatlands. Peat extraction and use as fuel has taken place for centuries in Northern Europe (Gerding *et al.* 2015, Bord na Móna 2017, IVG 2022) and continues today in some regions for the production of electricity and heat. Since the second half of the 20th century, peat has also become a central constituent of horticultural growing media. Peat used in horticulture is almost exclusively extracted from bogs and consists of dead *Sphagnum*. It should not be confused with fresh *Sphagnum*, which is also used to a smaller extent as a growing media constituent. Peat is extracted for other purposes as well in minimal amounts. A review of the world peat extraction data estimated that around 80 % of the peat extraction worldwide takes place in Europe (Hirschler & Osterburg 2021).

Due to the slow pace of its natural formation, peat is considered fossil by the International Panel on Climate Change (IPCC) (Garg *et al.* 2006). Peat extraction, through the destruction of peatland soils and the release of long-term stored organic carbon, constitutes one the threats to the climate regulation provided by peatlands. These greenhouse gas (GHG) emissions, mostly in form of carbon dioxide (CO_2), occur during (1) the combustion of extracted peat (off-site emissions from fuel peat), (2) the mineralisation of extracted peat (off-site emissions from peat for non-energy use), for example in horticulture, and (3) the mineralisation of peatland soils on the extraction site (on-site emissions). Most of the emissions originate from the extracted peat itself (off-site). GHG emissions from peat are reported by parties of the United Nations Framework Convention on Climate Change (UNFCCC). Off-site emissions from fuel peat consumption are reported in the category 1. Energy. Emissions from extracted peat for non-energy use (off-site) and from all extracting sites (on-site) are reported in the land use, land use change and forestry sector (LULUCF) in the sub-category 4.D Wetlands, which corresponds to anthropogenic emissions from flooded land and managed peatlands that are not used for agriculture, forestry or settlements (Blain *et al.* 2006, Hiraishi *et al.* 2014). In the European Union (EU 27, as of 2022), the total emissions from fuel and horticultural peat reported under the UNFCCC for the year 2019 amounted to 21.4 million tons CO_2-eq. With 16 % of the anthropogenic emissions from organic soils in the EU27, peat extraction is responsible for a limited share of the total emissions from peatlands compared to agriculture and forestry use. However, the extraction of peat causes the highest emissions per hectare in comparison with other uses of organic soils.

In the context of growing climate concerns (UN Climate Change 2015), the importance of preserving the carbon sequestration and storage capacity of peatland soils has been widely recognised (Parish *et al.* 2008, Joosten 2012, Leifeld & Menichetti 2018) and constitutes today the principal criticism of peat extraction. Peat extraction is also linked to the destruction of habitats and biodiversity (Lindholm & Heikkilä 2016). However, this negative effect is not always clear in cases where the extraction takes place on formally drained peatlands in agricultural use and when a restoration takes place after use, as is the case at least for new extraction sites in Germany. The discussion on the future of peat extraction focuses mostly on the balance between the environmental costs for climate and biodiversity and the socio-economic benefits of the industry directly, for example as an employer in remote regions, or indirectly along the supply chain, especially as a supplier of growing media to the horticulture sector as input for the production of food and ornamental plants.

In some countries, governments have decided to address the extraction and/or the use of peat, and developed strategies to achieve and support their goals. In Ireland, peat extraction for electricity and heat production is planned to be phased-out by 2030 (Bord na Móna 2015). The shutdown of peat extraction in Ireland in 2019 was the result of a court decision regarding extracting licenses and not a political decision. In Finland, peat for use as fuel is planned to be at least halved by 2030 (Finnish Government 2019). The United Kingdom, Switzerland, Norway, Germany and Ireland have developed strategies to strongly reduce or phase-out the use of peat in horticulture (Federal Council of Switzerland 2012, BMUB 2016, Ministry of Climate and Environment 2017, HM Government 2018, Norwegian German Federal Government 2019, Government of Ireland 2022). In the Alpine Convention (1998), ratified by the European Union and countries of the Alpine region, the parties also stated that “the use of peat shall be discontinued completely in the medium term”. In the European Union, off-site emissions from fuel peat for electricity and heat are integrated in the EU Emissions Trading System (ETS) since 2005 and in the EU climate targets since 2009 (EC 2022). As set by the LULUCF Regulation (EU) 2018/841, emissions from the category Wetlands will also be accounted for in the achievement of the legally binding mitigation targets of the EU member states from 2026 onwards. As a result, emissions from peat extraction are expected to gain relevance in climate policy in the near future.

In the context of growing debates on national and European level, a precise and common understanding of the peat market is needed for all stakeholders involved, especially those responsible for the preparation and the monitoring of policies. However, data on peat extraction on national level are spread across separate sources and available in different units, which makes it difficult to obtain an overview of peat flows. Moreover, systematic and publicly available data on peat use in the horticultural sector are still lacking. For this reason, the development of the peat reduction strategies in the UK and Switzerland included national projects to quantify peat consumption (Defra 2009, BAFU 2021). This is also one aspect of the project MITODE in Germany, in which the authors of the present study are involved. In order to calculate emissions in the category Wetlands, UNFCCC parties also need reliable data on peat extraction, which are not systematically available. In Germany, for example, the poor data availability has led to criticism of the reported emissions (Hofer & Köbbing 2020). At several congresses (IPS Congress Bremen 2019, IPC Tallinn 2021), representatives of the International Peatland Society (IPS) have stressed the lack of available data on peat and growing media. For this reason, the IPS and the industry group Growing Media Europe (formerly EPAGMA, European Peat and Growing Media Association) have commissioned studies on the growing media market based on surveys among national industry groups in the main European countries for peat and growing media: Bohlin (2002), Altmann (2008), Schmilewski (2008), Schmilewski (2017) and one recently carried out by Rabobank (unpublished as of 05 May 2021). However, the existing studies focus on growing media production without quantifying trade flows and the end use of peat for horticulture.

In this current situation, this study aims to develop and discuss a repeatable method for the collection, selection and combination of available data. The expected output of this method is to (1) provide a reliable, consistent and broad picture (“best guess”) of the amounts of peat extracted, traded and consumed in Europe during the period 2013–2017 for which enough data are available. These results shall improve public information on the peat market available to decision makers, stakeholders and researchers in the field of peat and peatlands, growing media and horticulture. Another goal is to (2) identify discrepancies in data, which indicate uncertainties linked to the method as well as the quality of available data. The method could be used if additional data, especially more recent data on growing media production, are published in the future.

METHODS

Overview of the approach

The proposed method is based on the concept of the material flow analysis (MFA) defined by Brunner & Rechberger (2004). An MFA is based on the principle of mass conservation along the supply chain by balancing input and output in a given system. The use of this physical approach as a frame assures the coherency of the results and enables the identification of discrepancies between existing sets of data when a balance cannot be respected. The method is carried out using the following steps: (1) the collection of data available on peat in Europe, (2) the definition of the model structure, (3) the resolution of the model including data selection, data combination, the identification of discrepancies and data correction.

Data collection

Trade data

We collected peat trade data from the Comtrade (UNSD 2020) and the Eurostat (Eurostat 2020) databases. Using the mirroring method (Bacchetta *et al.* 2012), import statistics were taken to determine the flux between all world countries. The unit is the metric kilogram. Data were found under the international Harmonized System number 2703 (Referred in the following as HS2703) defined as "Peat; (including peat litter), whether or not agglomerated". The definition of the products EU Common Customs Tariff includes earth mix in which peat characterises the product, with a minimum of 75 % amount of peat by weight as set by the Regulation (EU) 3541/85. Bulk and transformed peat for energy and other purposes are also included under HS2703. Specific import data on energy peat were taken from Eurostat. No data could be found on import of energy peat in Belarus, Russia, Switzerland or other countries outside Europe, which are not covered by Eurostat.

Extraction and consumption data

We collected data on extraction (total, energy, non-energy) and consumption (total, energy) using a systematic internet research during the winter 2020/2021, using sources in English, German, French, Spanish and Russian with the help of publicly available translators. Data on peat extraction in natural unit (tons or cubic metres) could be found on national official statistics websites as well as geological surveys' websites. For France and Germany, data on peat extraction was communicated by the industry groups AFAIA and Industrieverband Garten e.V. (IVG). Data were also found in the following international databases: the Eurostat database in Economy-wide material flow accounts (Eurostat 2021a) and Energy statistics (Eurostat 2021b), the UN database in Industrial Commodity and Energy category (UNSD 2021) and the United States Geological Survey (USGS 2021). In the international databases, the data are available in tons. Some data in natural units were found in countries' national GHG inventory submissions available in the UNFCCC Database (UN Climate Change 2022) and the countries' National Inventory Report under the UNFCCC (NIR). In some cases, a back calculation of the original peat extraction data using GHG emissions data or energy data in terajoules was also possible using emission factors and net calorific values declared in the NIR. The primary extraction data chosen for each country before combination are presented in Table A1 in the Appendix.

Model structure

In order to compensate for the lack of information available and assure the consistency of the method, we based the model on numerous assumptions regarding the composition of peat and growing media, the data selection and the data combination. These assumptions are available in Table A2 and the most important ones are justified in the following paragraphs.

Core variables

The study concerns the total national territories of countries in Europe including Turkey and Russia. For each of them, we conducted the material flow analysis from extraction to consumption for peat differentiated between energy and non-energy purposes with four core variables: extraction, consumption, imports, and exports. Peat is considered as extracted when it is brought outside of the peat extraction site. Energy peat is considered as consumed when it is burned for the production of energy or heat. Peat for horticulture is considered consumed when a plant is seeded/planted in the growing media containing the peat or when it is integrated into the soil. Accordingly, the production of growing media through the mixing of peat with other constituents and fertilisers is not considered as peat consumption. Also, the trade of peat in form of bulk material and in growing media is considered but not the trade of plants, even if peat might be present in the growing media in which they are planted. Non-energy peat consumption also includes special uses like soil improvers, the production of activated carbon, animal husbandry, balneology, cosmetics, therapeutic use and whisky production.

Units

The units are the metric kilotons (kt) or megatons (Mt) and thousand metric cubic metres (1,000 m³) or million cubic metres (Mm³). In order to calculate conversion factors between tons and cubic metres (further referred as density factors), the composition of the different flows needs to be determined. This information is particularly important for the non-energy sector for which input data are available in different units. For this, we used the latest comprehensive dataset available on the use of constituents for growing media production in Europe provided by Schmilewski (2017). These data are based on surveys among the industry for the year 2013 and are given in cubic metres of growing media constituents before mixing obtained following the European norm on determination of a volume quantity of soil improvers and growing media EN12580 (CEN 2013). Therefore, we consider that all data on volumes of non-energy flows used in the model correspond to this norm (Assumption 1).

Equations

The model is based on the equations presented in Table A3, which are respected at all times. The equations (I), (II) and (III) reflect the mass conservation principles of the MFA and are the base of the material balance. Due to lack of data, we could consider neither variations of stocks in the equation (I) (Assumption 2), nor mass or volume losses along the supply chain due to shrinkage, carbon loss in the atmosphere or variations of the water content (Assumptions 3a, 3b and 3c).

Time period

The time period considered is from 2013 to 2017 for the following reasons: The use of a five-year average is expected to limit the effect of the non-consideration of changes in stocks. Moreover, the study of Schmilewski (2017) used for the determination of growing media composition applies to the year 2013 and constitutes the most recent dataset for this purpose. Therefore, we chose to apply the method to the last five-year period that included the year 2013 and did not apply it to more recent periods, although more recent data on extraction and trade are available.

Flow composition

We differentiated extraction and trade flows in order to calculate the density factors and, in the case of non-energy trade flows containing mixtures of peat and other constituents, the peat rate.

