Direct Land Use Change also affects surface albedo - should this be considered when estimating environmental benefits?

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Land Use Changes due to Bioenergy: Quantifying and Managing Climate Change and Other Environmental Impacts

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Overview

- What is albedo?
- Equivalency of change in albedo and change in carbon stocks
- Atmospheric effects
- Potential magnitude of the albedo effect
- Unresolved issues
- Conclusions

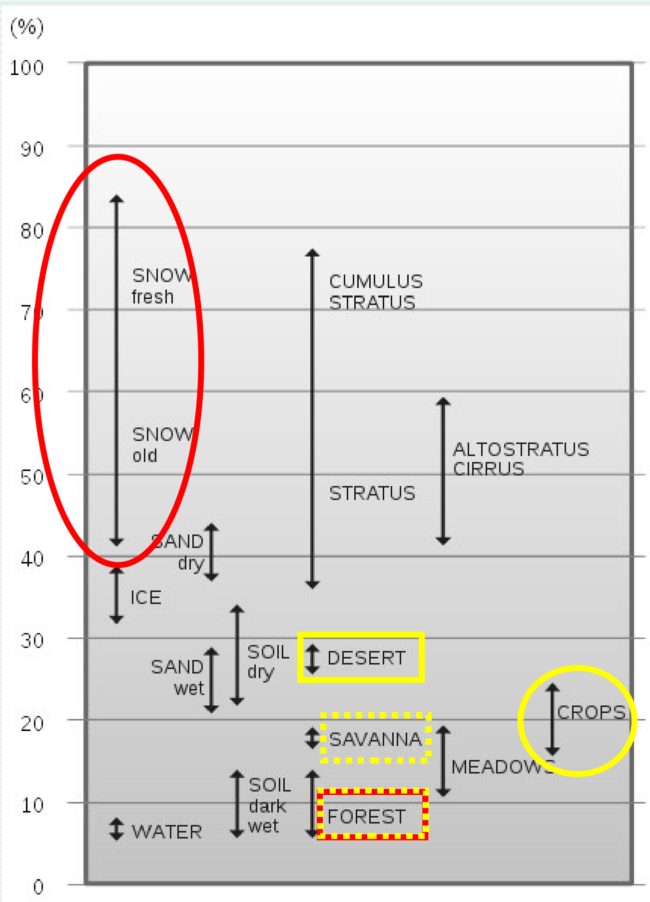
What is albedo?

- **The albedo of an object is the extent to which it diffusely reflects light from the Sun.**
- **It is defined as the ratio of diffusely reflected to incident electromagnetic radiation.**

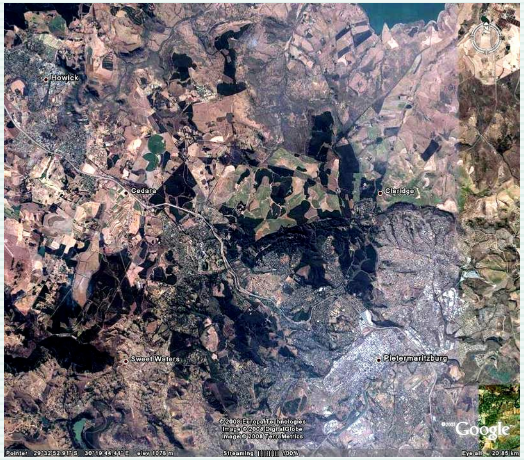
  Albedo = 1 – pure reflection

  Albedo = 0 – pure absorption
- **Change in albedo causes warming that is dependent on**
  - Magnitude of change in albedo; and
  - Latitude

Examples



Coniferous forest and snow
High latitudes
(Austria)



Pine plantations and savanna
Low latitudes
(South Africa)

Equivalency
ΔAlbedo ~ - ΔCO_2

- **Warming**
  - CO2 emissions
  - Darkening of the surface (decrease in albedo)
- **Cooling**
  - Carbon sequestration
  - Lightening of the surface (increase in albedo)
- **Not completely equivalent because**
  - Δalbedo causes warming in the year it occurs
  - ΔCO2 has a residence time in the atmosphere and causes warming over many years

