DiSAA
DIPARTIMENTO di SCIENZE AGRARIE e AMBIENTALI

UNIVERSITÀ DEGLI STUDI DI MILANO
DIPARTIMENTO DI SCIENZE AGRARIE E AMBIENTALI - PRODUZIONE, TERRITORIO, AGROENERGIA

PhD School ''Agriculture, Environment and Bioenergy''
XXXIII Cycle Doctoral Program (2018-2019)
PhD School Coordinator: Prof. Daniele Bassi

Research Project Title:

A stand-level model to assess forest biomass and carbon stocks using site-specific primary data

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PhD School Annual Meeting
Fognano di Brisighella (Ravenna, Italy), 23-25 September, 2019

INTRODUCTION and AIM of the PhD PROJECT

Woody biomass (WB) supply and carbon (C) stock: most important ESs to support forest management and climate change mitigation

PROBLEMS

1. Forests (local level) managed only through Forest Management Plans (FMPs);
2. models designed for large areas;
3. tree-level models not satisfactory for forest management;
4. scarse availability of stand-level models;
5. very difficult to analyze WB and C stock.

SOLUTIONS

Development and application of stand-level models

Aims of the Project

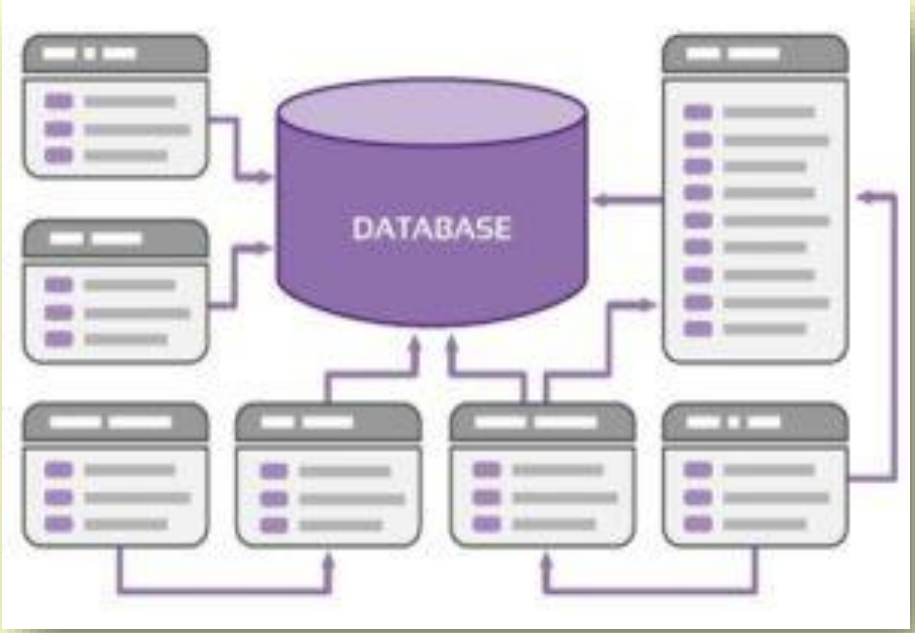
1. To develop a model based on site-specific primary data to quantify and map (i) WB supply (ES1) and (ii) C stock (ES2) at the stand level; case study = Valle Camonica District (Lombardy Region, Italy).

3 LINES of ACTIVITIES

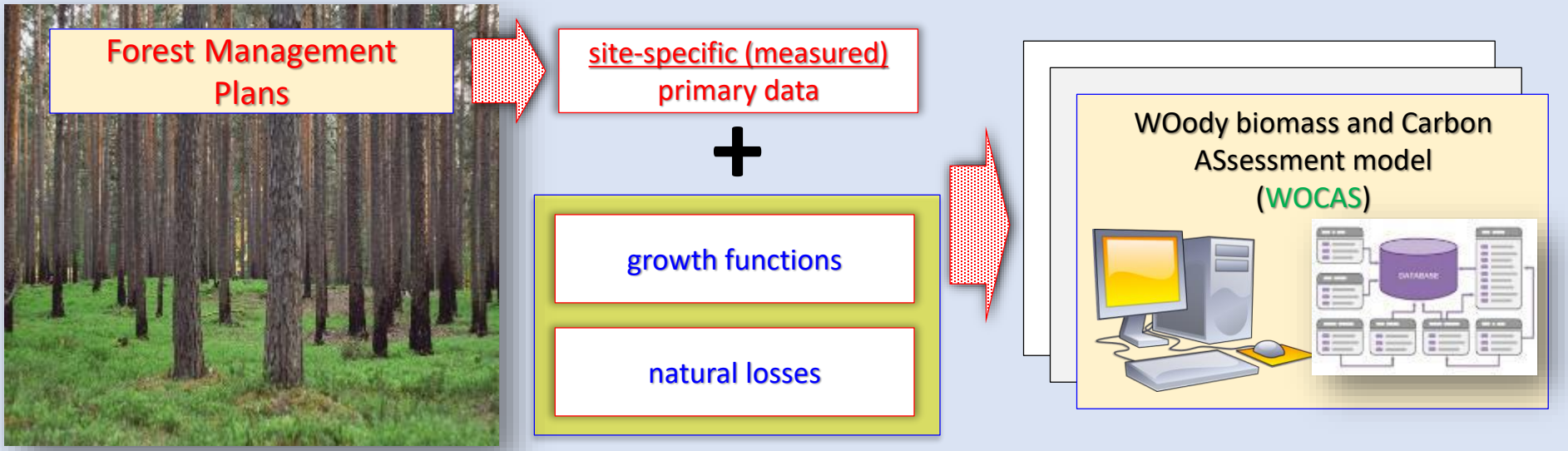
- **A1: WB and C stocks modelling**
  1. WB (t/ha·year DM) and C (t/ha·year) annually harvested;
  2. WB (t/ha·year DM) and C (t/ha·year) annually stocked (different pools).

