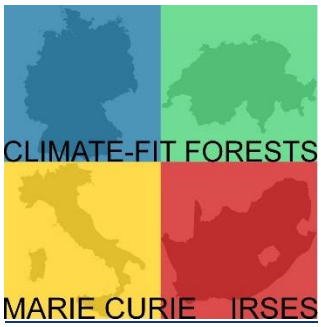
Marie Curie IRSES

Climate-Fit Forests

(GA 295136)

Solutions for adapted forest management strategies under the threat of climate change - learning from a climate gradient from Germany over Italy to South Africa



CO_2 emission in forest operations: the CO2FORMEC Database

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Introduction

During wood harvesting operation, carbon is released to varying degrees depending on the product being harvested and on emissions from the machines used in the process (Liski et al. 2001). Principal sources of CO_2 in forest operations result from direct core emissions from machines related to fuel use (Knechtle 1997; Schwaiger and Zimmer 2001; Klvač et al. 2003; Gonzalez-Garcia et al. 2009; Valente et al. 2011; González-García et al. 2012; Klvač et al. 2012; Picchio et al. 2012; Vusić et al. 2013).

CO_2 emissions in forest harvesting operations are also influenced by stand and terrain conditions, wood species, management methods, operator performance and machinery limitation or design (Van Belle 2006; González-García et al. 2009; Kärhä 2011; Vusić et al. 2013; Alam et al. 2014). Therefore, with increasing mechanisation of forest operations it can be expected that emissions could increase (Berg 1997; Athanassiadis 2000) even though forestry activities do not tend to emit vast amounts of greenhouse gases. However the necessity for a low carbon emission system still exists, bearing in mind that GHG emissions in the European Union must be reduced by 40% by 2030 (with 1990 as base-line). This proposed reduction must however be cost effective and sustainable in the long run.

CO2FORMEC Database

Data collection

The first step was to retrieve as many relevant scientific publications dealing with CO_2 emission from forest operations, including primary and secondary transportation, over the last 20 years (1994-2014).

Scopus and Google Scholar were selected as web search engines. Each of them were queried using the same keywords. English search terms and their various combinations using Boolean operators (AND OR), wild-cards (for any group of characters (*) or for a single character (?)) were used to perform the search (the strings were combined as follow: 1. AND 2. AND 3.) (Table 1).

Table 1. The combinations based on Boolean operators used to query the web search engines

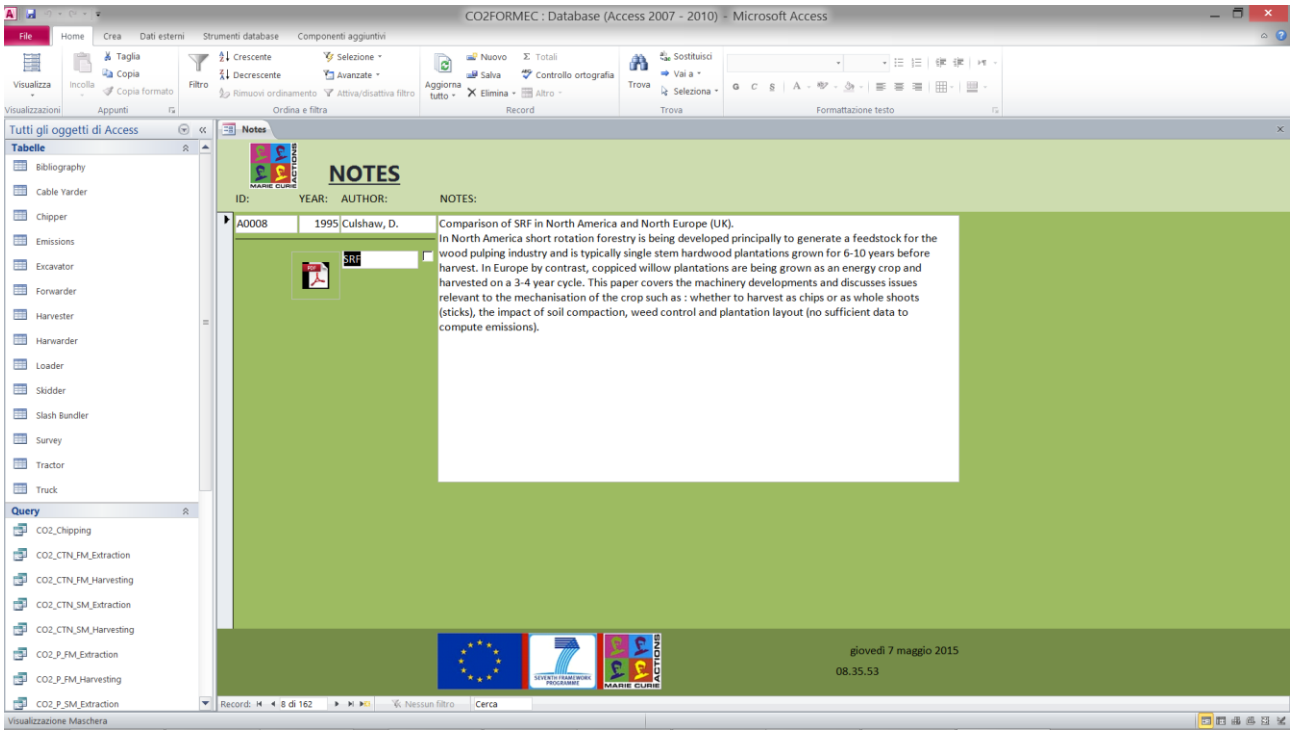
Search string for forest and forest products:	“forest*” OR “stand” OR “*wood*” OR “*timber” OR “spruce” OR “beech” OR “pine” OR “poplar”, “eucalyptus” OR “plantation” OR “close to nature”
Searching string for forest operations:	“operation” OR “logging” OR “harvest*” OR “forward*” OR “extraction” OR “skid*” OR “*haulage” OR “transport*” OR “machin*” OR “*mechaniz*”
Searching string for emissions:	“emission?” OR “CO_2” OR “ghg” OR “greenhouse*” OR “fuel consumption” OR “productivity” OR “rate” OR “time” OR “LCA” OR “life cycle”