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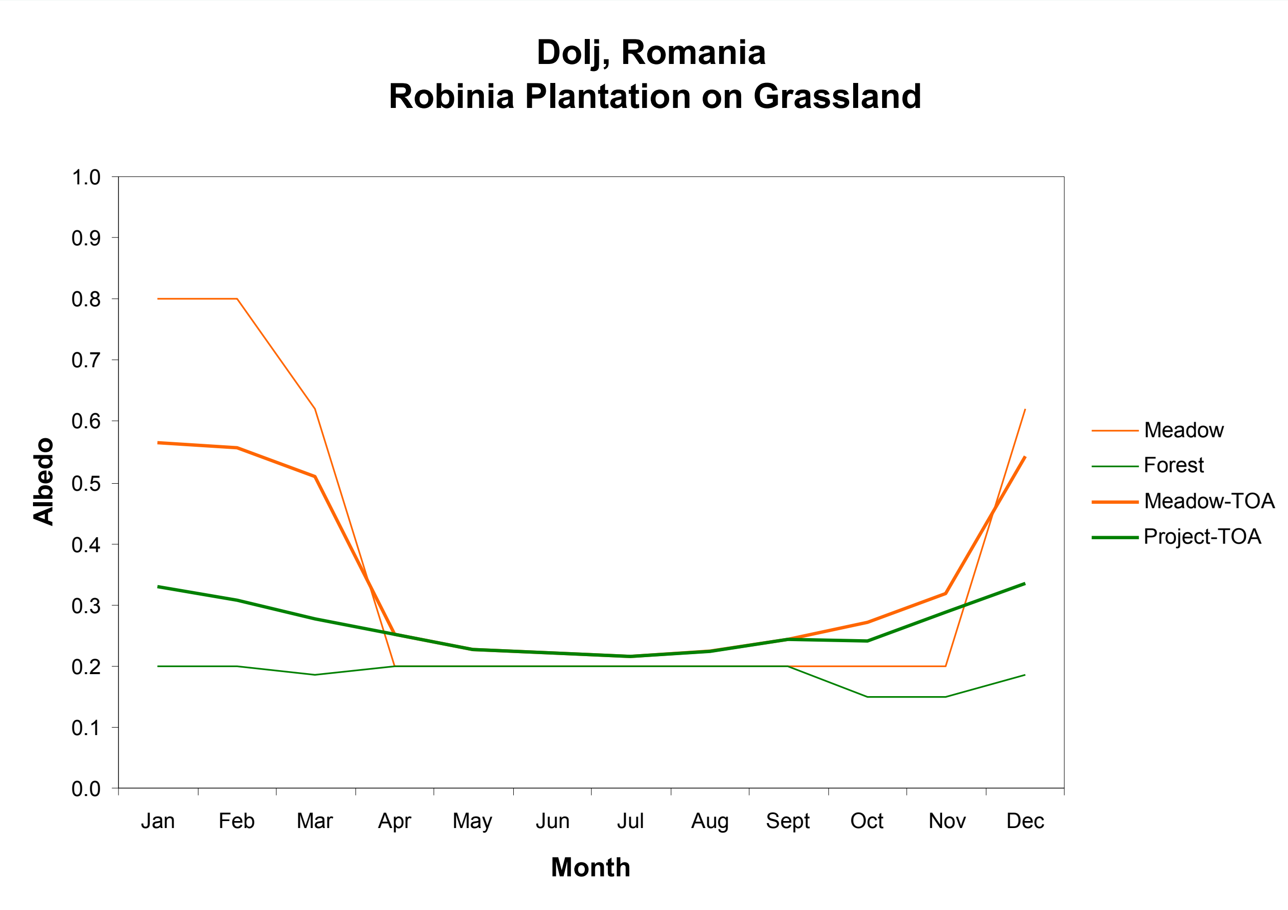