- **A2: harvesting chains analysis**
  1. most suitable machine(s) for each operation performed;
  2. economic (€/t DM) and environmental (t_{CO2eq}/t DM) costs of the operations.

- **A3: results mapping**



ACTIVITY 1 – WB and C STOCKS MODELLING



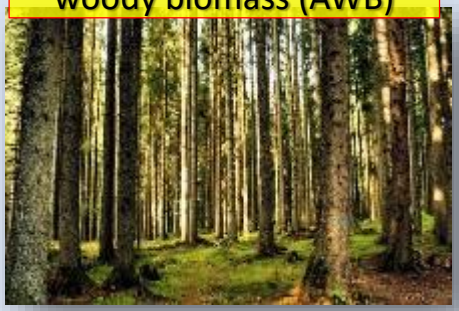
WOCAS model:

1. WB and C stocks and stock changes;
2. operational-scale model:
   - stand = smallest entity;
   - stands with similar characteristics aggregated to define spatial units.

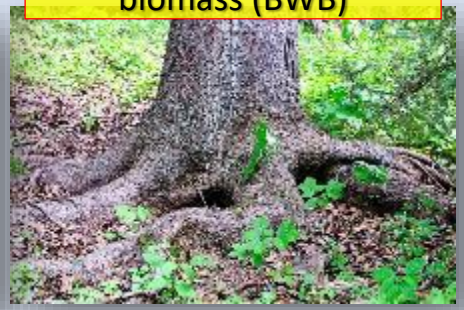
Calculation of:

1. annual growth and mortality;
2. annual fluxes between living biomass, Dead Organic Matter (DOM) and atmosphere;
3. WB and C annually harvested under different management scenarios;
4. WB and C annually stocked in 4 pools.

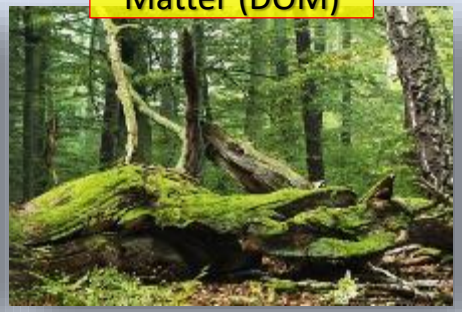
Aboveground woody biomass (AWB)



Belowground woody biomass (BWB)



Dead organic Matter (DOM)



Harvested woody products (HWPs)

