

The HarvestCO₂-App

Technical description

R Version and Packages

We developed the HarvestCO₂-App in R Shiny¹ using R-version 4.3.0². The R Shiny Package offers a range of functions which enable users to develop web-based applications. The R-code builds an HTML-interface which can be integrated into websites or published on a server. Additional packages used were common³, XML⁴, xml2⁵, readxl⁶, tidyverse⁷, shinyBS⁸, shinyWidgets⁹, tools¹⁰ and conflicted¹¹.

Tree Data

The app uses an excel-document containing kiln density and total shrinkage of 8 conifers and 24 deciduous trees which allows species-specific calculations of carbon content in the harvested wood. Values were drawn from Ulf Lohmann “Holzhandbuch” (1999) and Rudi und André Wagenführ “HolzAtlas” (2022). For most species these books report a range of values for both kiln density and total shrinkage. Whenever three values were reported, we chose the middle value. When only two values were given, we averaged the two values.

Table 1: Kiln densities and total shrinkage of conifers as defined in HarvestCO₂.

Species	Scientific Name	Kiln Density [kg/m ³]	Total Shrinkage [%]
Douglas fir	<i>Pseudotsuga menziesii</i>	470	11,9
Grand fir	<i>Abies grandis</i>	370	10,85 ¹²
Larch	<i>Larix decidua</i>	550	13,2
Norway Spruce	<i>Picea abies</i>	430	11,8
Scots pine	<i>Pinus sylvestris</i>	490	11,8
Silver fir	<i>Abies alba</i>	410	10,85
Weymouth pine	<i>Pinus strobus</i>	370	9,0
Yew	<i>Taxus baccata</i>	640	8,8
Average Conifers	Coniferales	466	11,03

Table 2 Kiln densities and total shrinkage of deciduous trees as defined in HarvestCO₂.

Species	Scientific Name	Kiln Density [kg/m ³]	Total Shrinkage [%]
Alder	<i>Alnus spec.</i>	510	13,4
Ash	<i>Fraxinus excelsior</i>	650	13,2

¹ <https://www.rdocumentation.org/packages/shiny/versions/1.7.5>, accessed 11.09.2023

² <https://www.r-project.org/other-docs.html>, accessed 11.09.2023

³ <https://cran.rstudio.com/web/packages/common/index.html>, accessed 11.09.2023

⁴ <https://cran.r-project.org/web/packages/XML/index.html>, accessed 11.09.2023

⁵ <https://cran.r-project.org/web/packages/xml2/index.html>, accessed 11.09.2023

⁶ <https://CRAN.R-project.org/package=readxl>, accessed 09.10.2023

⁷ <https://www.tidyverse.org/>, accessed 11.09.2023

⁸ <https://cran.r-project.org/web/packages/shinyBS/index.html>, accessed 12.12.2023

⁹ <https://rdr.io/cran/shinyWidgets/>, accessed 12.12.2023

¹⁰ <https://rdr.io/r/tools/tools-package.html>, accessed 12.12.2023

¹¹ <https://cran.r-project.org/web/packages/conflicted/index.html>, 12.12.2023

¹² No total shrinkage could be found for grand fir which is why we use the value for silver fir