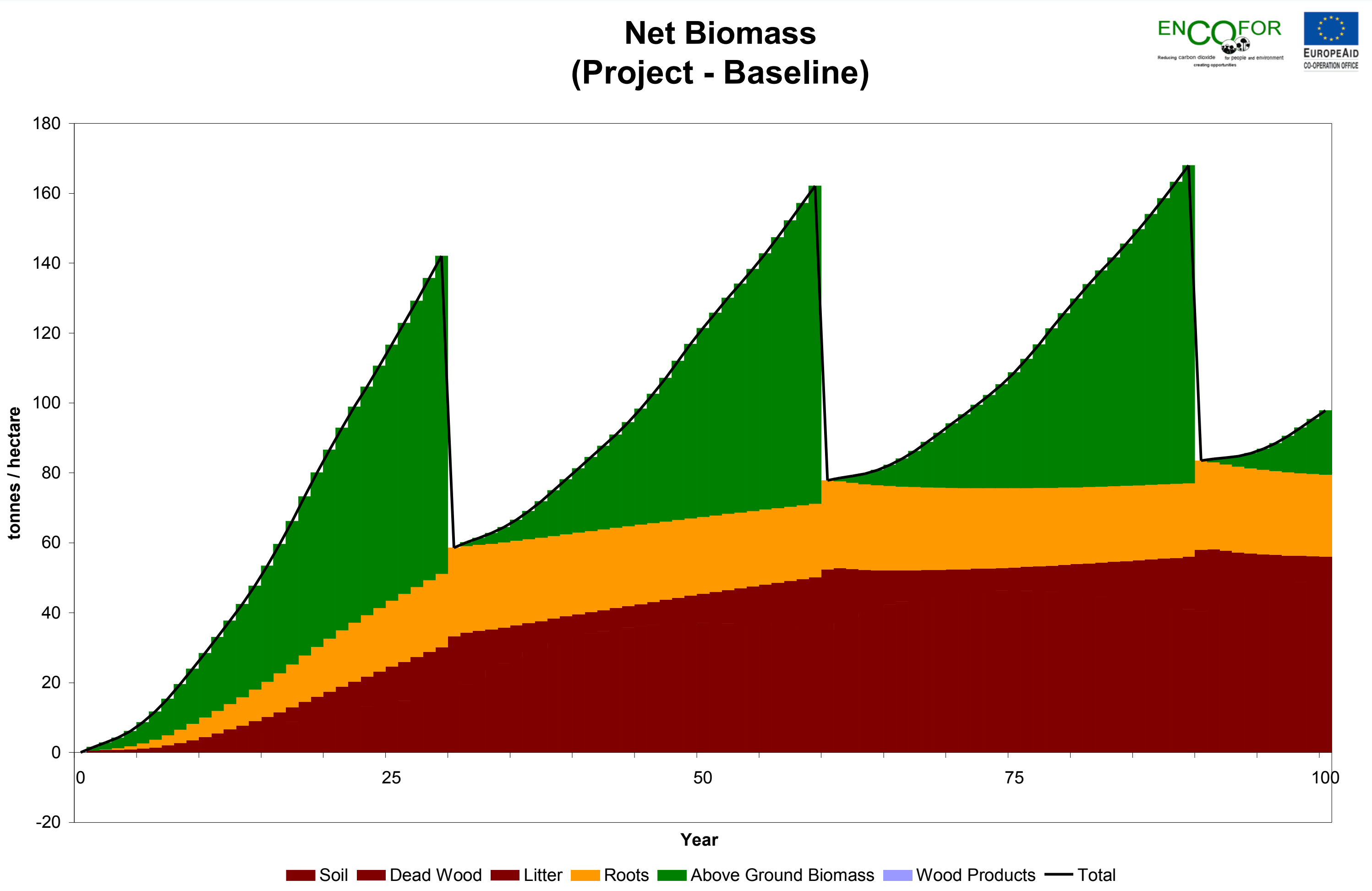
Atmospheric effects