Database structure

All the identified literature was re-organized into a database built in Microsoft Access®. The framework of the database is taken up in the following tables: Bibliography, Emissions and Survey.

In the Bibliography, all the principal features of the papers analysed were reported, such as the Title, Year, Author/s and Country. A link to the relative Portable Document Format (PDF) file was also provided in order to access easily to the documentation (Figure 1). The Emissions table, in which all the most relevant data and values were collected, was connected with the Bibliography table through a “one-to-many” relation between the ID field, where a unique ID identified each paper. Another “one-to-many” relation connected the Survey to Emission through the field “ID_S” (survey). In the former, specific data of the field survey areas were reported when they were available. The database also included specific tables containing technical data on the relative categories of machines (e.g., harvester, forwarder, slash bundler, skidder, tractor, cable yarder, excavator, chipper and truck) according to the way in which information was provided by each study. They were then simply connected to the Emission table through the field “ID_M” (machine).

Figure 1: Database mask to access to the article pdf



Key fields and definitions

The Emissions table (Table 2) is the key table of the database, in which all the most relevant data and values are collected.

Table 2. Field and definition included in the Emission table.

FIELD/*Value*	DESCRPITION
ID	*Identification code of the **article/paper**, it is the same of the respective paper stored in database "Reference"*
ID_S	*Identification code of the **survey** area*
ID_M	*Identification code of the **machine***
YEAR_S	*Year of the survey*
DATA COLLECTION	*Span of time in which the data of the survey are collected*
YR	Values collected during the year of the survey (YEAR_S)
NYR	Average national data collected during the year of the survey (YEAR_S)
Nyears	Average national data collected during the time span written
COUNTRY_S	*Country of the survey*
CATEGORY	*Type of classification of the paper*
E	Emission
P	Productivity
LCA	Life Cycle Assessment
SRF	Short Rotation Forestry
ACCESSORY	Useful papers for complementary informations
REGION	*Region of the survey*
CONTINENT	*Continent of the surveys*
WOOD SPECIES	*Principal species present in the stand*
WORK CLASSIFICATION	*Peculiar aspects or proceedings evaluated in the work and explained in the field "notes"*
ROTATION	*Rotation time of the forest/stand (years)*
REVOLUTION	*Revolution time of the forest/stand(years)*
WOOD TYPE	*Type of wood*
H	Hardwood
S	Softwood
M	Mixed
ROUGHNESS	*Roughness index (Table A0032 (Tiernan et al., 2004))*
EV	Even
UV	Uneven
RH	Rough
MEAN SLOPE	*Mean slope value expressed in % (Table A0032 (Tiernan et al., 2004))*
0-10	Gentle (0-10%)
11-20	Intermediate (11-20%)
21-33	Steep (21-33%)
>33	Very steep (>33%)
REGIME	*Type of forest regime*
ST	Standard