Aspen	<i>Populus tremula</i>	450	11,9
Beech	<i>Fagus sylvatica</i>	680	17,9
Birch	<i>Betula pendula</i>	610	13,95
Black cherry	<i>Prunus serotina</i>	545	12,85
Black locust	<i>Robinia pseudoacacia</i>	740	11,8
Black poplar	<i>Populus nigra</i>	410	12,5
Black walnut	<i>Juglans nigra</i>	570	12,65
Chequers	<i>Sorbus torminalis</i>	710	17,15
Cherry	<i>Prunus avium</i>	550	13,85
Chestnut	<i>Castanea sativa</i>	560	11,45
Elm	<i>Ulmus spec.</i>	640	12,8
Hornbeam	<i>Carpinus betulus</i>	790	18,8
Horse chestnut	<i>Aesculus hippocastanum</i>	510	11
Linden	<i>Tilia spec. (cordata & platyphyllos)</i>	490	14,65
Maple	<i>Acer spec.</i>	590	11,65
Oak (pedunculate & sessile)	<i>Quercus robur & petraea</i>	650	14,1
Pear	<i>Pyrus spec.</i>	700	14,15
Plane	<i>Platanus spec.</i>	580	13,95
Red oak	<i>Quercus rubra</i>	660	13,1
Rowan	<i>Sorbus aucuparia</i>	730	18
Walnut	<i>Juglans regia</i>	640	13,7
Willow	<i>Salix spec.</i>	330	9,6
Rowan (any species)	<i>Sorbus spec.</i>	720	17,15
Mean hardwood		613	13,31
Mean softwood		518	13,49
Mean deciduous		596	13,67

For other tree species the app defaults to total mean values of 563 kg/m³ for kiln density and 13,01 % for total shrinkage.

The excel sheet contains species names in German, English, French and Latin, as well as a subset of species groups in Swedish, Norwegian and Finnish. Importantly, because R is case-sensitive the app may not recognize a species name written in capital letters, unless the species name in the excel-document is also written in capital letters. For the same reason, the app will not recognize alternate spellings or synonyms of species names. In such cases the app uses the default average values.

Input data

In order to calculate the CO₂-Balance of an individual felling event, the app requires input from the user. Users can chose between typing the input in manually or uploading the .hpr and .mom files generated by the harvester and forwarder. The uploading of files automatically overwrites any prior manual inputs for the same value. Currently, it is not possible to combine manual input and file upload for the same value. However, it is possible to upload an .hpr file but manually add the diesel consumption of harvester and forwarder.

Tree Species Norway Spruce ▼	Harvest Volume [m³] 1	OR	Harvester .hpr-File Browse... No file select
Diesel Harvester [l] 1	OR	Harvester .mom-File Browse... No file select	
Diesel Forwarder [l] 1	OR	Forwarder .mom-File Browse... No file select	

Figure 1: Extract of the user interface of HarvestCO₂ showing the input fields for harvester and forwarder data. Users can choose to type data in manually or upload the files produced by the harvester and forwarder.

Manual input

If the users choose to manually type in their data, the app limits them to one species at a time, which is chosen through a drop-down list. The users then add the volume of harvested wood and the volume of diesel consumed by the harvester and forwarder during felling and skidding.

Input from files

Users can choose to upload up to three files: the .hpr-file generated by the harvester, the .mom-file generated by the harvester and the .mom-file generated by the forwarder. To alleviate data privacy concerns, the app is specifically designed to access as little information as possible. Thus, uploaded files cannot be stored and are deleted as soon as the app interface is closed.

Transport data

Users can choose to insert transport information to complete the carbon balance. The app generates three input fields for each of the species or assortments it finds in the .hpr file. If users chose manual input, only three input fields are generated, since manual input limits the input to one species at a time. The three input fields ask for the distance over which the logs were transported by truck, train or ship respectively.

Would you like to add the CO₂-Balance of transport?

Please insert the transport distance in kilometers for each of your assortments.

Transport Distance Truck [km] Norway Spruce 0	Transport Distanc Train [km] Norway Spruce 0	Transport Distance Ship [km] Norway Spruce 0
---	--	--

Figure 2: Extract of the user interface of HarvestCO₂ showing the input fields for transport distances. In the case of manual input, as shown here, three fields are generated.

Additional harvest information

After inserting the information necessary for calculating the carbon balance, users can choose to add additional information concerning the harvest event. This information is only relevant, if users agree to transmit the data relating to their harvest event to KWF for a long-term study. The study's goal is to understand the correlations between harvest conditions and carbon emissions.

In which country did the harvest operations take place?