- **Clouds**
  - With or without ice
- **Haze**
  - Air pollution
- **Length of travel path through atmosphere**
- **Reduce the difference between light and dark surfaces**

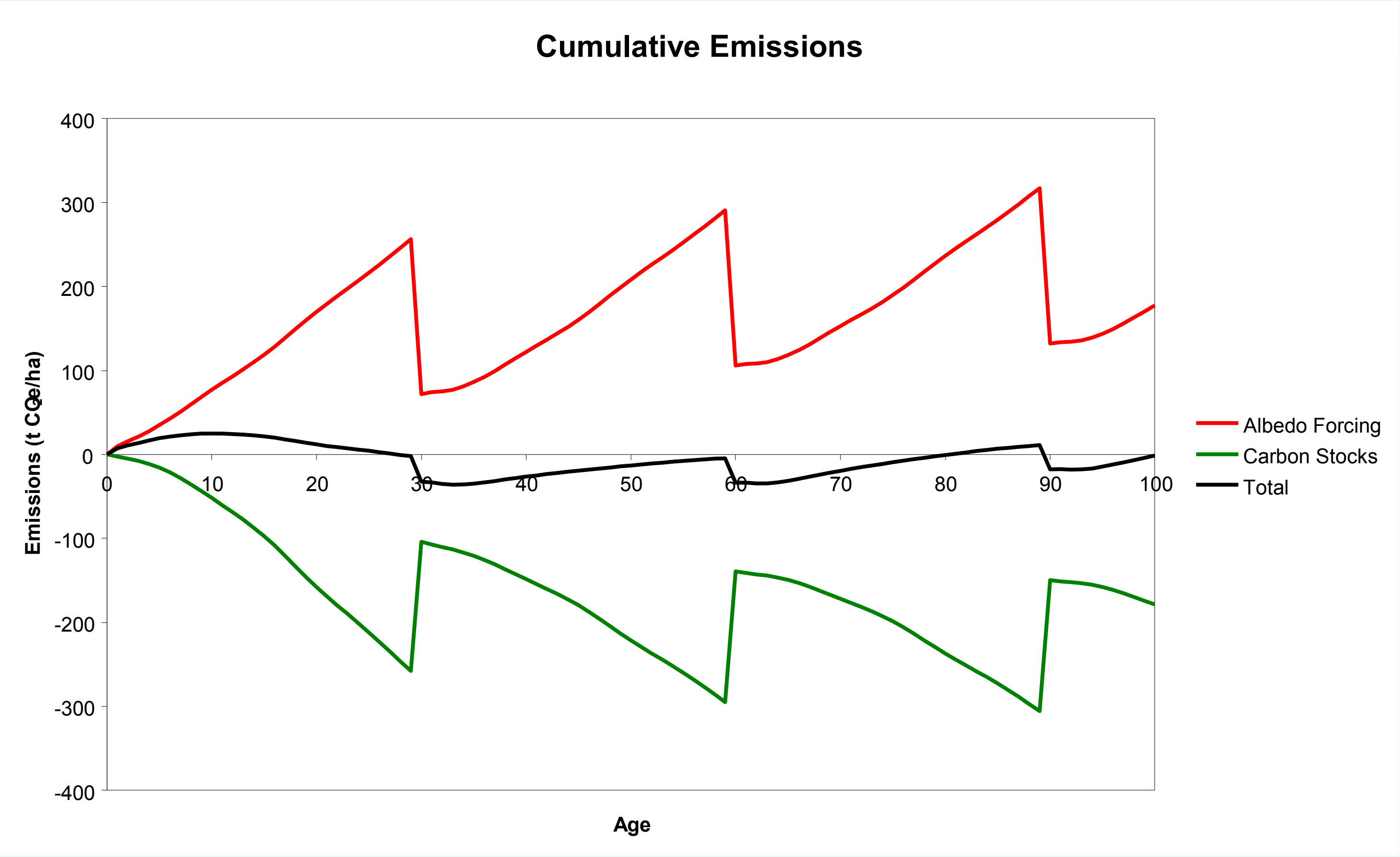