FIELD/*Value*		DESCRPITION
	SL	Salvage
APPROACH		*Type of approach of the whole harvesting work*
	CTN	Close to nature
	P	Plantation
WOOD USE		*Destination use of the wood*
	SW	Sawlog
	PW	Pulpwood
	EW	Energywood
	TB	Timber (used where it is mixed between saw log or pulp wood)
REGENERATION		*The natural or artificial process of re-establishment tree cover on [IUFRO]*
	CP	Coppice
	HF	High forest
	SD	Stand (Generally all forest stands belong to plantation approach. Anyway it also refers to high forest origin which was managed with tending operation)
	SRF	Short rotation forestry
SYLVICULTURAL SYSTEM		*Planned program of treatments throughout stand's life (synonym of "forest system")[IUFRO]*
	SHW	Shelter-wood cutting system
	CC	Clear cutting system
	SC	Selective cutting system (synonym "partial cutting", which is not a method [IUFRO])
TREATMENT		*Type of cut (in brackets associable terms are reported, which were also used in the database to make it easier)*
	ETH	Early thinning
	LTH	Late thinning
	TH	Thinning
	PRC (ETH)	Preparatory cutting
	SDC (TH)	Seed cutting
	SRC (LTH)	Secondary cutting
	FC	Final cutting
	STC (FC)	Standard clearcut (synonym of "block clearcut")
	PAC	Patch clearcut
	SRC	Strip clearcut
	CCR	Clear cutting with reserve
WORK SYSTEM		*Operational cutting phase management*
	FT	Full tree
	TL	Tree length (debranched and topped tree)
	CTL	Cut to length
	E	Energetic (from dedicated crop)
	ER	Energetic from residues (only early thinning or windthrows, branches and residues are processed)
OPERATION (1; 2; 3)		*Type of operation (modified by Table I of A0051 (Dias et al., 2007))*
SP		SITE PREPARATION
	SR	Stump removal

FIELD/*Value*			DESCRPITION
	CR		Clearing
		HR	Harrowing
		DK	Disking
		MW	Mowing
		HB	Herbiciding
	SF		Soil scarification
		EP	Escaving planting pits
		RP	Ripping
		SB	Subsoiling
		P	Ploughing
		FR	Furrowing and ridging
		TC	Terrace construction
SE			STAND ESTABLISHMENT
	PL		Planting
	SO		Sowing
	NR		Natural regeneration
ST			STAND TENDING
	CL		Cleaning
	FR		Fertilizing
	SL		Soil loosening
	SC		Selection of coppice stems
	PT		Precommercial thinning
	PR		Pruning
	TH		Thinning
LG			LOGGING
	F		Felling
	BN		Bunching
	DL		Delimbing
	B		Bucking (cross cutting)
	DB		Debarking
	W		Winching
	SK		Skidding
	EX		Extraction
	LL		Log loading
	C		Chipping
	RG		Root grinding
T			TRANSPORTATION
	LH		Long haulage (>150 Km)
	MH		Medium haulage (50-150 Km)
	SH		Short haulage (< 50 Km)
IE			INFRASTRACTURE ESTABLISHMENT
	RBM		Road building and maintenance
	FBM		Firebreak building and maintenance
MECHANIZATION			*Level of mechanization*
		FM	Full mechanized
		SM	Semi mechanized