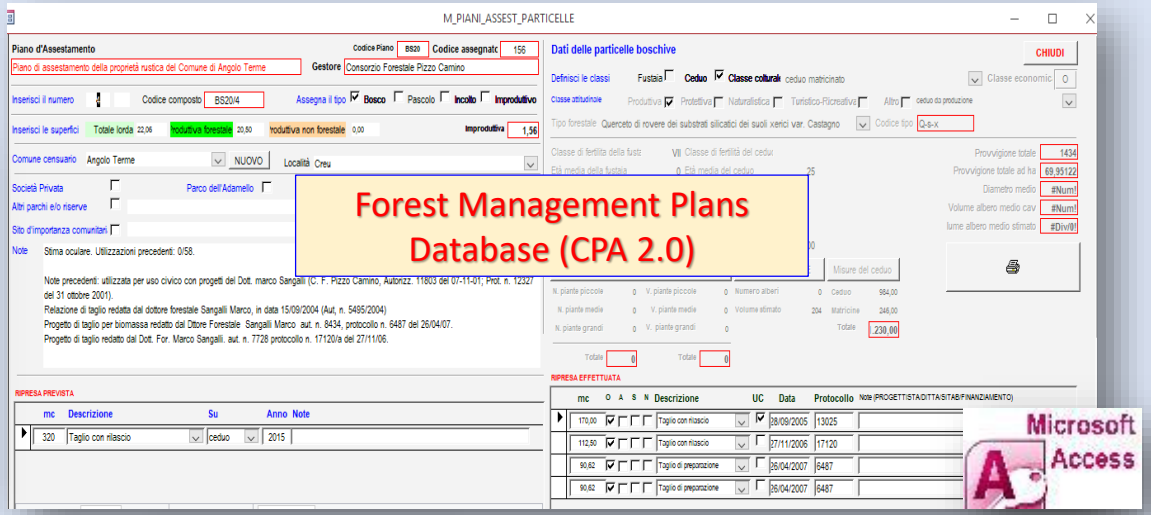
	Classification Criteria (CC, 283 in total)						Codification	Specific Parameters
N°	SC 1 FOREST STRUCTURE		SC 2 FOREST FUNCTION		SC 3 FOREST TYPOLOGY		CLASSIFICATION CRITERIA CODE (CC)	
	Name	Code	Name	Code	Name	Code		
1	Irregular high forest	a11	Production coniferous	b6	Abietetum of carbonatic substrates	1	a11b61	a11b61 parameters
2	Mature high forest	a12	Production coniferous	b6	Larch in succession with Norway Spruce	35	a12b635	a12b635 parameters
3	Irregular coppice	a4	Production coppices	b3	Mountain beech of typical carbonatic substrates	27	a4b327	a4b327 parameters

STAND N.	PRMs	MODULE 1	MODULE 2 - ANTR. DISTURB.		MODULE 3 - NATURAL LOSSES		MODULE 4	MODULE 5	MODULE 6
		STAND INPUT DATA	WB HARVESTING	WB HARVESTING RESIDUES	IRREGULAR MORTALITY	REGULAR MORTALITY	BIOMASS GROWTH	DEAD ORGANIC MATTER	CARBON STOCK
1									
2									
3									
4									
2020									

mass balances (*"gain-loss approach"*)

Module 1: "j" stand input data

Raw data extraction from 45 (FMPs): 2020 forest stands, 37000 ha, 1984-2016



EXTRACTION of

Detailed stand data

40 types of data for each stand

- starting ($YR_{S(j)}$) and deadline ($YR_{D(j)}$) year of each FMP
- administrative unit
- structure (form of management)
- prevailing function
- forest typology
- forest area (ha)
- growing stock (gross cormometric volume, (m^3/year) at $YR_{S(j)}$
- gross annual increment in volume (m^3/year) at $YR_{S(j)}$
- volume harvested (m^3) and type of cutting performed in each operation
- disturbances history
- orographic conditions (average slope)
- …

Module 2: anthropogenic disturbances

Sub-module 2a: WB harvesting

Intensity (m^3) and cutting type for each operation → total mass of stem annually extracted ($H_{n(j)}$; t/ha·year DM);

Sub-module 2b: aboveground harvesting residues

Branches and tops: mass annually produced ($AHR_{n(j)}$; t/ha·year DM):

$$AHR_{n(j)} = (H_{n(j)} \cdot k_2) - H_{n(j)}$$

LOSS from living biomass pool and GAIN for DOM pool

Sub-module 2c: belowground harvesting residues

Coarse roots: mass annually produced ($BHR_{n(j)}$; t/ha·year DM):

$$BHR_{n(j)} = H_{n(j)} \cdot k_3$$

k_1 = wood basic density (WBD, ratio between wood DM and wood fresh volume (t/m^3 DM);
k_2 = biomass expansion factor (BEF, aboveground woody biomass DM on growing stock biomass DM);
k_3 = root-shoot ratio (R, belowground woody biomass DM on growing stock biomass DM).

Sub-module 2b: aboveground harvesting residues

Mass of residues harvested → forest management scenarios (extraction rate criteria)

CRITERIA		SUB-CRITERIA
1	Stand's characteristics	function and management
2	Working conditions	Road transitability Stand's accessibility Stand's slope
3	Harvesting system type	Short wood system (SWS) Long tree system (LTS) Full tree system (FTS)
4	Local market requirement	

EXTRACTION RATE

(1) theoretical

(2) real

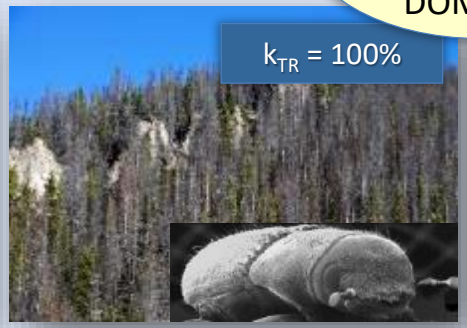
Module 3: natural losses

Sub-module 3a: irregular mortality

1. in some models not explicity simulated;
2. in the WOCAS model information on type, target growing stock volume (m^3) and years of occurrence defined by the user;
3. calculation of target growing stock mass ($GS_{IRn(j)}$; t/ha·year DM) transferred to the DOM pool → total $AWB_{n(j)}$ to the DOM pool.