We differentiated energy peat between milled and sod peat (differentiation due to the extracting process) (Assumption 4). This differentiation was chosen due to the information available in statistics and studies. Input data on the composition of extracted energy peat are presented in Table A4.

We assumed non-energy trade flows to be limited to two types of products: growing media and bulk peat (Assumption 5). Growing media are defined following the Fertilising Products Regulation (EU) 2019/1009 as products other than soil in situ, the function of which is for plants or mushrooms to grow in. Growing media are themselves differentiated between products for the hobby market and products for the professional market. Growing media often consist of a mixture of peat and other constituents like wood fibres, bark products, coco products, composted products, other biomass products and mineral products. In this study, we define bulk peat as peat that was not mixed or transformed into other products. Bulk peat consists exclusively of peat and can theoretically be used for the production of growing media as well as non-energy purposes. The non-energy peat consumption is calculated by balancing extraction and trade and there is no differentiation of flows within the country. Therefore, the non-energy peat consumption can neither be differentiated between growing media for the professional and for the hobby market, nor between growing media and peat for other uses.

We differentiated non-energy peat between three types of peat (Assumption 6) based on the humification grade on the von Post scale as used by Schmilewski (2017): White raised bog peat (H1–H5), black raised bog peat (H6–H10) and fen peat. According to the definition of the available trade statistics (see Trade data), other growing media constituents are also considered in non-energy trade flows. Data on the composition of growing media produced were mostly taken from the study of Schmilewski (2017) or from other national industry sources in case they applied better to the period 2013–2017. If no information could be found, the average growing media composition for all countries from Schmilewski (2017) was taken as default value. Some information on the proportion of bulk peat in exports in volume percentage was obtained from industry experts but most of the data used were interpreted from the literature or assumed.

The data on composition of extracted non-energy peat and exported growing media for each country obtained as a result of the model resolution are available in Table A5. The density factors for each constituent used are presented in Table A6.

The elements and the boundaries of the system considered are illustrated in Figure 1.

Model resolution

The process of data collection, selection and combination is presented in Figure 2.

Data selection

In order to assure the consistency of the model, the use of the material balance equation (I) implies the calculation of one of the variables using the others and thus their prioritisation to be used as input. The calculated variable is considered the "apparent flow". In equation (I), we decide to prioritise extraction and trade data over consumption data for energy as well as non-energy peat (Assumption 7), which implies that the consumption is systematically the calculated apparent flow. This is justified by the fact that most peat consumption data available in statistics are based on aggregates and not on primary data.

We assumed that trade data used, based under the international Harmonised System number 2703 (HS2703), include all products containing peat, irrespective of the peat content (Assumption 8), despite the official definition. This is justified by discussions with the industry implying that growing media under 75 % peat content are also declared under HS2703. For the selection of total trade data (HS2703), we generally prioritised Eurostat over Comtrade because the Eurostat definition is more adapted to the definition of the study (country of consignment) (Assumption 10). Based on the equation (III), total trade data (HS2703) and specific trade data on energy peat are combined to calculate non-energy trade data (including growing media).

In the case of multiple available datasets for peat extraction, the input data need to be determined through a selection process based on (1) the available information on the methodology, (2) whether it is primary data or obtained from calculation, (3) the geographical scope (national, European, international) of the source with priority given to national data (Assumption 11).

Data combination

The steps of the data combination are presented in Table A7.

Balancing the material flows using equations (I) and (III) implies using data in a single unit. In the case of energy peat, most of the data are available in tons and the trade flow in tons is considered only constituted by peat, which makes the resolution of the model possible in a few steps. However, for non-energy peat, a majority of the data on extraction are given in cubic metres and data on composition of non-energy peat and peat products are given in volume percentage, whereas undifferentiated trade data are available in tons. Therefore, in order to

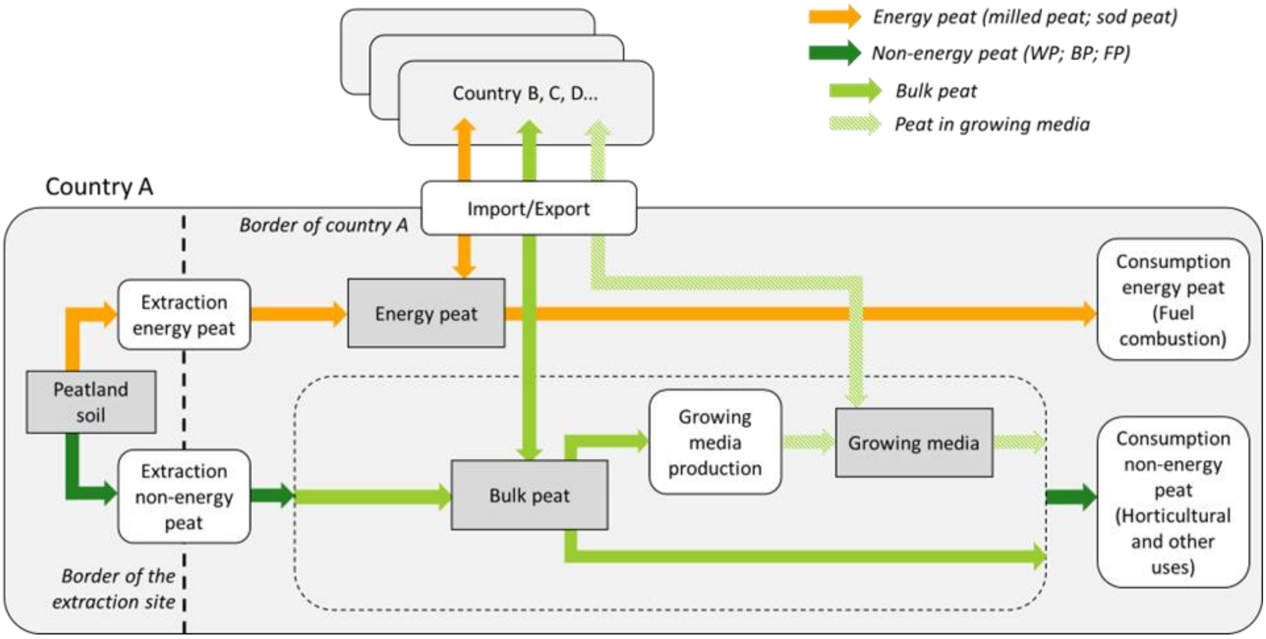

Figure 1. Schematic representation of the system considered. WP = White bog peat; BP = Black bog peat; FP = fen peat.

balance the model in tons, densities of the different flows need to be calculated first in order to convert the data on composition in mass percentage and the quantities in tons. Since the composition of imports can play a role in the composition of exports (steps NE7 and NE8), the modelling process for non-energy peat includes a loop (step NE13).

Identification of discrepancies and data correction
After running the model, the plausibility and the sensibility of the value obtained for consumption was tested. The value was considered implausible in case it was negative (Assumption 22a), or too uncertain by a variation of more than 100 % by a 10 % variation of the input variables (extraction and trade) in equation (I) (steps E3 and NE15 presented in Table A7) (Assumption 22b). In these cases, we used input data for consumption and corrected the value of one other variable. For non-energy peat, we decided to prioritise trade data and correct extraction data (Assumption 23). This is justified by the fact that all traded products are officially registered by public authorities following a comparable methodology, whereas the method for other statistics depends on the source (official statistics, industry group, scientific study…) and can be subject to discrepancies (for example minimum size of companies for statistics, partial representativity of an industry group…). The correction of non-energy peat extraction is realised using equation (I) based on input on peat consumption or the production of growing media. In this case, the peat extraction information obtained is an apparent flow. In the case of discrepancy in the energy peat balance, the extraction data are prioritised and the export data are corrected (Assumption 24) using energy consumption data as input.

RESULTS

Countries' peat balance

The results of the material balance for energy and non-energy peat and the method used to obtain the peat extraction values are presented in Table 1.

Overview of Europe

A total amount of 19.6 Mt peat per year, equivalent to 66 Mm³, was extracted in Europe (excluding Russia) for the period 2013–2017, including 16.6 Mt or 56.3 Mm³ in the EU27.

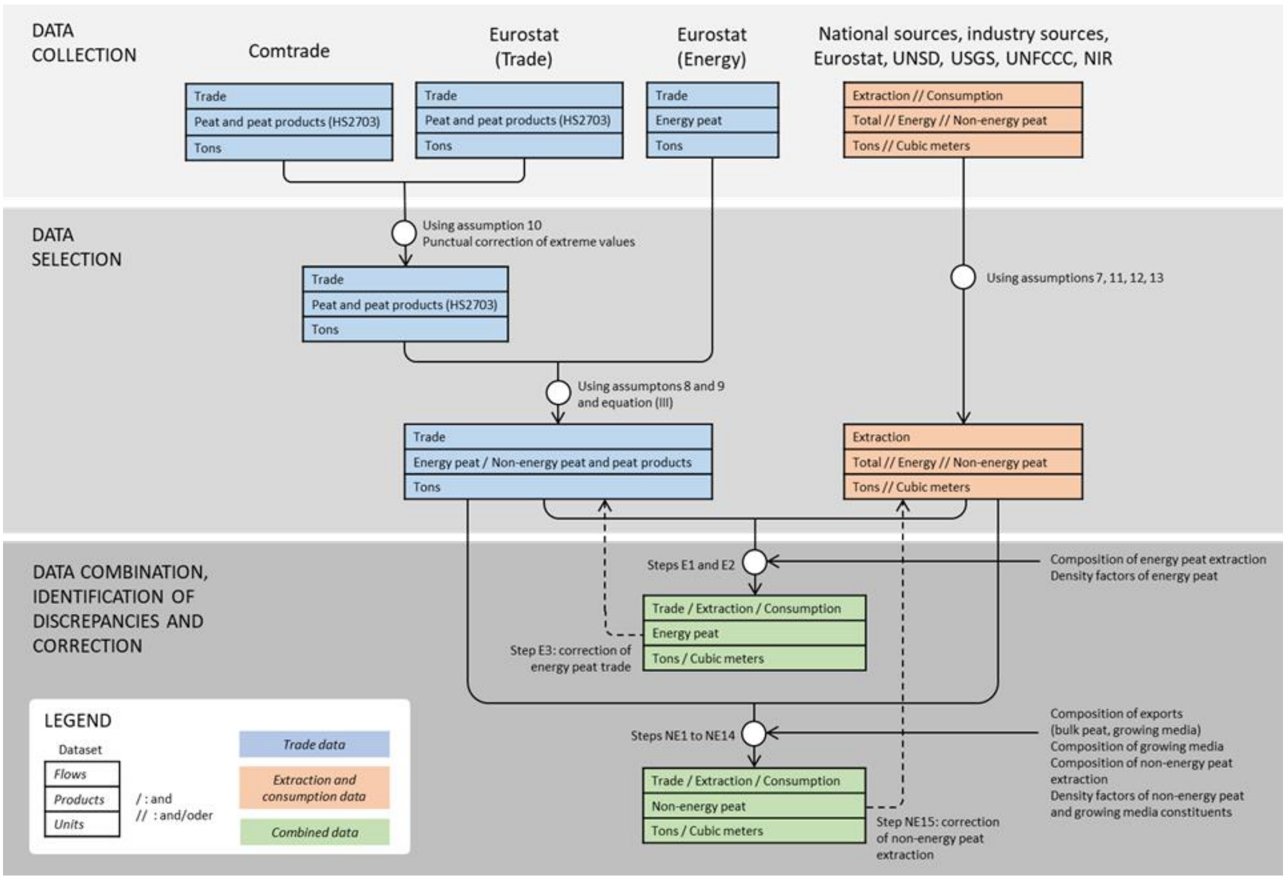

Figure 2. Data collection, selection and combination.