FIELD/*Value*	DESCRPITION
MM	Motor manual (used when chainsaws are use in addition within a FM system)
TYPE OF MACHINE	*Category of machine investigated*
CS	Chainsaw (eventually followed by the number of chainsaw used)
HW	Harvester
SGH	Single-grip harvester
TGH	Two-grip harvester
FW	Forwarder
EX	Excavator
EXHW	Excavator with an harvester's head
EXGS	Excavator with grapple saw (GS)
HR	Harwarder
FBH	Feller-buncher
SB	Slash bundler
TR	Tractor
TRCH	Tractor with chipper (CH), drum (TRDRCH) or disk (TRDSCH)
TRPR	Tractor with processor (PR). Differently from TRHW, in this case the tractor must work in a stable and still position.
TRHW	Tractor with felling head or processor
TRWH	Tractor with winch (WH)
TRWHLA	Tractor with winch (WH) and logging arch (LA)
TRTL	Tractor with trail (TL)
TRFB	Tractor with forwarding bins (FB)
TRLD	Tractor with loader (LD)
TRCB	Tractor with cable way (CB)
TRGR	Tractor with root grinder (GR)
HS / HS2,4,…	Horse (eventually followed by the number of horses when used together for the same operation in the same time)
HSEFW	Horse with an eco-forwarder attached
ML / ML2,4,…	Mule (eventually followed by the number of mules when used together for the same operation in the same time)
SK	Skidder
RSK	Rubber-tired skidder
CWTRSK	Crawler tractor skidder
CSK	Cable skidder
GSK	Grapple skidder
CY	Cable yarder
L	Loader
TK	Truck
TLTK	Trailer truck
BTK	Biomass truck
TTK	Timber truck
TTKB	Timber truck with boom log loader (B)
TTLTK	Timber trailer truck
TTLTKB	Timber trailer truck with boom loader

FIELD/*Value*	DESCRPITION
TSLTKB	Timber semi-trailer truck with boom loader
CH	Chipper
DRCH	Drum chipper
DSCH	Disk chipper
CHW	Chipper-harvester (or chipharvester)
CHT	Chipper-tipper (or chiptipper)
BZ	Bulldozer
CT	Chute
EXTRACTION SYSTEM	*Type of extraction system (depending on the equipment available)*
GBS	Ground based system
CBS	Cable based system
SKIDDING DISTANCE (m)	*Distance of skidding from the felling site to the landing in m*
EXTRACTION DISTANCE (m)	*Distance of extraction from the landing site to the forest road/logging site in m*
TRANSPORTATION DISTANCE (km)	*Distance of transportation from logging site to the delivery centre in Km*
AVERAGE STEM SIZE (m^3)	*Average volume of the stem in m3*
VOLUME	*Amount of felled wood (timber, energy-wood …)*
VOLUME_U.M.	*Measure unit of VOLUME*
DIAMETER	*Where diameter (or volume) is measured*
UB	Under bark
OB	Over bark
DIAMETER SIZE (m)	*Value of diameter at breast height (dbh) in m*
PRODUCTIVITY	*Amount of wood per work time*
PRODUCTIVITY_U.M.	*Measure unit of* PRODUCTIVITY
DELAY	*Dead time of machine in action included in the computations (min)*
FUEL	*Type of fuel consumed by the machine*
D	Diesel oil
EC3	Swedish environmental class 3 (diesel)
EC1	Swedish environmental class 1 (diesel)
RME	Rapeseed methyl ester (diesel)
G	Gasoline
K	Kerosene
RME	Rapeseed methyl ester
POWER	*Power of the machine in kWh*
CONSUMPTION	*Fuel consumption reported*
CONSUMPTION_U.M.	*Measure unit of* CONSUMPTION
ID C METHOD	*Possible bibliography reference code (CXXXX or AXXXX) of* CONSUMPTION
CO_2	*Amount of carbon dioxide computed by the study*
CO_2_U.M.	*Measure unit of* CO_2 and of all other gasses
ID E METHOD	*Possible bibliography reference code (CXXXX or AXXXX) of* EMISSION (CO_2)
CO2_Computed	*Amount of carbon dioxide computed in the database (kg/m^3 or kg/m^3km)*

FIELD/*Value*	DESCRPITION
CO_2e	*Amount of equivalent carbon dioxide computed by the study*
CO_2e_U.M.	*Measure unit of* CO_2e and of all other gasses
CO	*Amount of carbon monoxide computed by the study*
NO_x	*Amount of nitrogen oxides computed by the study*
N_2O	*Amount of dinitrogen oxide computed by the study*
HC	*Amount of hydrocarbon computed by the study*
CH_4	*Amount of methane computed by the study*
NMVOC	*Amount of non methyl volatile organic matter computed by the study*
PM	*Amount of particulate matter computed by the study*

Boundaries and Functional Unit

The boundary of the study related to the Emission table was fixed to activities related to the harvesting site and the transport of forest products. Hence, only data on emissions from the functional phases of felling, extraction (primary transport) and transportation (secondary transport) was collected. Other work stages typical of forestry operations in a plantation, such as site preparation and tending, were not considered.