Albedo
Robinia, Dolj, Romania



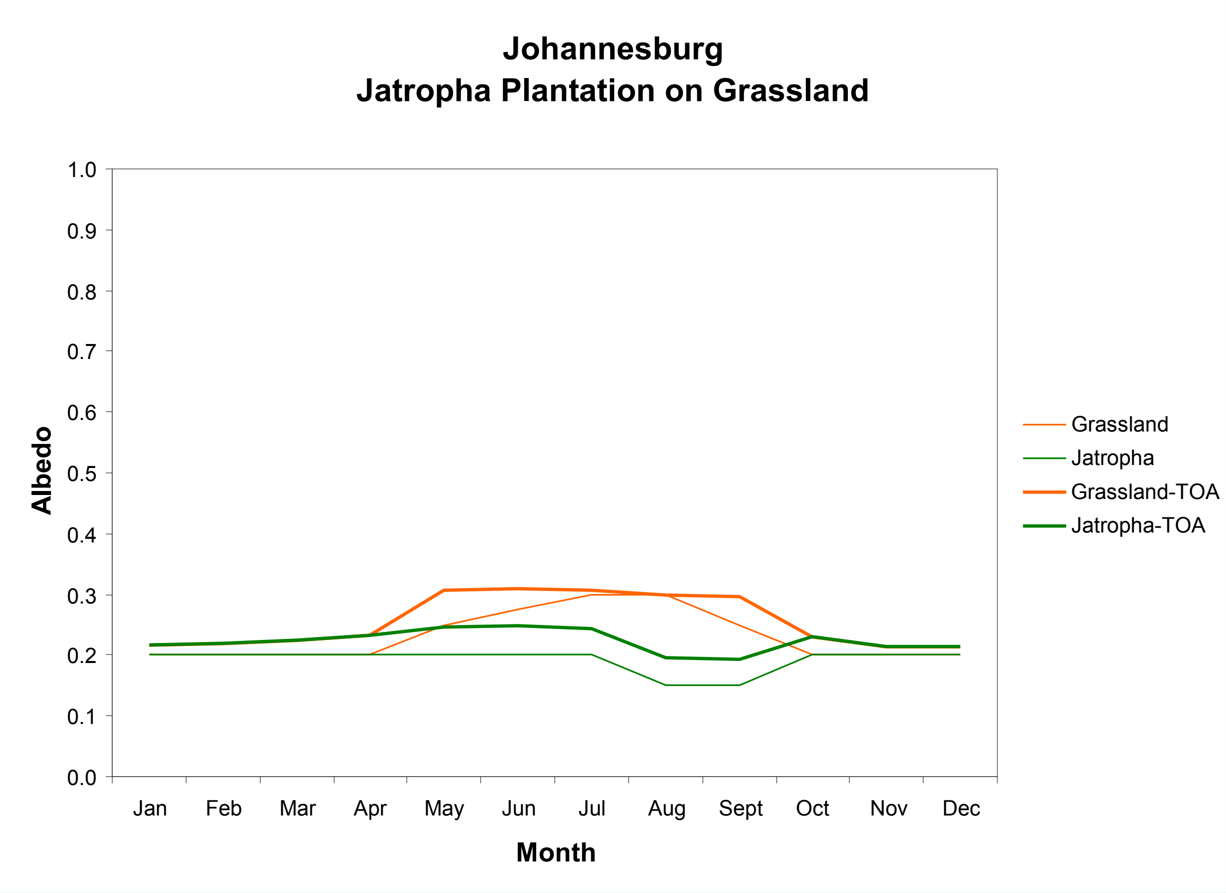
Net Biomass Robinia, Dolj, Romania



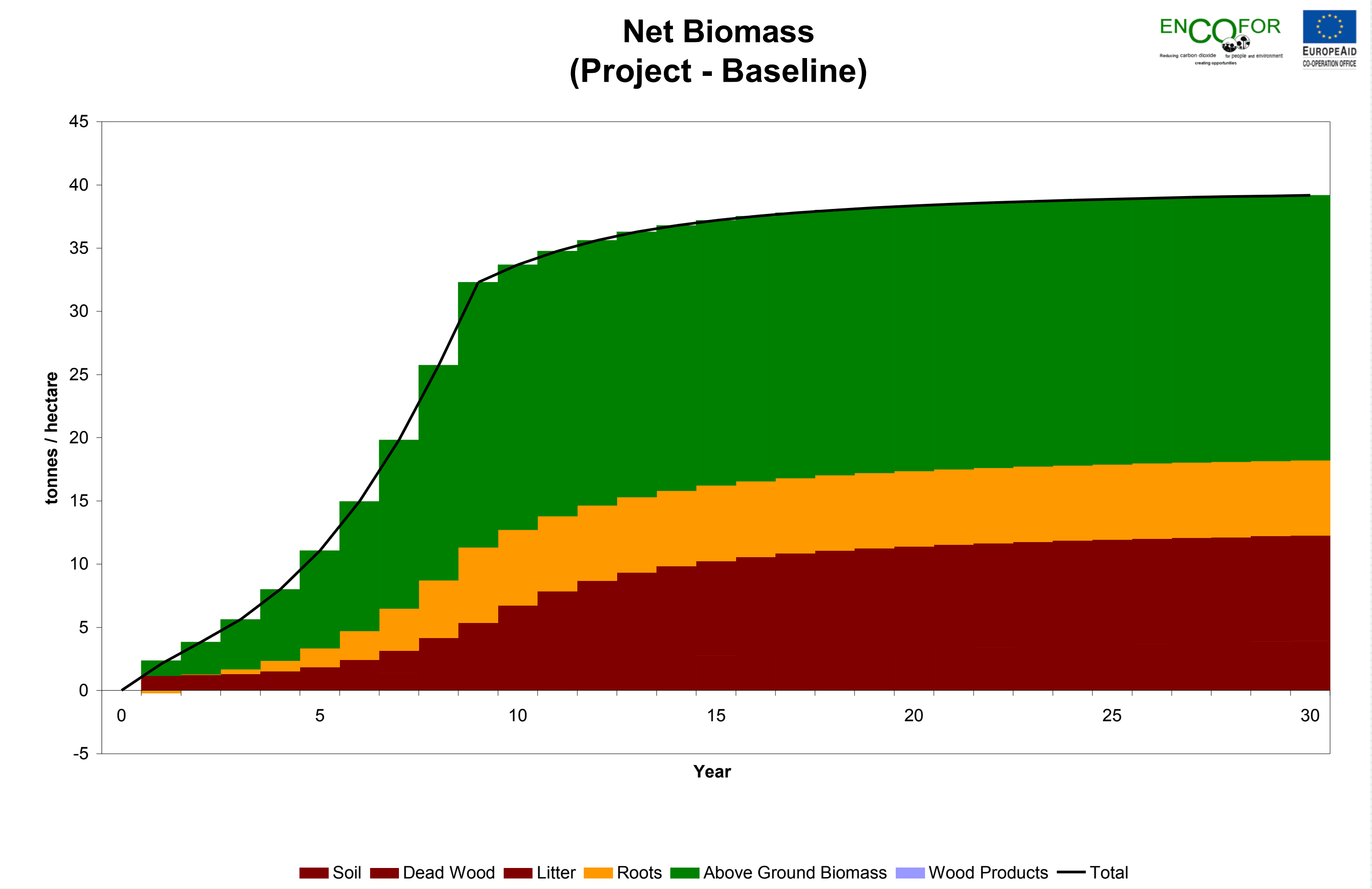
Net CO_2 Emissions Robinia, Dolj, Romania