Table 1. Material balance of peat for energy and non-energy purposes for each country. Average amounts per year for the period 2013–2017. Country codes: ISO 3166 Alpha-3 code available at https://www.iso.org/obp.

Category	Country code	Extraction			Import	Export	Consumption
		kt	1,000m³	(source)	kt	kt	kt
Energy peat							
	FIN	4,665	14,400	(a*)	44	3	4,706
	IRL	4,564	13,603	(a)	0	0	4,564
	BLR	1,641	5,110	(a)	0	114	1,526
	RUS	1,148	3,409	(a)	0	17	1,131
	SWE	551	1,637	(a*)	85	24	613
	UKR	494	1,468	(a)	11	1	505
	EST	155	461	(a)	0	44	112
	LTU	60	165	(a)	61	14	108
	GBR	8	25	(a*)	0	0	8
	LVA	4	12	(a)	1	1	4
	ROU	4	12	(a)	15	0	19
	AUT	0.3	1	(a)	0	0	0.3
	All other countries	0	0	(a)	0	0	0
	EU27	**10,004**	**30,290**		**207**	**85**	**10,125**
	Europe	**12,147**	**36,893**		**218**	**201**	**12,164**
	Europe + Russia	**13,295**	**40,303**		**218**	**218**	**13,295**
Non-energy peat							
	DEU	2,154	7,152	(c*)	912	1,930	1,136
	LVA	1,133	5,430	(c)	51	1,140	44
	RUS	989	3,952	(a)	15	82	922
	LTU	758	3,466	(c*)	49	722	85
	IRL	692	2,043	(c)	11	634	69
	EST	608	2,730	(c)	5	581	32
	FIN	385	1,604	(a*)	4	53	336
	SWE	354	1,586	(a*)	15	86	283
	POL	298	1,185	(b*)	206	41	463
	GBR	268	987	(b*)	408	15	661
	BLR	186	745	(a)	13	92	107
	TUR	161	642	(b)	83	1	243
	UKR	111	442	(a)	6	29	88
	ESP	88	353	(b)	174	16	246
	NOR	68	270	(a*)	24	1	91

Category	Country code	Extraction			Import	Export	Consumption
		kt	1,000m³	(source)	kt	kt	kt
Non-energy peat (continued)							
	HUN	61	246	(a*)	46	23	85
	DNK	45	154	(b*)	87	36	96
	FRA	25	83	(a*)	495	11	509
	BIH	10	40	(c)	12	14	8
	ROU	0	0	(a)	18	2	16
	AUT	0	0	(a)	110	6	104
	BEL	0	0	(a)	462	247	214
	BGR	0	0	(a)	6	0	6
	CYP	0	0	(a)	7	0	7
	CZE	0	0	(a)	97	29	68
	GRC	0	0	(a)	42	2	40
	HRV	0	0	(a)	49	1	49
	ITA	0	0	(a)	466	6	460
	LUX	0	0	(a)	5	0	5
	MLT	0	0	(a)	2	0	2
	NLD	0	0	(a)	1,599	593	1,006
	PRT	0	0	(a)	35	2	33
	SVK	0	0	(a)	56	7	49
	SVN	0	0	(a)	27	2	25
	ALB	0	0	(a)	4	0	3
	CHE	0	0	(a)	74	0	74
	MDA	0	0	(a)	7	0	7
	MKD	0	0	(a)	6	0	6
	MNE	0	0	(a)	3	0	3
	SRB	0	0	(a)	14	3	11
	EU27	**6,602**	**26,032**		**5,038**	**6,170**	**5,470**
	Europe	**7,406**	**29,159**		**5,692**	**4,655**	**6,772**
	Europe + Russia	**8,395**	**33,111**		**5,707**	**6,407**	**7,695**
Total							
	EU27	**16,605**	**56,322**		**5,245**	**6,256**	**15,595**
	Europe	**19,553**	**66,052**		**5,910**	**4,856**	**18,937**
	Europe + Russia	**21,690**	**73,414**		**5,925**	**6,625**	**20,990**

*Converted into tons from cubic metres; (a) Input data (Table 3); (b) Calculated with input data on total and energy peat extraction using equation (III); (c) Corrected data calculated with input data on non-energy peat consumption using equation (I) (Table A3).

Peat extraction for the energy sector amounts to 12.1 Mt, representing 62 mass- % of the total. The extraction of peat for energy is concentrated in a few countries, principally Finland, Ireland, Belarus and Sweden. The international trade of energy peat is almost non-existent: Peat for energy is consumed where it is produced.

Peat extraction for non-energy purposes amounts to 7.4 Mt or 29.2 Mm³ representing 38 % of the total. The extraction of peat for non-energy purposes is concentrated in the Baltic States, Germany, Ireland and Scandinavia. Although the national data for Germany are uncertain, the place of Germany as a peat extracting country in Europe is undisputable: it is ranked first using the balance approach, and second using industry data. The amounts of peat exported from European countries represent 85 % of the extracted amounts (for non-energy peat). A large majority stays within Europe. Imports from outside of Europe, for example from Russia, are almost non-existent: all the peat consumed in Europe comes from Europe. The major exporters of non-energy peat are the Baltic States, Germany, Ireland and the Netherlands. Exports from Germany and the Netherlands strongly depend on imports from the Baltic States and Ireland, which export most of the peat they extract. Germany and the Netherlands are also the major consumers of peat, followed by the United Kingdom, France and Italy which are almost entirely dependent on imports.

The map presented in Figure 3 provides an overview of the extraction, trade and consumption flows of energy and non-energy peat in Europe.

Discrepancies

The data combination shows some discrepancies between extraction and trade data for non-energy peat. The data used for non-energy consumption and the correction of peat extraction are presented in Table A8. Despite the high uncertainty of the method used to determine non-energy consumption for Estonia and Bosnia-Herzegovina (comparison with neighbouring country), we consider it acceptable due to the limited amount considered. For Germany, the difference between corrected value for peat extraction (apparent extraction) and the original data of the Industrieverband Garten e.V. (IVG) amounts to 3.9 Mm³ (+121 % of the original value). This difference is far greater than for Lithuania (0.9 Mm³, +31 % of the original value) and the other cases of discrepancy (less than 10 % or less than 6 kt of the original value).

The discrepancies in the energy peat balance concerned 15 countries with no or very limited energy consumption. All corrections were under 7 kt and can be considered minimal.

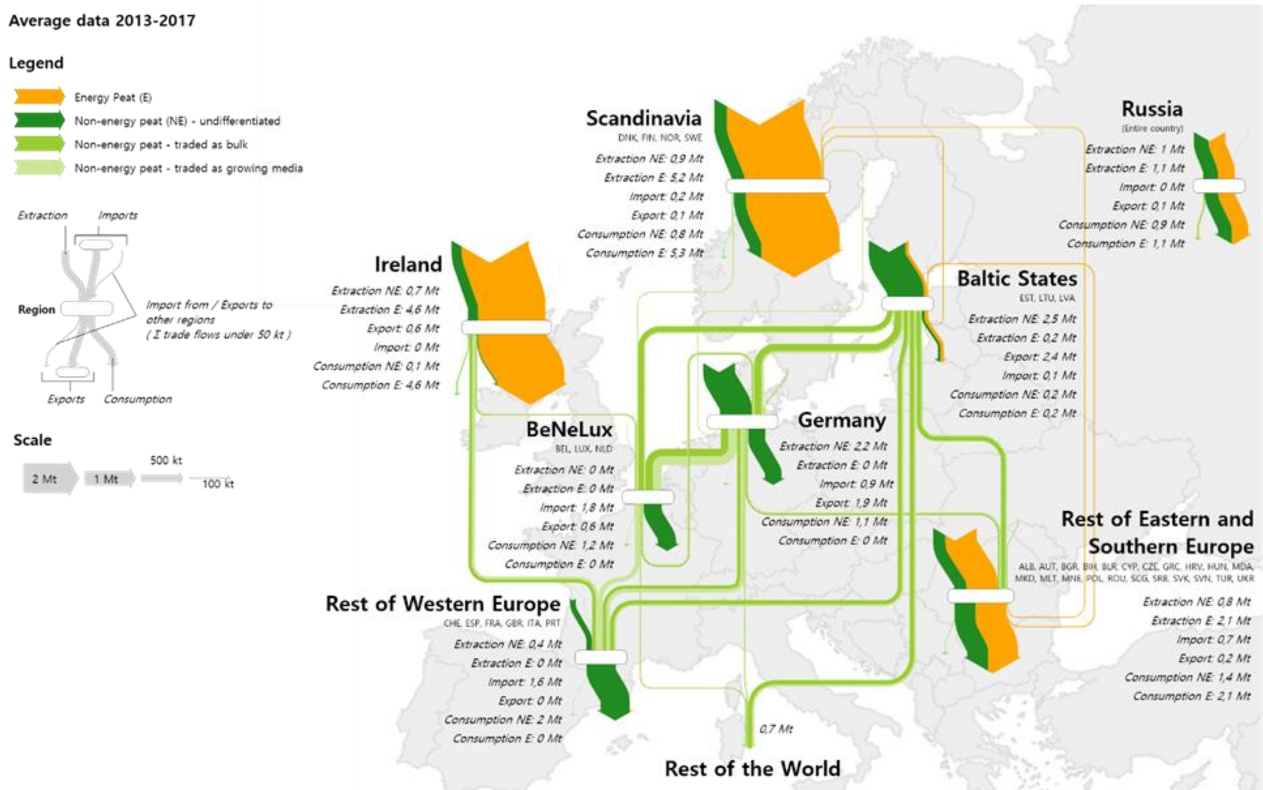

Figure 3. Material flows of energy (E) and non-energy (NE) peat in Europe and Russia. Average data in Mt per year for the period 2013–2017.

DISCUSSION

Implications for policies on peat

This analysis shows the major importance of the intra-European trade of peat and growing media for the horticultural industry. In a context of climate strategies to reduce peat oxidation, carbon leakage through the trade of peat and peat products can undermine the mitigation potential and the fairness of policy measures. This risk also concerns finished horticultural products for which peat was used, e.g. ornamental plants or seedlings, and that were not considered in this study. However, no significant trade flows occur between the EU27 and the rest of the world. Therefore, the risk of carbon leakage could be limited by the development of a coordinated European strategy to address climate impacts of non-energy peat. Since Europe is by far the major region concerned by peat extraction, the European Union has a strong responsibility for the mitigation of its climate impacts.

Data availability and timeliness

As presented in the paragraph “time period”, the material flow analysis presented in this study was not applied to more recent periods due to the availability of data on growing media from which flow composition can be derived, even if more recent data on extraction and trade are available in the meantime. In cases where data on flow composition could be made available for other periods, especially more recent ones, this material flow approach could be a good way to describe and quantify middle and long-term evolutions of the market. According to discussions with stakeholders, the peat market was exposed to evolutions since the period 2013–2017. Among them, short-term changes occurred, e.g., a strong drop of the energy use in Finland, the shutdown of extraction in Ireland in 2019 and the rupture of trade between the European Union and Russia and Belarus due to the war in Ukraine in 2022. In parallel, long-term trends went on, e.g., a further transfer of peat extraction from Germany to the Baltic States, an increase in the demand for growing media and a reduction of peat rates in growing media. With this study, we call the growing media industry to organise a differentiated, methodically transparent and regular publication of data on peat extraction, growing media production and exports to document these changes and allow the implementation of material flow approaches for other periods.