$$AWB_{n(j)} \text{ to DOM pool} = GS_{IRn(j)} \cdot k_{TR} \cdot k_2$$

LOSS from AWB pool but GAIN for DOM pool



k_2 = biomass expansion factor (BEF, aboveground woody biomass DM on growing stock biomass DM);
k_{TR} = transfer coefficient (growing stock mass DM transferred to the DOM pool on growing stock mass DM under disturbance).

Sub-module 3b: regular mortality

1. in some models not explicity simulated;
2. In the WOCAS model calculated by assuming that it occurs each year; growing stock mass losses ($GS_{RMn(j)}$; t/ha·year DM):

$$GS_{RMn(j)} = 0 - 50\% \text{ of } GAI_{n(j)} \text{ or } 0 - 1.2\% \text{ of } GS_{n(j)}$$

3. total $AWB_{n(j)}$ transferred to the DOM pool

$$AWB_{n(j)} \text{ to DOM pool} = GS_{RMn(j)} \cdot k_2$$

LOSS from AWB pool but GAIN for DOM pool

k_2 = biomass expansion factor (BEF, aboveground woody biomass DM on growing stock biomass DM);
$GAI_{n(j)}$ = Gross Annual Increment ($t \cdot ha^{-1} \cdot year^{-1}$ DM);
$GS_{n(j)}$ = growing stock mass of the j-stand in the current year ($t \cdot ha^{-1} \cdot year^{-1}$ DM).

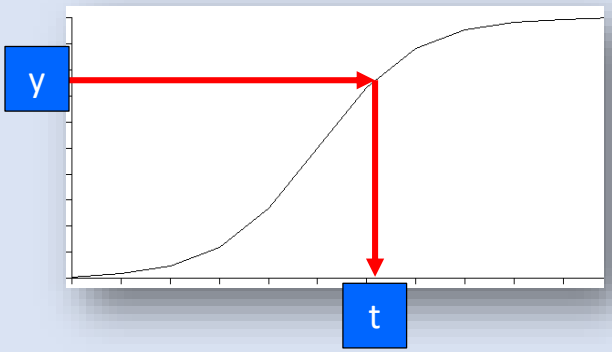
Module 4: biomass growth (increment)

1. Very often correlated to age;
2. in natural stands growing stock influences increment more than age;
3. strong relation growing stock/increment shown by several studies;
4. for uneven-aged stand very difficult to correlate increment to age.

Richards growth function:

$$y = a \cdot \boxed{[1 - e^{(\beta - kt)}]^{-1/\vartheta}}$$

Modifier that reduce the maximum dimension to the current value at the time t → decline of stand's growth over time



- y = current dimension (growing stock, $GS_{n(j)}$; t/ha·year DM);
- t = time (year);
  - a = maximum dimension of y (t/ha·year DM); a > 0
  - β = parameter which allows the time at which y = a/2 to be varied. Dimensionless;
  - k = relative growth rate (RGR) coefficient (1/year); k > 0
  - ϑ = shape parameter → it allows the curve inflexion point to be at any value between the minimum and the maximum dimension of y. Dimensionless. ϑ ≠ 0

Solving by t:

$$y = \frac{a}{\sqrt[\vartheta]{1 - e^{(\beta - kt)}}} \rightarrow y^{\vartheta} = \frac{a^{\vartheta}}{1 - e^{(\beta - kt)}} \rightarrow e^{(\beta - kt)} = 1 - \frac{a^{\vartheta}}{y^{\vartheta}} \rightarrow \beta - kt = \ln\left(1 - \frac{a^{\vartheta}}{y^{\vartheta}}\right) \rightarrow t = \frac{\beta}{k} - \frac{1}{k} \cdot \ln\left(1 - \frac{a^{\vartheta}}{y^{\vartheta}}\right)$$