Germany

Type of wood harvest I

- Clear cut
- Selective
- Beetle calamity
- Wind calamity

Use of technology I

- Crane tip control
- Fleet control software
- Intralogistics

Infrastructure

- 20 m Skidroad
- 30 m Skidroad
- 40 m Skidroad

Distance covered by harvester [km]

0

Type of wood harvest II

- Thinning
- Later thinning
- Final felling

Use of technology II

- Hybrid engine
- Thermostatic fans
- Dual gear

Stand type

- Monoculture
- Mixed stand

Distance covered by forwarder [km]

0

Type Harvester

- Small
- Medium
- Large

Use of technology III

- High flotation tires
- Tire pressure control system
- Continuous track

Stand situation

- Visual restrictions / rejuvenation
- Large boulders

Type Forwarder

- Small
- Medium
- Large

Incline

- < 35 %
- 36 - 50 %
- > 50 %

Transmit results to KWF

Figure 3: Extract of the user interface of HarvestCO₂ showing the input questionnaire at the end of the interface. Users are encouraged to add information concerning their harvest operations and transmit the data to KWF for a long-term study.

Variables were selected because they have been little studied in the past, in terms of their effects on the carbon balance of wood harvests. Harvester and Forwarder types are specifically defined¹³.

Harvester types are defined as¹⁴:

- Small: < 20 cm diameter at breast height (DBH)
- Medium: 20-50 cm DBH
- Large: > 50 cm DBH

Forwarder types are defined as¹⁵:

- Small: < 10 t of payload
- Medium: 10- < 13 t of payload
- Large: ≥ 13 t of payload

Server Computations

Reading of harvester and forwarder files

A major challenge was reading the harvester and forwarder files and extracting the correct information. The app allows users to upload two kinds of StanForD files: the .mom files of harvester and forwarder and the .hpr files. These files are written in extensible markup language (xml) which

¹³ <http://dbwaldarbeit.kwf-online.de/>, accessed 15.12.2023

¹⁴ http://dbwaldarbeit.kwf-online.de/betriebsmittel/1_Harvester/, accessed 15.12.2023

¹⁵ http://dbwaldarbeit.kwf-online.de/betriebsmittel/1_Forwarder/, accessed 15.12.2023

stores information in nested lists. Two separate methods needed to be used for the different file types.

The .mom files contain highly sensitive data which must be protected and which is mostly irrelevant for the proper functioning of the app. The only data they contain, which the app needs, is the fuel consumption of the most recent felling event. This information is stored as a series of values all relating to separate steps within the most recent felling event. In order to retrieve this information, the app reads the file, searching for the keyword "FuelConsumption" and picks only the values that are linked to this word, ignoring all the rest. This ensures data privacy for the users who upload their files. The individual measurements are summed up to return a single value for the fuel consumption of the machine during the harvesting event.

The harvester produces the .hpr file, which contains several nested lists each further subdivided into more nested lists. Each species and each assortment is given an identifying key. This key is used throughout the file, rather than the name of the species or assortment. In addition, the file stores three volume values for each individual log: volume (unspecified), volume over bark and volume under bark. Therefore, merely searching for the names of a species or the word "volume" will result in confusion where products are potentially matched to the wrong species or volume. Instead, three nested lists were identified, which need to be unnested and turned into R-readable data frames: "SpeciesGroupDefinition", "ProductDefinition" and "Stem".

In a first step, the app scans the "SpeciesGroupDefinition" list and extracts the "SpeciesGroupName" and "SpeciesGroupKey" information. The app temporarily stores this information in a data frame which matches each species key (SpeciesGroupKey) to the name of the species it represents. Because of the nested list structure of the .hpr file, the app initially produces a data frame of all information stored in the list and its sublists before discarding superfluous information. This process happens analogously for steps two and three.

In a second step, the app repeats this process for the "ProductDefinition" list from which it extracts "ProductName" and matches this to its respective "SpeciesGroupKey". By combining the two lists, the app then matches each product with the correct species name.

In a third step, the app reads in the "Stem" data. This list stores information concerning each individual stem processed by the harvester. The stems are further subdivided into logs. Each log is assigned a product key which identifies the assortment the log belongs to and the species of the stem. The app then extracts the three volumes for each log. Since the app only uses volume over bark, it discards the two extra volumes and generates a data frame which contains all logs, their respective volumes, the assortments they belong to and the species of the tree they came from. This data frame forms the basis for all further calculations.