However, due to the numerous uncertainties and the lack of data, especially on variations in stocks, the present method is not adapted to analyse short-term changes at the scale of a few years. For this reason, this approach is not meant to produce yearly time series for use in policy monitoring, which should be based on specific statistics. This current material-flow approach could be used to check the coherency of data used in such monitoring.

Accuracy and effect of assumptions

We consider the amplitude and the number of the discrepancies observed sufficiently limited to validate the results as a best guess of the situation of the peat extraction, trade and consumption in Europe for the period in question. We investigated the effect of the following characteristics and assumptions which we expect to be an important source of error and which could explain the discrepancies for non-energy peat. The effect of not considering them is investigated.

Bulk peat in trade flows and confrontation with data on growing media production

We compared the data on bulk peat from the model to existing data on the use of peat for growing media production from Schmilewski (2017), which apply for the year 2013 and are based on a survey among the industry, with the assumption that their values should be close to the values for 2013–2017. This comparison (Table 2) shows that for some countries the difference between the model and data from Schmilewski (2017) is important. A positive difference can be explained by domestic use of peat other than growing media, for example as bedding for animal husbandry in the case of Finland or Sweden. However, for the Baltic States, the Netherlands, France and Italy, there is a strong deficit of bulk peat in the model in comparison to what is needed for the growing media industry according to Schmilewski (2017). For Germany, there is no difference because consumption and extraction are themselves calculated using data from Schmilewski (2017). The comparison also shows that there is a total deficit of around 2.4 Mm³ bulk peat between the model and data from Schmilewski (2017). This difference would be increased by the consideration of other uses of peat, which were estimated to be 1.9 Mm³ by Altmann (2008). Imports of peat and peat products to these countries from outside of these countries are very limited (0.1 Mm³) and can consequently not explain the difference. This also means that these countries constitute a zero-sum system and that correcting the proportion of bulk peat in exports for one country (for example in the case of Estonia and Lithuania, less export of bulk peat) would increase the difference for other countries (less import of bulk peat for Italy and the Netherlands, also in deficit). The difference could be explained by variations in storage or errors in density factors for extracted peat and traded bulk peat used in the model. Another explanation could be an overestimation in data collected by Schmilewski (2017), due to different interpretation of the definition of growing media production in the different countries.

This comparison shows a discrepancy between data on peat extraction used in the model and data on growing media production from Schmilewski (2017). Without correction of data for some countries in the model, this discrepancy would be greater. It also shows that the uncertainty linked to the rate of bulk peat and growing media in trade flows in the model, for which numerous data were assumed, is potentially high. However, the proportion of peat in trade flows can only vary between the proportion of peat in growing media (75 % of the volume on average in Europe according to Schmilewski 2017), and 100 %. Therefore, this uncertainty has a limited effect on the peat amounts obtained in the model.

Variations of stocks

We expect the assumption 5 ignoring the variations of stock to be a significant source of error, although the use of a 5-year-average theoretically reduces this discrepancy in comparison to a single year balance. For example, in the case of energy peat consumption in Finland, we expect variations of stocks to be the major explanation of the difference between the result of the modelling process (4.7 Mt) and the existing statistics (5.7 Mt, from Eurostat 2021b).

Mass and volume conservation

Assumption 6a is that material loss through peat mineralisation in the atmosphere along the supply chain is insignificant. Peat mineralisation was estimated at 5 % per year (Peano *et al.* 2012 interpreted from Cleary *et al.* 2005). Considering this effect would imply estimating the average time between the extraction and consumption of the peat. Considering this loss would reduce calculated peat consumption.

Assumption 6b is that volume loss through shrinkage during the mixing of different constituents for the growing media production is insignificant. This assumption has limited effects on the model because volumes are defined as growing media constituents before mixing. This effect could induce

Table 2. Difference between data on growing media production and differentiated results of the modelling process. Unit: 1,000 m³.

Country code	Growing media production 2013 (Schmilewski 2017)	Use of bulk peat for growing media production or other non-energy purposes 2013–2017 (own model)	Difference (positive difference can be explained by other non-energy use)
IRL	769	1,041	+272
FIN	800	1,617	+817
SWE	1,060	1,631	+571
LTU	1,962	268	-1,694
LVA	1,952	3,333	+1,381
EST	1,138	134	-1,004
DNK	290	285	-5
GBR	1,424	1,645	+221
POL	1,820	1,835	+15
DEU	6,800	6,800	0
NLD	2,992	1,861	-1,131
BEL	810	1,082	+272
AUT	185	220	+35
FRA	1,541	877	-664
ITA	2,443	934	-1,509
PRT	4	46	+42
Total	25,990	23,611	-2,421

an error in the conversion of the proportion of growing media in trade flows from volume percentage to mass percentage. According to IVG (personal communication), the volume loss could amount to up to 20 %. Using this value and for a trade flow with a peat rate of 75 % on average, the underestimation of the peat rate would represent less than 2 %, which is minimal.

Assumption 6c is that variations of water content along the supply chain are insignificant. The water content has a direct effect on the peat content in a flow and on its density factor. Unfortunately, no data could be found on the water content or dry matter content along the supply chain.

Coverage of peat trade flows using HS2703

The definition of data under the international number HS2703 including peat products with more than 75 % peat constitutes one of the main difficulties of the approach, because the composition of trade flows (share and composition of growing media) is unspecified and needs to be estimated. Assumption 7 is that data on peat products with less than 75 % peat are assumed to be collected under HS number 2703, despite its definition. If this assumption were false, the real amount of peat in trade flows would be underestimated by ignoring peat contained in products under 75 % peat rate. In this case and for a trade flow of growing media with a peat rate of 75 % on average and following a β-distribution (α=8), the amounts of peat uncovered by the statistics would represent 40 % of the total peat flow. Therefore, we consider the definition of the HS number 2703 as base for the trade data and the uncertainty regarding its actual implementation a major source of error of the approach. Not considering this assumption would increase peat consumption for net growing media importers and reduce it for net growing media exporters. Therefore, this source of error cannot explain the discrepancies observed and would increase them.

The problem linked to the definition of the international number HS2703 and the uncertainty concerning its implementation can be expected to gain importance in the perspective of increased amounts of peat-reduced and peat-free growing media on the market. In this situation, an adaptation or a differentiation of the trade statistics could constitute a significant improvement of public information on the peat and growing media market.

Explanation of discrepancies and case of Germany

All cases of discrepancies observed concern net exporting countries. Therefore, considering the definition of HS2703 and the material loss through mineralisation would tend to lower the calculated value of consumption and thus increase the amplitude of the discrepancy. The diminution of stocks or an increasing water content along the supply chain could counterbalance these effects and explain the discrepancies for Bosnia-Herzegovina, Estonia, Ireland, Latvia and Lithuania, for which we consider the discrepancy limited.

However, in the case of Germany, we expect the amplitude of the discrepancy not to be explainable by these sources of error. Moreover, the comparison of the model with data on growing media production from Schmilewski (2017) shows that the exports of bulk peat from the Baltic States and the Netherlands, main supplier of bulk peat for Germany, could be overestimated in the model, which also implies an underestimation of the discrepancy. The data combination and the analysis of the uncertainties for Germany suggests that the available peat extraction data from the IVG (around 3.2 Mm³ for the period 2013–2017) are underestimated. This underestimation could be due to the coverage of the statistics of the IVG (not all peat extraction companies are IVG members, although data of non-members can also be obtained or estimated). Also, the IVG statistic is collected in the volume unit “Wassermaß” (water volume) for which the conversion to the unit based on EN12580 used in the model is not known and was therefore assumed to be 1:1.

The only alternative available statistics on peat extraction are provided by the German Federal Statistical Office (Destatis) which are used for the calculation of national reported GHG emissions (around 7.9 Mm³ for the period 2013–2017). However, these statistics originally corresponded to the sales of peat and peat products, which include growing media produced from bulk peat imports. Due to this methodological deficiency, these data theoretically constitute a significant overestimation when used as extraction data as pointed out by Hofer & Köbbing (2020). However, the results of the correction in the modelling process suggest that apparent extraction is of the same scale (7.2 Mm³ for the period 2013–2017).

Based on our results, we consider that the peat extraction data from the IVG should not be used as an alternative for the calculation of national reported GHG emissions without further investigations. More research and additional data on the quantity and the composition of the flows specific to Germany are needed to improve the model and explain this discrepancy.

ACKNOWLEDGEMENTS

We particularly thank Prof. Dr. Daniela Thrän, Prof. Dr. Martin Banse, Susanna Hönle, Joseph Rocchio, Robin Auer and the two reviewers for their valuable feedback on previous versions of the manuscript, as well as Gerald Schmilewski, Cecilia Luetgebrune, Eugenia Arcos Messana (Growing Media Europe), Hannu Salo (Bioenergia), Ingrida Krigere (Latvian Peat Association), Bert von Seggern (Klasmann-Deilmann) and Arne Hückstädt (IVG) for their input and comments on the method.

AUTHOR CONTRIBUTIONS

OH and BO developed the research question and conceptualised the study; OH developed the method with BO's support; OH collected the data, processed them and wrote all versions of the manuscript. BO contributed text and data on the climate relevance of peat extraction.

REFERENCES

Alpine Convention (1998) *Protocol on the Implementation of the Alpine Convention of 1991 in the Domain of Soil Conservation Germany - France - Austria - Liechtenstein - Monaco - Austria - Switzerland - Slovenia - the European Union*. Online at: https://www.alpconv.org/fileadmin/user_upload/Convention/EN/Protocol_Soil_Conservation_EN.pdf, accessed 30 May 2022.

Altmann, M. (2008) *Socio-Economic Impact of the Peat and Growing Media Industry on Horticulture in the EU*, CO CONCEPT, Luxemburg. Online at: http://coconcept.lu/fileadmin/Downloads/Socio_Economic_Study1.pdf, accessed 15 Oct 2021.

Bacchetta, M., Beverelli, C., Cadot, O., Fugazza, M., Grether, J.-M., Helble, M., Nicita, A., Piermartini, R. (2012) *A Practical Guide to Trade Policy Analysis*. WTO Publications, New York, Geneva, 232 pp. Online at: https://www.wto.org/english/res_e/publications_e/wto_unctad12_e.pdf, accessed 10 Oct 2021.

BAFU - Bundesamt für Umwelt (2021) *Market participants join forces to reduce peat use*. Online at: https://www.bafu.admin.ch/bafu/en/home/topics/economy-consumption/info-specialists/peat-exit-plan.html, accessed 12 Oct 2021.

BMUB - Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (2016) *Climate Action Plan 2050: Principles and Goals of the German Government's Climate Policy*. Online at: https://www.bmuv.de/fileadmin/Daten_BMU/Pools/Broschueren/klimaschutzplan_2050_en_bf.pdf, accessed 08 Feb 2022.

Belstat - National Statistical Committee of the Republic of Belarus (2021a) *Manufacture of Selected Industrial Products in Physical Terms*. Online at: http://dataportal.belstat.gov.by/, accessed 25 Jan 2021. 10206000007 Manufacture of selected industrial products in physical terms > 08.92.10.120 Peat for agriculture.

Belstat - National Statistical Committee of the Republic of Belarus (2021b) *Primary Energy Production*. Online at: https://www.belstat.gov.by/en/ofitsialnaya-statistika/real-sector-of-the-economy/energy-statistics/annual-data/, accessed 25 Jan 2021. Economic statistics > Energy > Primary energy production.