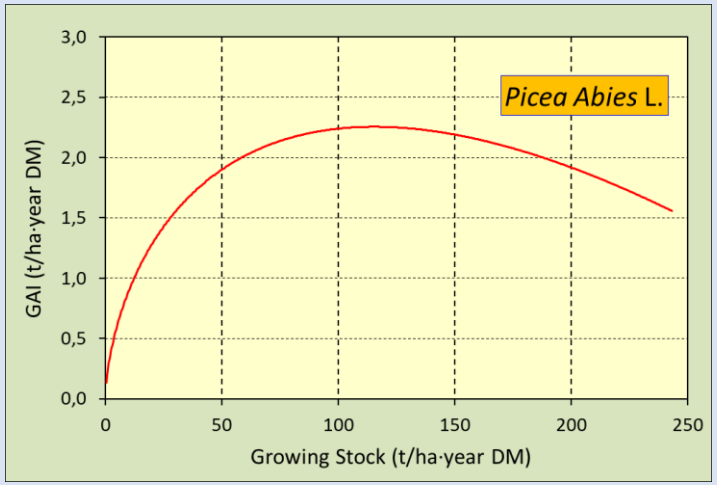
Time required to produce a specific mass within the stand

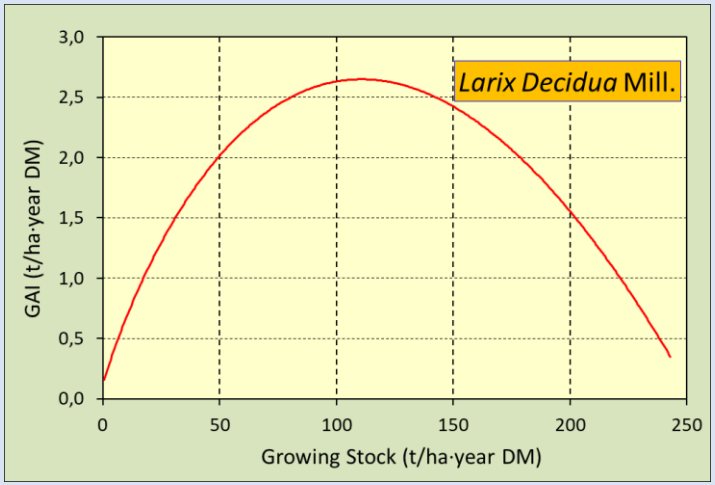
$$\frac{dt}{dy} = \frac{d\left[\frac{\beta}{k} - \frac{1}{k}\cdot\ln\left(1-\frac{a^{\vartheta}}{y^{\vartheta}}\right)\right]}{dy} \rightarrow -\frac{1}{k}\cdot\frac{d\left[\ln\left(1-\frac{a^{\vartheta}}{y^{\vartheta}}\right)\right]}{dy} \rightarrow -\frac{y^{\vartheta}\cdot a^{\vartheta}\cdot\vartheta\cdot y^{(\vartheta-1)}}{k\cdot y^{2\vartheta}(y^{\vartheta}-a^{\vartheta})} \rightarrow -\frac{y^{(2\vartheta-1)}\cdot a^{\vartheta}\cdot\vartheta}{k\cdot y^{2\vartheta}(y^{\vartheta}-a^{\vartheta})} \rightarrow -\frac{a^{\vartheta}\cdot\vartheta}{k\cdot y\,(y^{\vartheta}-a^{\vartheta})}$$

y' (first derivative of the mass with respect to time) = Gross Annual Increment (GAI; t/ha·year DM)

$$GAI = \frac{dy}{dt} = -\frac{k\cdot y\,(y^{\vartheta}-a^{\vartheta})}{a^{\vartheta}\cdot\vartheta} \rightarrow = \frac{k}{\vartheta}\cdot y\cdot\left[1-\left(\frac{y}{a}\right)^{\vartheta}\right] + y_0$$

- k, ϑ, a, y_0 → Regional calibration dataset (I.S.P.R.A;. Regional yield table - Lombardy Region)





use of specific values for each classification criteria

In the WOCAS model the user defines which increment to use (constant – from FMPs or variable – Richards function).

$$GS_{n(j)} = GS_{n-1(j)} + GAI_{n(j)} - H_{n(j)} - GS_{IMn(j)} - GS_{RMn(j)}$$

CALCULATION of

$$AWB_{n(j)} = GS_{n(j)} \cdot k_2$$

$$BWB_{n(j)} = GS_{n(j)} \cdot k_3$$

In the WOCAS model the user defines which k_2 (BEF) to use (constant – Italian National Forest Inventory or variable – growing stock dependent function).

k_2 = biomass expansion factor (BEF, aboveground woody biomass DM on growing stock biomass DM);
k_3 = root-shoot ratio (R, belowground woody biomass DM on growing stock biomass DM).

Module 5: Dead Organic Matter

1. input: (i) harvesting residues, (ii) growing stock due to mortality;
2. output: decomposition (decay rates for each classification criteria).