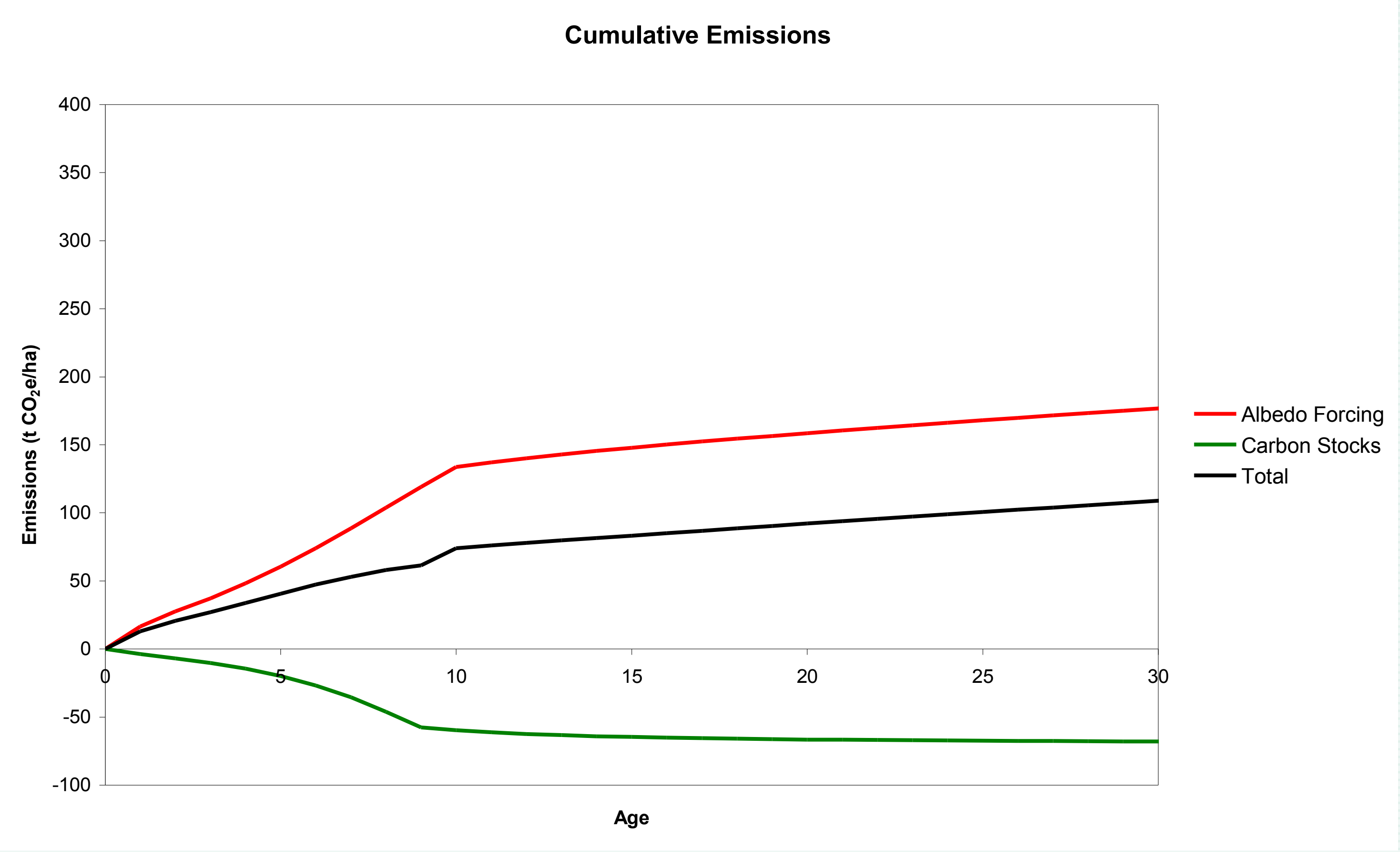
Albedo
Jatropha, Johannesburg



Net Biomass Jatropha, Johannesburg



Net CO_2 Emissions Jatropha, Johannesburg



Potential Magnitude of the Albedo Effect

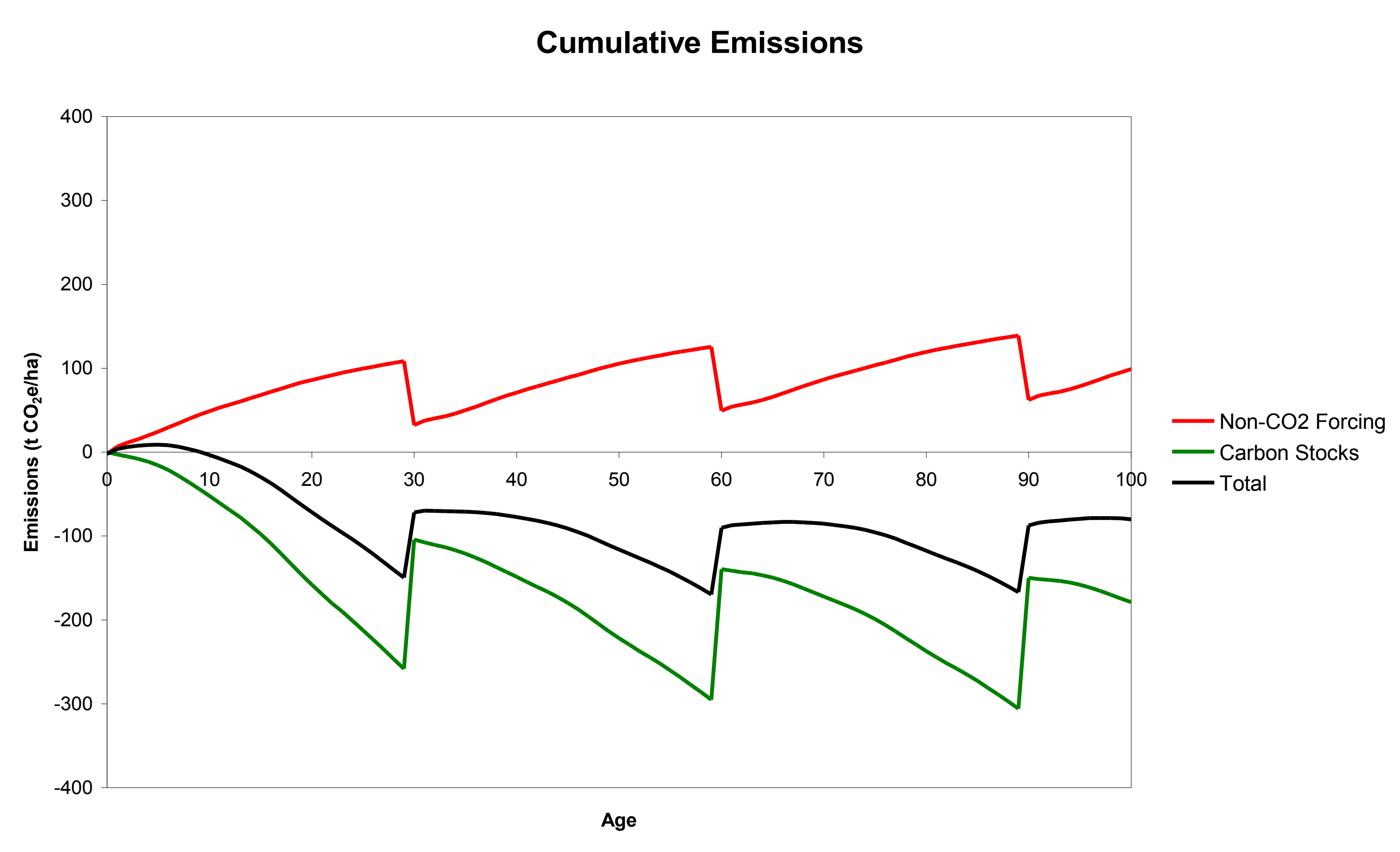
	units	Robinia, Rumania	Jatropha, South Africa
Biomass	(t/ha/yr)	3.2	1.9
Useable energy			
Diesel	(GJ/ha/yr)		71.7
Electricity	(kWh/ha/yr)	1851	
Emissions			
Combustion of biofuel	(t CO2e/ha/yr)	0.2	0.4
Maximum emissions saved from displacement of fossil fuel	(t CO2e/ha/yr)	-1.9	-5.3
Net excluding land-use change	**(t CO2e/ha/yr)**	**-1.7**	**-4.9**
Sequestration	(t CO2e/ha/yr)	-6.2	-6.4
Albedo	(t CO2e/ha/yr)	5.5	14.6
Net including land-use change	**(t CO2e/ha/yr)**	**-2.4**	**3.3**
Albedo/Sequestration		89%	229%
LUC / Energy		0.41	1.66