Blain, D., Row, C., Alm, J., Byrne, K., Parish, F., Duchemin, É., Huttunen, J.T., Tremblay, A., Delmas, R., Menezes, C.F.S. (2006) Chapter 7: Wetlands. In: Eggleston, S., Buendia, L., Miwa, K., Ngara, T., Tanabe, K. (eds.) *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Institute for Global Environmental Strategies, Hayama, Japan. Online at: https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_07_Ch7_Wetlands.pdf, accessed 30 May 2022.

Bohlin, C. (2002) Data on the use of growing media constituents. In: Schmilewski, G., Rochefort, L. (eds.) *Peat in Horticulture: Quality and Environmental Challenges; Proceedings of the International Peat Symposium*. International Peat Society, Jyväskylä, 144–150.

Bord na Móna (2015) *Bord na Móna announces biggest change of land use in modern Irish history*. Online at: https://www.bordnamona.ie/company/news/articles/bord-na-mona-announces-biggest-change-of-land-use-in-modern-irish-history/, accessed 16 Mar 2020.

Bord na Móna (2017) *Brief History of the Peat Industry in Ireland*. Online at: https://www.bordnamonalivinghistory.ie/article-detail/brief-history-of-the-peat-industry-in-ireland/, accessed 10 Jun 2021.

Brown, P., Cardenas, L., Choudrie, S., Jones, L. and 37 others (2020) *UK Greenhouse Gas Inventory, 1990 to 2018: Annual Report for Submission under the Framework Convention on Climate Change*. Ricardo Energy & Environment, Oxfordshire, UK, 624 pp. Online at: https://unfccc.int/documents/225987, accessed 30 May 2022.

Brunner, P.H., Rechberger, H. (2004) *Practical*

Handbook of Material Flow Analysis. Publ. No. 1, Lewis, Boca Raton FL, 318 pp.

CEN - European Committee for Standardization (2013) *Soil Improvers and Growing Media - Determination of a Quantity*. 12580:2013.

Cleary, J., Roulet, N.T., Moore, T.R. (2005) Greenhouse gas emissions from Canadian peat extraction, 1990–2000: A life-cycle analysis. *AMBIO A Journal of the Human Environment*, 34, 456–461.

CSB - Central Statistical Bureau of Latvia (2021a) *Energy Balance*. Online at: https://www.csb.gov.lv/en/statistics. Environment and Energy > Energy > Annual data > ENG010, accessed 23 Feb 2021. Energy balance, in natural units (NACE Rev.2) > Peat; Peat briquettes.

CSB - Central Statistical Bureau of Latvia (2021b) *Material Flow Accounts*. Online at: https://www.csb.gov.lv/en/statistics, accessed 23 Feb 2021. Environment and Energy > Environment > Annual data > VIG080. Material flow accounts-domestic extraction.

CSO - Central Statistics Office (2020) *Material Flow Accounts*. Online at: https://data.cso.ie/, accessed 19 Nov 2020. Environment > Environment Accounts > Material Flow Accounts.

CSO - Central Statistics Office (2021) *Energy Balance Statistics*. Online at: https://data.cso.ie/, accessed 23 Feb 2021. Other Public Sector Bodies > Sustainable Energy Authority of Ireland > Energy Balance Statistics.

Defra - Department for Environment, Food and Rural Affairs (2009) *Basis of the UK BAP target for the reduction in use of peat in horticulture - SP0573*. Online at: http://sciencesearch.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=15991, accessed 03 Jun 2019.

EC - European Commission (2022) *EU Emissions Trading System (EU ETS)*. Online at: https://ec.europa.eu/clima/eu-action/eu-emissions-trading-system-eu-ets_en, accessed 09 May 2022.

EU - European Union (1985) *Council Regulation (EEC) No 3541/85 of 12 December 1985 on the classification of goods under subheading 27.03 A of the Common Customs Tariff*. Publ. No. 338. Online at: http://data.europa.eu/eli/reg/1985/3541/oj, accessed 04 Jun 2019.

EU - European Union (2018) *Regulation (EU) 2018/841 of the European Parliament and of the Council of 30 May 2018 on the inclusion of greenhouse gas emissions and removals from land use, land use change and forestry in the 2030 climate and energy framework, and amending Regulation (EU) No 525/2013 and Decision No 529/2013/EU (Text with EEA relevance)*. Publ. No. 156. Online at: https://eur-lex.europa.eu/eli/reg/2018/841/oj, accessed 04 Jun 2019.

EU - European Union (2019) *Regulation (EU) 2019/1009 of the European Parliament and of the Concil of 5 June 2019 laying down rules on the making available on the market of EU fertilising products and amending Regulations (EC) No 1069/2009 and (EC) No 1107/2009 and repealing Regulation (EC) No 2003/2003 (Text with EEA relevance): European Union*. Publ. No. 170. Online at: http://data.europa.eu/eli/reg/2019/1009/oj, accessed 10 Jun 2021.

Eurostat (2020) *EU Trade since 1988 by HS2,4,6 and CN8*. Online at: https://ec.europa.eu/eurostat/data/database, accessed 20 Apr 2020. Database by themes > International trade in goods - detailled data (ext_go_detail) > EU trade since 1988 by HS2,4,6 and CN8 [DS-645593].

Eurostat (2021a) *Material Flow Accounts*. Online at: https://ec.europa.eu/eurostat/data/database, accessed 25 Feb 2021. Database by themes > Environment and energy > Environment (env) > Material flow accounts (env_ac_mfa).

Eurostat (2021b) *Supply, Transformation and Consumption of Solid Fossil Fuels*. Online at: https://ec.europa.eu/eurostat/data/database, accessed 1 Apr 2021. Database by themes > Environment and energy > Energy (nrg) > Energy statistics (nrg_bal) > Supply, transformation and consumption - commodity balances (nrg_cb) > Supply, transformation and consumption of solid fuels (nrg_cb_sff).

Federal Council of Switzerland (2012) *Bericht des Bundesrates in Erfüllung des Postulats 10.3377 Diener Lenz 'Torfausstiegskonzept' (Report of the Federal Concil to implementing the postulate 10.3377 Diener Lenz 'peat phase-out concept')* (in German). Online at: https://www.newsd.admin.ch/newsd/message/attachments/29089.pdf, accessed 12 Oct 2021.

Finnish Government (2019) *Finland has an excellent opportunity to rebuild itself in line with the principles of sustainable development: 3.1 Carbon neutral Finland that protects biodiversity*. Online at: https://valtioneuvosto.fi/en/article/-/asset_publisher/3-1-hiilineutraali-ja-luonnon-monimuotoisuuden-turvaava-suomi, accessed 17 Mar 2020.

Garg, A., Kazunari, K., Pulles, T. (2006) Chapter 1: Introduction. In: Eggleston, S., Buendia, L., Miwa, K., Ngara, T., Tanabe, K. (eds.) *2006 IPCC Guidelines for National Greenhouse Gas*

Inventories, Institute for Global Environmental Strategies, Hayama, Japan. Online at: https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_1_Ch1_Introduction.pdf, accessed 30 May 2022.

Gerasimov, Y. (2010) *Energy sector in Belarus: Focus on Wood and Peat Fuels*, Finnish Forest Research Institute, Vantaa, Finland. 62 pp. Online at: https://www.researchgate.net/publication/249650495_Energy_sector_in_Belarus_Focus_on_wood_and_peat_fuels, accessed 30 May 2022.

Gerding, M., Karel, E., de Vries, G. (2015) The history of the peat manufacturing industry in The Netherlands: Peat moss litter and active carbon. *Mires and Peat*, 16, 10, 9 pp.

German Federal Government (2019) *Klimaschutzprogramm 2030 der Bundesregierung zur Umsetzung des Klimaschutzplans 2050* (*Climate Action Programme 2030 for the Implementation of the Climate Action Plan 2050*) (in German). Online at: https://www.bundesregierung.de/resource/blob/974430/1679914/e01d6bd855f09bf05cf7498e06d0a3ff/2019-10-09-klima-massnahmen-data.pdf?download=1, accessed 30 May 2022.

GME - Growing Media Europe (2020) *Terminology for the Growing Media and Horticultural Sector*, Brussels. Online at: https://www.growing-media.eu/single-post/2020/06/22/terminology-for-the-growing-media-and-horticultural-sector, accessed 10 Jun 2021.

Government of Ireland (2022) *Working Paper to Address Challenges Related to Peat Supply in the Horticulture Sector*. Online at: https://www.gov.ie/en/publication/39315-working-paper-to-address-challenges-related-to-peat-supply-in-the-horticulture-sector/, accessed 02 Feb 2022.

Hartmann, H. (2014) Kapitel 2: Produktion, Bereitstellung und Eigenschaften biogener Festbrennstoffe (Chapter 2: Production, processing and properties of bio-based fuels). In: Eltrop, L. (ed.) *Leitfaden feste Biobrennstoffe: Planung, Betrieb und Wirtschaftlichkeit von Bioenergieanlagen im mittleren und großen Leistungsbereich*, FNR Fachagentur Nachwachsende Rohstoffe e.V, Gülzow-Prüzen, 17–54 (in German).

Hirschler, O., Osterburg, B. (2021) *An Overview of the World Peat Industry and Its Climate Impact*. Thünen-Institut, 16th International Peatland Congress, May 4, 2021. Online at: https://www.peatlandcongress2021.com/wp-content/uploads/2021/04/Abstract_Hirschler_Osterburg_Industry_Summit_IPC2021_final.pdf, accessed 30 May 2022.

Hiraishi, T., Krug, T., Tanabe, K., Srivastava, N., Baasansuren, J., Fukuda, M., Troxler, T.G. (eds.) (2014) *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands*. IPCC, Switzerland. Online at: https://www.ipcc.ch/site/assets/uploads/2018/03/Wetlands_Supplement_Entire_Report.pdf, accessed 30 May 2022.

HM Government (2018) *A Green Future: Our 25 Year Plan to Improve the Environment*, 151 pp. Online at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/693158/25-year-environment-plan.pdf, accessed 16 Mar 2020.

Hofer, B., Köbbing, J. (2020) Faktencheck – Treibhausgasemissionen aus dem Einsatz von Torf in Blumenerden (Fact check - Greenhouse gas emissions from the use of peat in potting soils). *TELMA Beiheft zu den Berichten der Deutschen Gesellschaft für Moor- und Torfkunde*, 50, 193–198 (in German).

Hofer & Pautz GbR (2011) *Studie zur Situation des Torfabbaus im Baltikum* (Study on the situation of peat extraction in the Baltic States) (in German). Online at: https://www.hofer-pautz.de/Downloads/studie_torfabbau.pdf, accessed 30 May 2022.

INE - Instituto Nacional de Estadística (National Statistics Institute) (2020). *Material Flow Accounts*. Online at: https://www.ine.es/dyngs//INEbase/en/listaoperaciones.htm, accessed 22 Dec 2020. Agriculture and environment > Environmental accounts > Material flow accounts.

IVG - Industrieverband Garten e.V. (2022) *Erden & Substrate - Historie der Entwicklung von Torfsubstraten (History of the Development of Peat Substrates)* (in German). Online at: https://www.erden-substrate.info/torf-fuer-den-gartenbau/historie, accessed 11 Feb 2022.

Joosten, H. (ed) (2012) *Peatlands - Guidance for Climate Change Mitigation Through Conservation, Rehabilitation and Sustainable Use*. Publ. No. 5, Food and Agriculture Organization of the United Nations, Rome, 100 pp.

Kavaliauskas, G. (2019) *Lithuanian Peat Producers – Association „Lietuviškos Durpes“*. Lituanian Peat Producers Association, Palanga, 2019. Online at: https://balticpeatproducersforum.eu/wp-content/uploads/2019/09/15_Giedrius-kavaliauskas-Durpes_2019.pdf, accessed 26 Feb 2021.