Module 6: Carbon stock

1. C annually stocked (t/ha·year) in (i) AWB, (ii) BWB, (iii) DOM and (iv) HWPs;
2. carbon fraction (k) in each pool defined for each classification criteria.

$$C_{AWBn(j)} = AWB_{n(j)} \cdot k_4 \quad + \quad C_{BWBn(j)} = BWB_{n(j)} \cdot k_5 \quad + \quad C_{DOMn(j)} = DOM_{n(j)} \cdot k_6$$

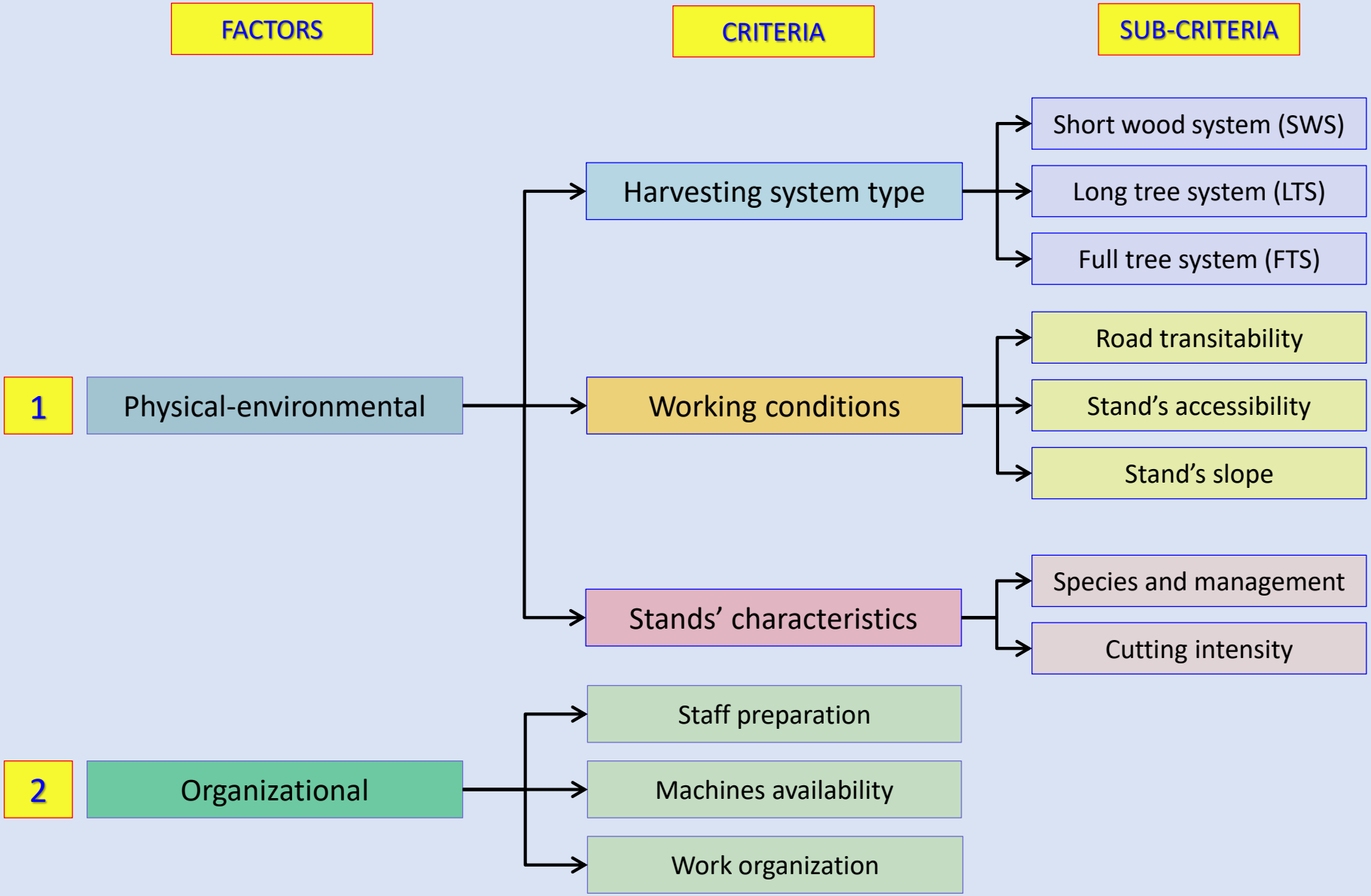
$$C_{TBn(j)} = C_{LBn(j)} + C_{DOMn(j)}$$