Unresolved Issues

- **Evapotranspiration**
  - Trees need 20% water than grasslands (on average)
  - Albedo energy may be used to evaporate water
  - Energy dispersed by
    - Clouds (daytime cooling, night time warming)
    - Convection
    - Mechanical deformation
- **Canopy closure**
  - Timing
- **Angular effects at high latitudes**
  - Slopes facing the equator have deciduous trees
  - Slopes facing the poles have coniferous trees

Net CO_2 Emissions Example Dolj, Romania

With Evapotranspiration



Conclusions

- **Darkening of the surface causes warming that is equivalent to a CO_2 emission**
  - Forests in areas with snow
  - Crops and forests in areas with drought
- **Albedo change is muted by atmospheric effects**
- **Albedo change could counteract sequestration benefits**
  - It should be considered when considering environmental impacts
  - Must include evapotranspiration, increase in clouds

Albedo and CO_2 Equivalent Emissions

$$F_{CO_2}^{Ann}[\mathrm{Wm}^{-2}] = \frac{\Delta F_{2X}[\mathrm{Wm}^{-2}]}{\ln(2)} \ln\left(1 + \frac{1.0 \times 10^6[\mathrm{ppmv}]\,\Delta CO_2[\mathrm{g}]\,M_{air}[\mathrm{gmole}^{-1}]}{pCO_{2,ref}[\mathrm{ppmv}]\,M_{CO_2}[\mathrm{gmole}^{-1}]\,1.0 \times 10^6\, m_{air}[\mathrm{Mg}]}\right)$$

$$F_{CO_2}^{Ann}(t)[\mathrm{Wm}^{-2}] \approx \frac{\Delta F_{2X}[\mathrm{Wm}^{-2}]}{\ln(2)} \left(\frac{1.0 \times 10^6[\mathrm{ppmv}]\,\Delta CO_2(t)[\mathrm{g}]\,M_{air}[\mathrm{gmole}^{-1}]}{pCO_{2,ref}[\mathrm{ppmv}]\,M_{CO_2}[\mathrm{gmole}^{-1}]\,1.0 \times 10^6\, m_{air}[\mathrm{Mg}]}\right) \otimes Decay_{CO_2}^{Ann}(t)$$

$$F_{CO_2}^{Ann}(t) \approx K\Delta CO_2(t) \otimes Decay_{CO_2}^{Ann}(t)$$

$$\Delta CO_2eq(t) \approx \frac{F^{Ann}(t)}{K} \otimes InvDecay_{CO_2}^{Ann}(t)$$

$$Decay_{CO_2}^{Ann}(t) \otimes InvDecay_{CO_2}^{Ann}(t) = 1$$

Decay and *InvDecay*