Kis-Kovács, G., Tarczay, K., Labancz, K., Lilla Ludányi, E., Lovas, K., Somogyi, Z., Szakálas, J., Tobisch, T. (2020) *National Inventory Report for*

1985–2018 - Hungary, Hungarian Meteorological Service. Online at: https://unfccc.int/documents/226419, accessed 12 Oct 2021.

Leifeld, J., Menichetti, L. (2018) The underappreciated potential of peatlands in global climate change mitigation strategies. *Nature Communications*, 1, 9, 1071. https://doi.org/10.1038/s41467-018-03406-6

Lindholm, T., Heikkilä, R. (2006) Destruction of mires in Finland. *The Finnish Environment*, 23, 179–192. Online at: https://www.researchgate.net/publication/261070498_Destruction_of_mires_in_Finland, accessed 30 May 2022.

Loe Bjønness, K. (ed.), Flugsrud, K., Rostrup Gabrielsen, A., Gjerald, E. and 24 authors (2020) *Greenhouse Gas Emissions 1990–2018, National Inventory Report*, Norwegian Environment Agency, Statistics Norway, Norwegian Institute of Bioeconomy Research. Online at: https://unfccc.int/documents/215704, accessed 30 May 2022.

Luke - Natural Resources Institute Finland (2021) *Production, Consumption and Foreign Trade of Peat*. Online at: http://statdb.luke.fi/, accessed 23 Feb 2021. Forest statistics > Other > Energy > Production, consumption and foreign trade of peat > Horticultural, bedding and environmental peat - Production (1000 m³) / Energy peat - Production - Milled and sod peat (1000 m³).

MEEP - Ministry of Energy and Environmental Protection of Ukraine (2020) *UKRAINE’S GREENHOUSE GAS INVENTORY 1990–2018: Annual National Inventory Report for Submission under the United Nations Framework Convention on Climate Change and the Kyoto Protocol*, Kyiv. Online at: https://unfccc.int/documents/228016, accessed 30 May 2022.

Minaeva, T., Sirin, A. & Mischenko, A. (2008) Inventory Overview of Status of Peatlands in Russian Federation (European part). In: Thiele, A. (ed.) *Inventory on Area, Situation and Perspectives of Rewetting of Peatlands in Belarus Russia & Ukraine*, Lauterbach, Germany.

Norwegian Ministry of Climate and Environment (2017) *Norway’s Climate Strategy for 2030: a Transformational Approach Within a European Cooperation Framework: Meld. St. 41 (2016 – 2017) Report to the Storting (white paper)*. Online at: https://www.regjeringen.no/en/dokumenter/meld.-st.-41-20162017/id2557401/, accessed 30 May 2022.

Paappanen, T., Leinonen, A. (eds.), Hillebrand, K. (2006) *Fuel peat industry in EU. Summary report.*, VTT - Technical Research Centre of Finland, Jyväskylä.

Peano, L., Loerincik, Y., Margni, M., Rossi, V. (2012) *Comparative Life Cycle Assessment of Horticultural Growing Media Based on Peat and Other Growing Media Constituents: Final Report*. Quantis, Switzerland, 156 pp. Online at: https://warumtorf.kundenprojekt.info/fileadmin/user_upload/comparative-life-cycle-assessment-of-horticultural-growing-media-based-on-peat-and-other-growing-media-constituents.pdf, accessed 30 May 2022.

Parish, F., Sirin, A., Charman, D., Joosten, H., Minayeva, T., Silvius, M., Stringer, L. (eds.) (2008) *Assessment on Peatlands, Biodiversity and Climate Change: Main Report*. Global Environment Centre, Kuala Lumpur and Wetlands International, Wageningen, 179 pp.

Polish Geological Institute (2021) *Mineral Resources of Poland - Peat*. Online at: http://geoportal.pgi.gov.pl/surowce/skalne/torfy, accessed 23 Feb 2021.

SCB - Statistics Sweden (2021) *Peat; Production, Use, Environmental Impact*. Online at: https://www.scb.se/en/finding-statistics/statistics-by-subject-area/environment/land-use/peat-production-use-environmental-impact/, accessed 24 Feb 2021. Environment > Peat; production, use, environmental impact > Publications. Annual reports: Peat production, use, environmental impact.

Schmilewski, G. (2008) Peat covers 77 percent of the growing media production in the EU. In: International Peatland Society (ed.) *Peatlands International 1/2008*, Saarijärvi, 39–43.

Schmilewski, G. (2017) Growing media constituents used in the EU in 2013. *Acta Horticulturae*, 1168, 85–92.

Schmilewski, G. (2018) *Kultursubstrate und Blumenerden - Eigenschaften, Ausgangsstoffe, Verwendung*, (*Growing Media for Professional Horticulture and for the Retail Market - Properties, Constituents, Use*). Industrieverband Garten e.V. 254 pp. Online at: https://substratbuch.ivg.org/, accessed 30 May 2022 (in German).

Statistics Denmark (2020) *Extraction of Raw Materials in Denmark*. Online at: https://www.statbank.dk, accessed 21 Dec 2021. Mining and Quarrying > Extraction of raw materials in Denmark. by type of raw material, region and time.

Statistics Estonia (2021a) *Energy Balance*. Online at: https://andmed.stat.ee/en/stat, accessed 28 Jan 2021. Energy > Energy consumption and production > Annual statistics > KE0230:

ENERGY BALANCE SHEET BY TYPE OF FUEL OR ENERGY (EUROSTAT METHODOLOGY).

Statistics Estonia (2021b) *Material Flow Accounts*. Online at: https://andmed.stat.ee/en/stat, accessed 22 Feb 2021. Environment > Environmental accounts > Material flow accounts > KK91: USED DOMESTIC EXTRACTION BY TYPE OF RAW MATERIAL.

Statistics Finland (2020) *Energy Statistics*. Online at: http://tilastokeskus.fi/tup/julkaisut/taulukkopalvelut_en.html, accessed 21 Dec 2020. Home > Products and services > Publications > Online services of publications > Energy 2019 table service.

Statistics Lithuania (2021) *Fuel Commodities Balances*. Online at: https://osp.stat.gov.lt/statistiniu-rodikliu-analize#/, accessed 23 Feb 2021. Environmental protection and energy > Energy > Annual energy indicators > Fuel commodities balances > Peat; Peat briquettes and peat pellets.

Statistik Austria (2021) *StatCube - Energiebilanzen Österreich ab 1970* (*Energy Balance of Austria since 1970*) (in German). Online at: https://statcube.at/statistik.at/ext/statcube/jsf/tableView/tableView.xhtml, accessed 22 Feb 2021. Statistiken Energie, Umwelt > Energie > Energiebilanzen Österreich ab 1970.

Ukrstat - State Statistics Service of Ukraine (2021) *Energy Balance: Ukrstat.org - State Statistics Service of Ukraine Documents Publishing*. Online at: https://ukrstat.org/en/operativ/oper_new_e.html, accessed 24 Feb 2021. Energy > Energy balance data time series for the period of 1990–2019 > Energy balance data time series for the period of 1990–2019.

UN Climate Change - Secretariat of the United Nations Framework Convention on Climate Change (2015) *Adoption of the Paris Agreement. I: Proposal by the President (Draft Decision)*, United Nations Office, Geneva (Switzerland), 32 pp.

UN Climate Change - Secretariat of the United Nations Framework Convention on Climate Change (2022) *Greenhouse Gas Inventory Data*. Online at: https://di.unfccc.int/flex_annex1, accessed 06 May 2022. Non-energy: 4.D.1.a Peat Extraction Remaining Peat Extraction; 4.D.2.a Land Converted to Peat Extraction. Energy: 1.AA Fuel Combustion - Sectoral approach > Peat.

UNSD - United Nations Statistics Division (2020) *UN Comtrade: International Trade Statistics*. Online at: https://comtrade.un.org/data/, accessed 19 May 2020.

UNSD - United Nations Statistics Division (2021) *UNdata*. Online at: http://data.un.org/Explorer.aspx, accessed 25 Feb 2021.

USGS - United States Geological Survey (2021) *National Minerals Information Center - Peat Statistics and Information*. Online at: https://www.usgs.gov/centers/nmic/peat-statistics-and-information, accessed 25 Feb 2021.

Submitted 15 Oct 2021, final revision 31 May 2022
Editor: Stephan Glatzel

Author for correspondence:
Olivier Hirschler MSc, Thünen Institute, Coordination Unit Climate, Bundesallee 49, 38116 Braunschweig, Germany. Tel.: +49 531 596 1105; E-Mail: olivier.hirschler@thuenen.de

Appendix

Table A1. Peat extraction data used as input. T = Total, E = Energy, NE = Non-energy, *calculation using source.

Country Code	Cat.	Unit	Yearly values 2013	2014	2015	2016	2017	Source (Statistical category)
AUT	T	kt	0.5	0.5	0.5	0	0	Eurostat 2021a
DNK	T	1,000m³	154	192	156	163	107	Statistics Denmark 2020
ESP	T	kt	82	83	79	113	85	INE 2020
EST	T	kt	994	830	716	517	677	Statistics Estonia 2021b
GBR	T	1,000m³	1,231	763	981	981	981	Brown *et al.* 2020
IRL	T	kt	7,600	5,400	4,200	3,800	4,200	CSO 2020
LTU	T	1,000m³	2,900	2,920	3,180	2,350	2,507	Kavaliauskas 2019
LVA	T	kt	1,238	907	1,222	820	998	CSB 2021b
POL	T	1,000m³	1,205	1,245	1,285	1,157	1,033	Polish Geological Institute 2021
ROU	T	kt	1	2	4	7	7	Eurostat 2021a
TUR	T	kt	156	151	135	134	228	USGS 2021
BLR	NE	kt	164	216	237	164	151	Belstat 2021a
DEU	NE	1,000m³	3,500	2,582	2,558	3,647	3,873	IVG, 2020 (pers. comm.)
FIN	NE	1,000m³	2,190	1,653	1,153	1,425	1,600	Luke 2021
FRA	NE	1,000m³	83	103	79	91	60	AFAIA, 2019 (pers. comm.)
HUN	NE	1,000m³	285	166	286	217	274	Kis-Kovács *et al.* 2020
NOR	NE	1,000m³	303	330	279	220	220	Loe Bjønness *et al.* 2020, UN Climate Change 2022*
RUS	NE	kt	86 % of the energy peat extraction					Minaeva *et al.* 2008*
SWE	NE	1,000m³	1,815	1,512	1,266	1,676	1,662	SCB 2021
UKR	NE	kt	131	119	79	136	88	MEEP 2020
AUT	E	kt	0,5	0,5	0,5	0	0	Statistik Austria 2021
BLR	E	kt	2,269	1,433	1,000	1,457	2,045	Belstat 2021b
EST	E	kt	263	261	118	102	32	Statistics Estonia 2021a
FIN	E	1,000m³	21,727	20,415	10,945	9,411	9,500	Luke 2021
GBR	E	1,000m³	24	32	23	23	23	Brown *et al.* 2020
IRL	E	kt	6,855	5,006	3,861	3,377	3,721	CSO 2021*
LTU	E	kt	84	101	74	17	24	Statistics Lithuania 2021
LVA	E	kt	10	5	0	4	2	CSB 2021a
ROU	E	kt	1	2	4	7	7	Eurostat 2021b
RUS	E	kt	1,523	1,150	967	1,197	904	UN Climate Change 2022*
SWE	E	1,000m³	2,369	2,196	1,127	1,407	1,087	SCB 2021
UKR	E	kt	467	457	491	539	518	Ukrstat 2021

Eurostat 2021a: No peat extraction in ALB, BEL, BGR, BIH, CHE, CYP, CZE, GRC, HRV, ITA, LUX, MKD, MLT, NLD, PRT, SRB, SVK, SVN
Eurostat 2021b: No energy peat extraction in DEU, DNK, ESP, FRA, HUN, NOR, POL, TUR
MDA, MNE: No data found, assumed no peat extraction

Table A2. Assumptions used to design and solve the model.