Calculated for 2020 for 33 years

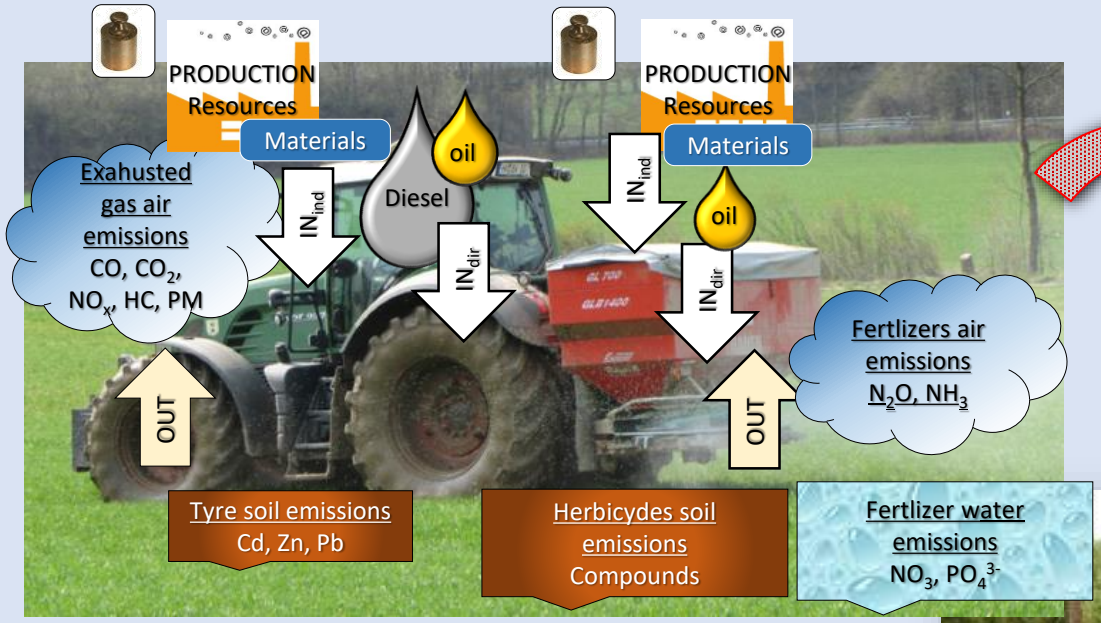
k_4 = carbon fraction of AWB DM;
k_5 = carbon fraction of BWB DM;
k_6 = carbon fraction of DOM DM.

ACTIVITY 2 – HARVESTING CHAINS ANALYSIS

Most suitable machine(s) for each harvesting operation: limiting factors and utilization criteria.

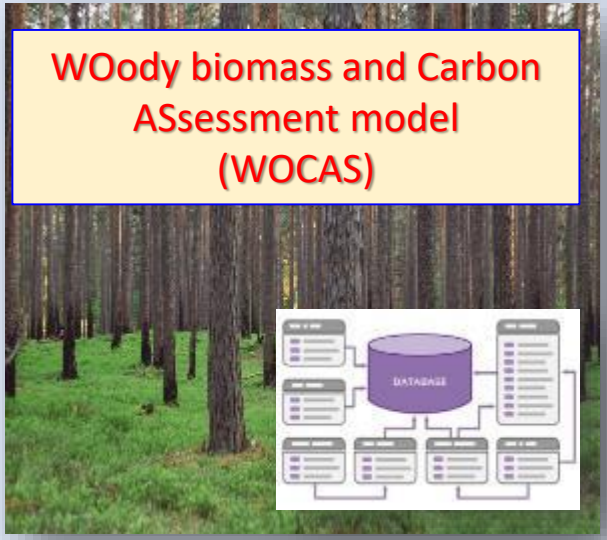


1. ENVIAM v.2 model implementation (forestry machines);
2. economic (€/t DM) and environmental (t_{CO2eq}/t DM) costs of a specific operation.
3. Two linked models: WOCAS + ENVIAM v.2