Secondly, the functional unit (FU) was expressed as kilograms of CO_2 directly emitted for every cubic meter of fresh (with a moisture content of 50%) wood processed and then expressed in $kgCO_2 \cdot m^{-3}$. "Directly emitted" means that only core direct emitted CO_2 (EPA 2008) was considered. Even if at times it was possible to distinguish between over bark (o.b.) and under bark (u.b.) diameter, this distinction was eventually not used.

All retrieved papers were divided in three groups according to the origin of the emission values:

- Emission: papers in which CO_2 emission values are stated;
- Fuel consumptions : papers in which CO_2 emission value are not stated, but they can be extracted through direct or indirect measurement of fuel consumption;
- Life Cycle Assessment (LCA): papers in which emission CO_2 and GHG emissions are provided in the measuring and assessing procedures of environmental performance of forest operations.

List of references

Alam, M., Walsh, D., Strandgard, M., Brown, M., 2014: A log-by-log productivity analysis of two Valmet 475EX harvesters. International Journal of Forest Engineering. 25(1): 14-22.

Athanassiadis, D., 2000: Energy consumption and exhaust emissions in mechanized timber harvesting operations in Sweden. Science of the Total Environment. 255(1-3): 135-143.

Berg, S., 1997: Some aspects of LCA in the analysis of forestry operations. Journal of Cleaner Production. 5(3): 211-217.

EPA, 2008: Direct Emissions from Mobile Combustion Sources. EPA - United States Environmental Protection Agency Climate Leaders, Washington DC. p. 31.

González-García, S., Bacenetti, J., Murphy, R. J., Fiala, M., 2012: Present and future environmental impact of poplar cultivation in the Po Valley (Italy) under different crop management systems. Journal of Cleaner Production. 26: 56-66.

Gonzalez-Garcia, S., Berg, S., Moreira, M. T., Feijoo, G., 2009: Evaluation of forest operations in Spanish eucalypt plantations under a life cycle assessment perspective. Scandinavian Journal of Forest Research. 24(2): 160-172.

Kärhä, K., 2011: Industrial supply chains and production machinery of forest chips in Finland. Biomass and Bioenergy. 35(8): 3404-3413.

Klvač, R., Fischer, R., Skoupý, A., 2012: Energy Use of and Emissions from the Operation Phase of a Medium Distance Cableway System. Croatian Journal of Forest Engineering. 33(1): 79-88.

Klvač, R., Ward, S., Owende, P. M. O., Lyons, J., 2003: Energy audit of wood harvesting systems. Scandinavian Journal of Forest Research. 18(2): 176-183.

Knechtle, N., 1997: Materialprofile von Holzerntesystemen–Analyse ausgewählter Beispiele als Grundlage für ein forsttechnisches Ökoinventar [Material profiles from forest harvest systems. Analyses of chosen examples as a base for forest LCI]. Departement Wald- und Holzforschung, ETH, Zürich. p. 65

Liski, J., Pussinen, A., Pingoud, K., Mäkipää, R., Karjalainen, T., 2001: Which rotation length is favourable to carbon sequestration? Canadian Journal of Forest Research. 31(11): 2004-2013.

Picchio, R., Maesano, M., Savelli, S., Marchi, E., 2009: Productivity and energy balance in conversion of a Quercus cerris L. coppice stand into high forest in Central Italy. Croatian Journal of Forest Engineering. 30(1): 15-26.

Schwaiger, H., Zimmer, B., 2001: A comparison of fuel consumption and greenhouse gas emissions from forest operations in Europe. Energy, Carbon and Other Material Flows in the Life Cycle Assessment of Forestry and Forest Products. Joensuu, European Forest Institute. 33-53.

Valente, C., Spinelli, R., Hillring, B. G., 2011: LCA of environmental and socio-economic impacts related to wood energy production in alpine conditions: Valle di Fiemme (Italy). Journal of Cleaner Production. 19(17-18): 1931-1938.

Van Belle, J. F., 2006: A model to estimate fossil CO2 emissions during the harvesting of forest residues for energy-with an application on the case of chipping. Biomass and Bioenergy. 30(12): 1067-1075.

Vusić, D., Šušnjar, M., Marchi, E., Spina, R., Zečić, T., Picchio, R., 2013: Skidding operations in thinning and shelterwood cut of mixed stands - Work productivity, energy inputs and emissions. Ecological Engineering. 61: 216-223.