Units, equations and flow composition	
1	All data originate from equivalent measurement methods. Data used for volume and density factors are in accordance with EN12580.
2	No variation of stocks takes place between the beginning and the end of the period considered (2013-2017).
3a	No shrinkage occurs along the supply chain before consumption.
3b	No carbon loss in the atmosphere occurs along the supply chain before consumption.
3c	No variation in the water content occurs along the supply chain before consumption.
4	Energy peat is differentiated in milled and sod peat.
5	Non-energy trade flows are differentiated in growing media and bulk peat.
6	Non-energy peat is differentiated in white bog peat, black bog peat and fen peat.
Data selection	
7	Trade data under HS number 2703 and extraction data are more reliable than consumption data.
8	Trade data under HS number 2703 include all peat trade, including in products under 75% peat content.
9	No energy peat trade takes place between considered countries not covered by Eurostat and between them and the rest of the world.
10	Eurostat trade data are more reliable than Comtrade data.
11	Data from national sources are more reliable than data from international sources.
12	Non-energy and energy peat extraction are more reliable than total extraction data.
13	Without other data available, data related to other periods apply for the period considered (2013-2017).
Data combination	
14	All flows from a same source, for example all exports from one country independently on the destination country, are qualitatively identical.
15	Growing media is not re-exported and only origins from domestic growing media production.
16	If for a country, non-energy peat extraction is more than five times greater than bulk peat imports, it is considered "independent" on bulk peat imports. Without more information, the composition of peat in the growing media exports is only determined by the extracted peat.
17	If for a country, bulk peat import is more than five times greater than non-energy peat extraction, it is considered "extremely dependent" on bulk peat imports. Without more information, the composition of peat in the growing media exports is only determined by bulk peat imports.
18	If a country is not "extremely dependent" nor "independent" on bulk peat imports, it is considered "partially dependent" on bulk peat imports. Without more information, the composition of peat in the growing media exports is determined by the extracted peat as well as the imports of bulk peat.
19	Bulk peat is not re-exported and only origins from domestic extraction, except for the Netherlands where no extraction takes place.
20	Bulk fen peat is not exported because of its lower horticultural value.
21	Bulk peat exported by the Netherlands is constituted by all imports of bulk peat at the exception of those coming from Germany.
Identification of discrepancies and data correction	
22a	The value for consumption considered implausible in case it is negative
22b	The value for consumption considered too uncertain if it varies of more than 100% by a 10% variation of the input parameters in equation (I)
23	Trade data under HS number 2703 are more reliable than extraction data.
24	Energy extraction data are more reliable than energy trade data.

Table A3. Equations used for the model resolution for each flow p, each country n, each element i and each unit u.

	Equation	Origin
(I)	$Q_{i,extraction,n,u} + Q_{i,import,n,u} = Q_{i,consumption,n,u} + Q_{i,export,n,u}$	Mass conservation, (10), (11)
(II)	$Q_{i,import\ from\ m,n,u} = Q_{i,export\ to\ n,m,u}$	Mass conservation, (11)
(III)	$Q_{total\ peat,p,n,u} = Q_{energy\ peat,p,n,u} + Q_{non-energy\ peat,p,n,u}$	Mass conservation
(IV)	$X_{i,p,n,u} = \frac{Q_{i,p,n,u}}{Q_{p,n,u}}$	Definition
(V)	$d_{p,n} = \frac{Q_{p,n,tons}}{Q_{p,n,m^3}}$	Definition
(VI)	$d_{p,n} = \sum_i X_{i,p,n,m^3} * d_{i,n,p} = 1 \Big/ \sum_i X_{i,p,n,tons}/d_{i,n,p}$	(V) (VI)
(VII)	$X_{i,p,n,tons} = X_{i,p,n,m^3} * \frac{d_{i,p,n}}{d_{p,n}}$	(V) (VI)

where:

- $Q_{i,p,n,u}$ is the quantity of the element i in the flow p of the country n in the unit u. If i is not precised, the total quantity of material in the flow is meant.
- $X_{i,p,n,u}$ is the proportion of the element i in the flow p of the country n in percentage of the unit u.
- $d_{i,n,p}$ is the density factor of the element i in the flow p of the country n. If i is not specified, the density factor of the total flow is meant.

Table A4. Composition of extracted energy peat used in the model in mass percentage.

Country Code	Milled peat	Sod peat	Source
FIN	93%	7%	Calculated based on Statistics Finland 2020
SWE	69%	31%	Calculated based on SCB 2021
IRL	100%	0%	Interpreted based on Paappanen *et al.* 2006
EST	74%	26%	Calculated based on Paappanen *et al.* 2006
LVA	44%	56%	Calculated based on Paappanen *et al.* 2006
LTU	26%	74%	Calculated based on Paappanen *et al.* 2006
BLR	95%	5%	Interpreted based on Gerasimov 2010
Default	72%	28%	Average composition other countries

Table A5. Composition of non-energy peat extraction and exports as a result of the modelling process.

Country Code	Dependency status on bulk peat imports	Composition peat extraction				Composition exports												
		Composition peat (%vol)				Share of growing media in exports (%vol)		Ratio professional (P) / hobby (H) growing media (%vol)			Peat rate in professional (P) and hobby (H) growing media (%vol)			Composition peat in growing media (%vol)				Composition in other constituents
		%WP	%BP	%FP	Source	%	Source	%P	%H	Source	P	H	Source	%WP	%BP	%FP	Source	Source
BLR	X1	62%	37%	1%	(0)	0%	Assumption	-	-	-	-	-	-	-	-	-	-	-
EST	X1	76%	24%	0%	(2b)	0%	Assumption	-	-	-	-	-	-	-	-	-	-	-
LTU	X1	78%	22%	0%	(2a)	0%	Assumption	-	-	-	-	-	-	-	-	-	-	-
RUS	X1	62%	37%	1%	(0)	0%	Assumption	-	-	-	-	-	-	-	-	-	-	-
UKR	X1	62%	37%	1%	(0)	0%	Assumption	-	-	-	-	-	-	-	-	-	-	-
IRL	X1	18%	82%	0%	(1)	50%	(3)	28%	72%	(1)	100%	82%	(1)	9%	91%	0%	(1)	(1)
LVA	X1	83%	17%	0%	(2a)	60%	(3)	60%	40%	(3)	93%	90%	(1)	70%	30%	0%	(4)	(1)
FIN	X1	68%	33%	0%	(1)	100%	(3)	49%	51%	(1)	99%	79%	(1)	49%	51%	0%	(1)	(1)
NOR	X1	62%	37%	1%	(0)	100%	Assumption: like FIN	56%	44%	(0)	0%	0%	(0)	43%	56%	1%	(4)	(0)
SWE	X1	74%	20%	7%	(1)	100%	Assumption: like FIN	23%	77%	(1)	87%	87%	(1)	58%	33%	9%	(1)	(1)
DEU	X2	35%	60%	5%	(3)	60%	(3)	81%	19%	(2a)	89%	73%	(1)	33%	67%	0%	(1)	(1)
BIH	X2	62%	37%	1%	(0)	100%	Assumption for X2 & X3	56%	44%	(0)	0%	0%	(0)	43%	56%	1%	(5)	(0)
DNK	X2	42%	58%	0%	(1)	100%	Assumption for X2 & X3	29%	71%	(1)	93%	85%	(1)	26%	74%	0%	(1)	(1)
ESP	X2	62%	37%	1%	(0)	100%	Assumption for X2 & X3	56%	44%	(0)	0%	0%	(0)	44%	56%	0%	(5)	(0)
GBR	X2	49%	43%	8%	(1)	100%	Assumption for X2 & X3	23%	77%	(1)	75%	48%	(1)	31%	60%	9%	(1)	(1)
HUN	X2	62%	37%	1%	(0)	100%	Assumption for X2 & X3	56%	44%	(0)	0%	0%	(0)	46%	54%	1%	(5)	(0)
POL	X2	55%	28%	16%	(1)	100%	Assumption for X2 & X3	49%	51%	(1)	94%	100%	(1)	39%	42%	20%	(1)	(1)
TUR	X2	62%	37%	1%	(0)	100%	Assumption for X2 & X3	56%	44%	(0)	0%	0%	(0)	47%	52%	1%	(5)	(0)
NLD	X3	62%	37%	1%	(0)	65%	(3)	84%	16%	(1)	65%	74%	(1)	33%	67%	0%	(1)	(1)
ALB	X3	62%	37%	1%	(0)	100%	Assumption for X2 & X3	56%	44%	(0)	0%	0%	(0)	28%	72%	0%	(6)	(0)
AUT	X3	62%	37%	1%	(0)	100%	Assumption for X2 & X3	24%	76%	(1)	60%	59%	(1)	59%	41%	0%	(1)	(1)
BEL	X3	62%	37%	1%	(0)	100%	Assumption for X2 & X3	60%	40%	(1)	85%	79%	(1)	27%	73%	0%	(1)	(1)
BGR	X3	62%	37%	1%	(0)	100%	Assumption for X2 & X3	56%	44%	(0)	0%	0%	(0)	41%	59%	0%	(6)	(0)

Country Code	Dependency status on bulk peat imports	Composition peat extraction				Composition exports												
		Composition peat (%vol)				Share of growing media in exports (%vol)		Ratio professional (P) / hobby (H) growing media (%vol)			Peat rate in professional (P) and hobby (H) growing media (%vol)			Composition peat in growing media (%vol)				Composition in other constituents
		%WP	%BP	%FP	Source	%	Source	%P	%H	Source	P	H	Source	%WP	%BP	%FP	Source	Source
CHE	X3	62%	37%	1%	(0)	100%	Assumption for X2 & X3	56%	44%	(0)	0%	0%	(0)	29%	71%	0%	(6)	(0)
CYP	X3	62%	37%	1%	(0)	100%	Assumption for X2 & X3	56%	44%	(0)	0%	0%	(0)	46%	54%	0%	(6)	(0)
CZE	X3	62%	37%	1%	(0)	100%	Assumption for X2 & X3	56%	44%	(0)	0%	0%	(0)	52%	48%	0%	(6)	(0)
FRA	X3	0%	0%	100%	(3)	100%	Assumption for X2 & X3	50%	50%	(1)	66%	40%	(2a)	30%	64%	6%	(1)	(2a)
GRC	X3	62%	37%	1%	(0)	100%	Assumption for X2 & X3	56%	44%	(0)	0%	0%	(0)	43%	57%	0%	(6)	(0)
HRV	X3	62%	37%	1%	(0)	100%	Assumption for X2 & X3	56%	44%	(0)	0%	0%	(0)	46%	54%	0%	(6)	(0)
ITA	X3	62%	37%	1%	(0)	100%	Assumption for X2 & X3	60%	40%	(1)	83%	60%	(2a)	48%	52%	0%	(1)	(1)
LUX	X3	62%	37%	1%	(0)	100%	Assumption for X2 & X3	56%	44%	(0)	0%	0%	(0)	24%	76%	0%	(6)	(0)
MDA	X3	62%	37%	1%	(0)	100%	Assumption for X2 & X3	56%	44%	(0)	0%	0%	(0)	49%	51%	0%	(6)	(0)
MKD	X3	62%	37%	1%	(0)	100%	Assumption for X2 & X3	56%	44%	(0)	0%	0%	(0)	55%	45%	0%	(6)	(0)
MLT	X3	62%	37%	1%	(0)	100%	Assumption for X2 & X3	56%	44%	(0)	0%	0%	(0)	40%	60%	0%	(6)	(0)
MNE	X3	62%	37%	1%	(0)	100%	Assumption for X2 & X3	56%	44%	(0)	0%	0%	(0)	31%	69%	0%	(6)	(0)
PRT	X3	62%	37%	1%	(0)	100%	Assumption for X2 & X3	46%	54%	(0)	3%	3%	(0)	35%	65%	0%	(6)	(0)
ROU	X3	62%	37%	1%	(0)	100%	Assumption for X2 & X3	56%	44%	(0)	0%	0%	(0)	39%	61%	0%	(6)	(0)
SRB	X3	62%	37%	1%	(0)	100%	Assumption for X2 & X3	56%	44%	(0)	0%	0%	(0)	56%	44%	0%	(6)	(0)
SVK	X3	62%	37%	1%	(0)	100%	Assumption for X2 & X3	56%	44%	(0)	0%	0%	(0)	49%	51%	0%	(6)	(0)
SVN	X3	62%	37%	1%	(0)	100%	Assumption for X2 & X3	56%	44%	(0)	0%	0%	(0)	35%	65%	0%	(6)	(0)