New aspect in forest WB and C modelling

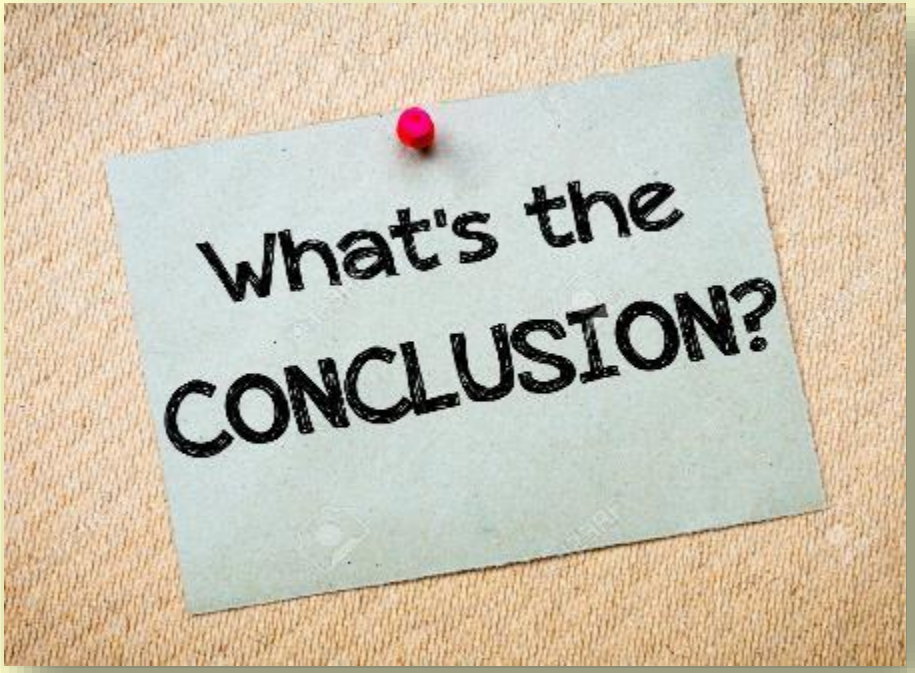
ACTIVITY 3 – RESULTS MAPPING



DEVELOPMENT of

Stand classification sheets:

1. K_1: general information extracted from FMPs;
2. K_{2A}: input and output calculated by the WOCAS model;
3. K_{2B}: mechanization data


What's the
CONCLUSION?

Conclusions

1. Use of models to quantify forest WB and C stocks essential for climate change mitigation;
2. the aim of the study is to develop a stand-level model (WOCAS) to support local Authorities in sustainable forest management;
3. interesting solution when data on single trees are not available;
4. WOCAS provides outputs at different spatial and temporal scales;
5. up to now only past scenario assessment is possible;
6. calculations must be improved;
7. results must be validated.

Scientific papers submitted

(1st and 2nd year: Oct 1st, 2017 - Sept 15th, 2019)

1. Nonini L., Fiala M. *Estimation of carbon storage of forest biomass for voluntary carbon markets: preliminary results.* Under review (Journal of Forestry Research).
2. Fiala M., Marveggio D., Viganò R., Demartini E., Nonini L., Gaviglio A. *LCA and wild animals: results from wild deer culled in a northern Italy hunting district*. Under review (Journal of Cleaner Production).
3. Fiala M., Nonini L. (2018). *Biomass and Biofuels*. In: Cifarelli L., Wagner F. (edited by). Lecture Notes - Joint EPS-SIF International School on Energy - Course 4: Advances in Basic Energy Issues. EPJ Web Conf., 189 (2018) 00006. DOI: https://doi.org/10.1051/epjconf/201818900006.

Project Reporting activities

(1st and 2nd year: Oct 1st, 2017 - Sept 15th, 2019)

1. Fiala M., Nonini L., Marveggio D. (2019). Environmental Assessment. BarPlus Project WP4-Task 4.3, FINAL REPORT, p 122.

Scientific papers under preparation

(1st and 2nd year: Oct 1st, 2017 - Sept 15th, 2019)

1. Use of site-specific primary data to improve forest biomass and carbon stocks assessment at the stand-level.
2. Environmental sustainability of barley cultivation in EU conditions.

Meetings, Conferences, Workshops and Symposia participation

(1st and 2nd year: Oct 1st, 2017 - Sept 15th, 2019)

1. Nonini L., Schillaci C., Fiala M. (2019). *Assessment of forest biomass and carbon stocks at stand level using site-specific primary data to support forest management*. Biosystem Engineering for sustainable agriculture, forestry and food production International Mid-Term Conference 2019 Italian Association of Agricultural Engineering (AIIA): September 12th - 13th, University of Basilicata, Matera (Italy). Oral presentation.

2. Fiala M., Nonini L. (2019). *High accuracy site-specific secondary data for mechanical field operations to support LCA studies*. Biosystem Engineering for sustainable agriculture, forestry and food production International Mid-Term Conference 2019 Italian Association of Agricultural Engineering (AIIA): September 12th - 13th, University of Basilicata, Matera (Italy). Oral presentation.

3. Fiala M., Nonini L., Marveggio D. (2018). *Sostenibilità ambientale delle operazioni meccaniche di campo*. In: La meccanica agraria oggi. Un confronto aperto su concetti idee e aspettative di una disciplina in continua evoluzione. Bietresato M., Mazzetto F. (edited by): November 23rd - 24th 2017, Free University of Bozen and NOI-Techpark, Bozen (Italy). First edition - Padova: Cleup sc. "Coop. Libraria Editrice Università di Padova". ISBN 9788867879472. - pp. 335-341. DOI: https://doi.org/10.23737/MECCANICA_AGRARIA_OGGI.HTML. Conference proceeding.

4. Fiala M., Marveggio D., Nonini L. (2018). Environmental assessment: preliminary results. BarPlus Project III Meeting: March 8th - 9th, University of Lleida, (Spain). Oral presentation.