Equations for CO₂-Balance

The equations follow Kaulen and Purfürst (in press). Each equation was implemented as a function. The equation for calculating transport emissions was broken down into three equations: one for transport by truck, one for transport by train and one for transport by ship. This enables the individual calling of the functions. In addition, each function is set so that they return zero if the number of kilometers in the input field for transport distance is zero. Thus, the app assumes that if the transport distance is zero, the method of transportation was not used. This is important because certain fixed emissions, such as those generated during construction of the vehicles would return a small amount of emissions, even when the transport distance is zero.

App output

The app displays two output tables. By default, the first contains tree species, assortment, wood volume, kiln density, carbon content of wood, harvest emissions and carbon balance of harvest. However, users may choose additional variables to display from a drop-down list. The second output table contains tree species, volume, transport emissions and total carbon balance including transport.

Select variables that interest you

Species [], Assortment [], Volume [m3], Kiln ▾

Species []	Assortment []	Volume [m3]	Kiln Density [kg/m3]	Carbon Content [kg]	Harvest Emissions [kg]	CO2-Balance Harvest [kg]
Buche	IS 3,0 Brennholz	1.17	680.00	340.40	2.16	1247.11
Buche	Unclassified	0.05	680.00	15.50	0.10	56.78
Fichte	ABS 5,0 m Käfer	601.37	430.00	118371.98	1106.53	433318.64
Fichte	IS FK 2,5 m	168.20	430.00	33106.88	309.48	121192.77
Fichte	Palette 2,4 m	7.42	430.00	1461.17	13.66	5348.83
Fichte	Papier 3,0m	19.09	430.00	3757.93	35.13	13756.47
Fichte	Pony 3,1m.+10	127.78	430.00	25150.87	235.11	92068.58
Fichte	Unclassified	6.47	430.00	1273.02	11.90	4660.08
Fichte	X-Holz	25.22	430.00	4964.12	46.40	18171.92

Figure 4: Extract of the user interface of HarvestCO₂ showing the first output table featuring a list of assortments from a harvester file along with the carbon balance of harvest for each assortment.

Species []	Assortment []	Volume [m3]	Transport Emissions [kg]	CO2-Balance Total [kg]
Buche	IS 3,0 Brennholz	1.17	36.23	1210.88
Buche	Unclassified	0.05	1.55	55.23
Fichte	ABS 5,0 m Käfer	601.37	18624.43	414694.21
Fichte	IS FK 2,5 m	168.20	5209.15	115983.62
Fichte	Palette 2,4 m	7.42	229.80	5119.03
Fichte	Papier 3,0m	19.09	591.22	13165.25
Fichte	Pony 3,1m.+10	127.78	3957.35	88111.23
Fichte	Unclassified	6.47	200.38	4459.70
Fichte	X-Holz	25.22	781.06	17390.86

Figure 5: Extract of the user interface of HarvestCO₂ showing the second output table featuring the same assortments as above as well as transport emissions and the total CO₂-Balance of harvest and transport.

Data Protection

We designed the app in accordance with EU data protection regulations. The app minimizes the amount of data it processes by selecting only the specific data or lists it needs and further discarding all data not required for calculating the carbon balance. If users choose to transfer data to KWF, only the data displayed in the user interface will be saved. Raw data or uploaded files cannot be saved and will be deleted as soon as the website is closed.

References

Kaulen, Alexander und Purfürst, Thomas (in press): Net Carbon Storage of supplied timber in Highly Mechanized Timber Harvest, o.O., o.D..

Lohmann, Ulf (1999): Holzhandbuch, 5. Auflage, DRW-Verlag, 1999.

Wagenführ, Rudi und Wagenführ, André (2022): Holzatlas, 7. überarbeitete und ergänzte Auflage, Hanser Verlag, 2022.