X1: Independent of bulk peat imports (see assumption 16); X2: Partially dependent on bulk peat imports (see assumption 18); X3: Extremely dependent on bulk peat imports (see assumption 17)

(0) Default: Average value in growing media production in Europe from Schmilewski (2017) (original data in m³)

(1) Average value in growing media production in the country from Schmilewski (2017) (original data in m³)

(2a) Calculated from industry data (original data in m³), LTU, LVA: IPS Survey 2019; DEU: IVG; FRA: AFAIA; ITA: AIPSA

(2b) Calculated from industry data (original data in t), EST: IPS Survey 2019

(3) Expert estimated data (original data in %m³), DEU, IRL, NLD: Bert von Seggern (Klasmann-Deilmann); FRA: Laurent Largant (AFAIA); LVA: Ingrida Krigere (Latvian Peat Association); FIN: Hannu Salo (Bioenergia)

(4) Composition of peat extraction (X1)

(5) Weighted average composition of peat extraction and bulk peat imports (X2)

(6) Composition of bulk peat imports (X3)

Table A6. Average density factors used as input. Unit: kg·m^{-3}. *density explicitly calculated using EN13040, in accordance with volume determination using EN12580.

Sector	Constituent	kg·m^{-3}	Source
Energy	Milled peat	320	Statistics Finland (2020), Net heat contents and densities of fuels
	Sod peat	380	Statistics Finland (2020), Net heat contents and densities of fuels
Non-energy	Bog /Sphagnum) peat H1–H5	175	Calculated from Schmilewski (2018), Tabelle 8, Hochmoortorf (H3-H5): 150−200 g·l^{-1}*
	Bog /Sphagnum) peat H6–H10	375	Calculated from Schmilewski (2018), Tabelle 8, Hochmoortorf (H6-8): 350−400 g·l^{-1}*
	Fen peat H1–H10	300	Undifferentiated peat, from Hofer & Pautz GbR (2011), Torf
	Bark (non-treated)	350	Calculated from Schmilewski (2018), Tabelle 8, Pinienrinde: 300−400 g·l^{-1}*
	Coir (pith, fibres, chips)	300	Calculated from Schmilewski (2018), Tabelle 8, Kokosmark: 250−350 g·l^{-1}*
	Wood-fibres	105	Calculated from Schmilewski (2018), Tabelle 8, Holzfaserstoffe: 90−120 g·l^{-1}*
	Wood (chips, etc,)	194	Hartmann (2014), Tab 2,13, Hackgut, Weichholz (Fichte)
	Rice hulls	100	Calculated from Schmilewski (2018), Tabelle 8, Reispelzen: 90−110 g·l^{-1}*
	Leaf mold; Heather soil	400	Assumed like composted bark
	Composted or aged bark	400	Calculated from Schmilewski (2018), Tabelle 8, Rindenhumus: 350−400 g·l^{-1}*
	Composted green waste	550	Calculated from Schmilewski (2018), Tabelle 8, Substratkompost: 500−600 g·l^{-1}*
	Composted wood waste	400	Assumed like composted bark
	Other composted/aged materials	550	Assumed like green compost
	Perlite (exfoliated)	117.5	Calculated from Schmilewski (2018), Tabelle 49, Blähperlit: 95−140 g·l^{-1}*
	Clay (fresh; dry)	1,125	Calculated from Schmilewski (2018), Tabelle 44, Tonminerale: 750−1500 g·l^{-1}
	Clay (exfoliated)	1,125	Assumed like clay (fresh; dry)
	Sand	1,600	Calculated from Schmilewski (2018), §5,2,6 Sand: 1,5−1,7 kg·l^{-1}*
	Vermiculite (exfoliated)	122.5	Calculated from Schmilewski (2018), Tabelle 52, Blähvermiculit: 115−130 g·l^{-1}*
	Lava	1,050	Calculated from Schmilewski (2018), Tabelle 53, Schaumlava: 900−1200 g·l^{-1}
	Pumice	550	Calculated from Schmilewski (2018), Tabelle 53, Bims: 500−600 g·l^{-1}
	Grit	1,600	Assumed like sand
	Loam	1,125	Assumed like clay (fresh; dry)
	Mineral wool (pre-shaped)	70	Peano *et al*. (2012), Table 9, Mineral wool

Table A7. Steps of the data combination, the identification of discrepancies and the data correction for energy (E) peat (E1 to E3) and non-energy (NE) peat (NE1 to NE15).

Step	Condition	Calculation	Assumptions
E1	$Q_{E,extraction,n}$ not in tons	$d_{E,extraction,n}$ using (VI) based on composition milled / sod peat $Q_{E,extraction,n,\ tons}$ using (V)	
E2		$Q_{E,consumption,n,tons}$ using (I)	12
E3	$Q_{consumptionE,n,tons} < 0$ OR $Q_{min,n} = 0.9 * Q_{E,extraction,n} + 0.9 * Q_{E,import,n} - 1.1 * Q_{E,export,n} > 0$ OR $Q_{max,n} = 1.1 * Q_{E,extraction,n} + 1.1 * Q_{E,import,n} - 0.9 * Q_{E,export,n} < 2 * Q_{E,consumption,n}$	Use original data on consumption $Q_{E,export,n,tons}$ using equation (I) $Q_{E,import,n,tons}$ using equation (II) $Q_{NE,export,n,tons}$ and $Q_{NE,import,n,tons}$ using equation (III)	24
NE1	$Q_{NE,extraction,n}$ not available as input	$Q_{NE,extraction,n}$ using (III) in tons or cubic meters	
NE2	$Q_{NE,extraction,n}$ not in tons	$d_{NE,extraction,n}$ using (VI) based on composition WP / BP / FP $Q_{NE,extraction,n,\ tons}$ using (V)	
NE3	$X_{i,GM\ production,n}$ is available	$X_{i,GM\ export,n} = X_{i,GM\ production,n}$	14, 15
NE4	$Q_{bulk\ peat,import,n,tons}$ is not available (1st loop)	$Q_{bulk\ peat,import,n,tons} = Q_{NE,import,n,tons}$	
NE5	$Q_{NE,extraction,n,tons} > 5 \times Q_{bulk\ peat,import,n,tons}$ AND $X_{i,extraction\ NE,n}$ is available	$X_{i,peat\ in\ GM\ export,n} = X_{i,extraction\ NE,n}$	16
NE6	$X_{i,extraction\ NE,n}$ is not available AND $X_{i,peat\ in\ GM\ production,n}$ is available	$X_{i,extraction\ NE,n} = X_{i,peat\ in\ GM\ production,n}$	
NE7	$Q_{bulk\ peat,import,n,tons} > 5 \times Q_{NE,extraction,n,tons}$ AND $X_{i,import\ bulk,n}$ is available	$X_{i,peat\ in\ GM\ export,n} = X_{i,import\ bulk,n}$	17

Step	Condition	Calculation	Assumptions
NE8	$5 \times Q_{bulk\ peat,import,n,tons} > Q_{NE,extraction,n,tons} > \frac{1}{5} \times Q_{bulk\ peat,import,n,tons}$ AND $X_{i,extraction\ NE,n}$ is available AND $X_{i,import\ bulk,n}$ is available	$X_{i,peat\ in\ export\ GM,n} = \frac{X_{i,extraction\ NE,n} * Q_{NE,extraction,n} + X_{i,import\ bulk,n} * Q_{import\ bulk,\ n}}{Q_{NE,extraction,n} + Q_{import\ bulk,\ n}}$	18
NE9	All countries except the Netherlands	$X_{i,export\ bulk,n} = X_{i,extraction\ NE\ except\ fen\ peat,n}$	19, 20
NE10		$d_{export\ GM,n}$ and $d_{export\ bulk,n,}$ using (VI) $X_{bulk\ peat,export,n,tons}$ and $X_{GM,export,n,tons}$ using (VII) $Q_{i,export\ NE,n,tons}$ using (IV)	
NE11	Only the Netherlands	$Q_{i,import\ NE,NDL,tons}$ using (II) $X_{i,import\ NE,NDL}$ using (IV) $X_{i,export\ bulk,NLD} = X_{i,import\ bulk\ (except\ DEU),NDL}$ Repeat step NE7 for NDL	21
NE12		$Q_{i,import\ NE,n,tons}$ using (II) $X_{i,import\ NE,n,tons}$ using (IV)	
NE13	If only one dependency test was carried out OR if for at least one country, the dependency status of the country changed since last NE13	Repeat the process back to Step NE1 using the new values	
NE14		$Q_{NE,consumption,n,tons}$ and $Q_{i,consumption\ NE,n,tons}$ using (I)	12
NE15	$Q_{NE,consumption,n,tons} < 0$ OR $Q_{min,n} = 0.9 * Q_{NE,extraction,n} + 0.9 * Q_{peat,import\ NE,n} - 1.1 * Q_{peat,export\ NE,n} > 0$ OR $Q_{max,n} = 1.1 * Q_{NE,extraction,n} + 1.1 * Q_{peat,import\ NE,n} - 0.9 * Q_{peat,export\ NE,n} < 2 * Q_{NE,consumption,n}$	Use original data on consumption $Q_{NE,extraction,n,tons}$ using (I)	23

Table A8. Calculation of consumption and correction of non-energy extraction data. GM = Growing Media; * = personal communication (2019).

Country Code	Unit	Original total extraction data	Result of the first calculation of consumption	Corrected non-energy consumption		Corrected total extraction	Difference original data	
		Amount		Amount	Source	Amount	Amount	%
IRL	kt	5,040	Implausible	69	Calculation based on IPS data* (10% non-energy peat extraction)	5,256	216	+4%
LTU	1000m³	2,771	Implausible	395	Data on non-energy peat production for the domestic market (IPS data* 2014-2017) + GM imports	3,630	859	+31%
LVA	kt	1,037	Implausible	44	Data on non-energy peat production for the domestic market (IPS data* 2014-2017) + GM imports	1,137	100	+10%
EST	kt	747	Too uncertain	32	Calculation based on Latvia's consumption and the comparison of the horticultural production and the population (factor 0.74)	763	16	+2%
DEU	1000m³	3,232	Implausible	4,483	Data on peat for growing media production (Schmilewski 2017, data 2013) - Export GM + Import GM	7,152	3,920	+121%
BIH	kt	0	Implausible	8	Calculation based on Albania's consumption and the comparison of the population (factor 1.33)	10	10	-