Global cost estimates of forest climate mitigation with albedo: a new integrative policy approach

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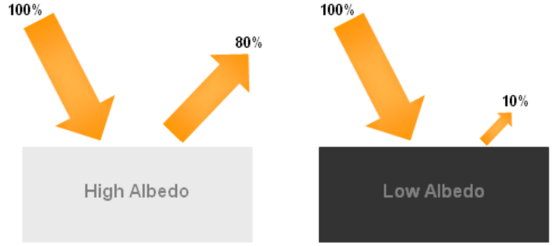
Albedo

- Albedo: percentage of incoming radiation reflected by a surface
  - White-snow surface has albedo close to 1 (low albedo effect)
  - Black surface has albedo close to 0 (high albedo effect)

- Forests have higher albedo effect than cleared land (cropland/bare land/ice)
  - Betts 2000; Bonan 2008

- Mature forests have higher albedo effect than young forests
  - Mykleby et al. 2017



Source: nasa.gov

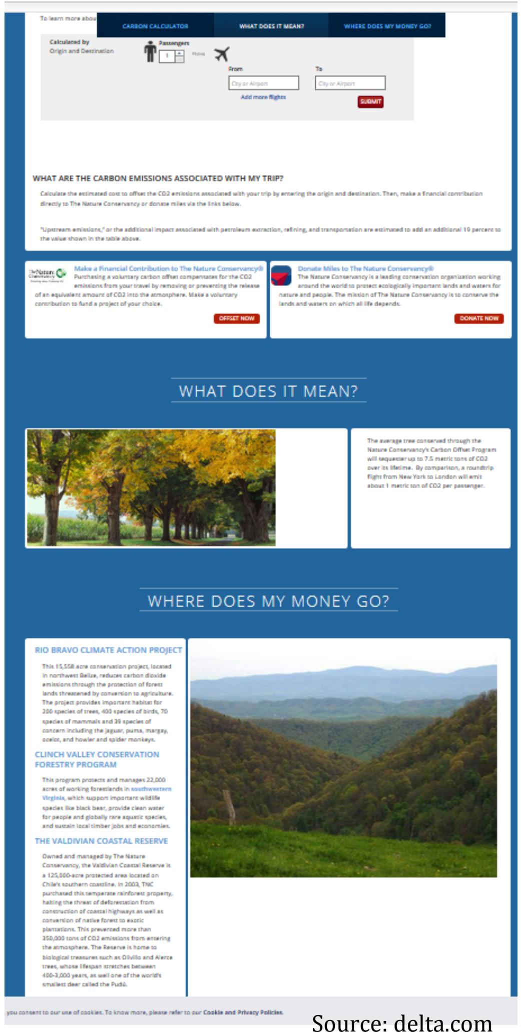
Motivation

- Forest-based activities (eg. avoided deforestation, increase forestland) are cheap and available mitigation responses
  - IPCC, AR5, WG3, Smith et al. 2014

- Forest activities used to offset individuals/firms emissions

- Effects forest-based climate mitigation policies on global average temperature (T):
  - Reduction of greenhouse gases concentrations (T ↓)
  - More solar radiation absorbed by forests (albedo effect) (T ↑)
  - In boreal/temperate forests, albedo reduction offsets mitigation benefits

    (Betts, 2000; Gibbard et al. 2005; Bala et al. 2007; Bonan et al. 2008)



Source: delta.com

Research question

- How effective is a mitigation policy that focuses only on forest carbon sequestration (Traditional Policy) without considering the albedo effect?
- Explore a more effective policy that prices both the negative and the positive climate externalities of forest (Innovative Policy)
- Build the Marginal Supply function of forest mitigation under alternative policies

Results preview

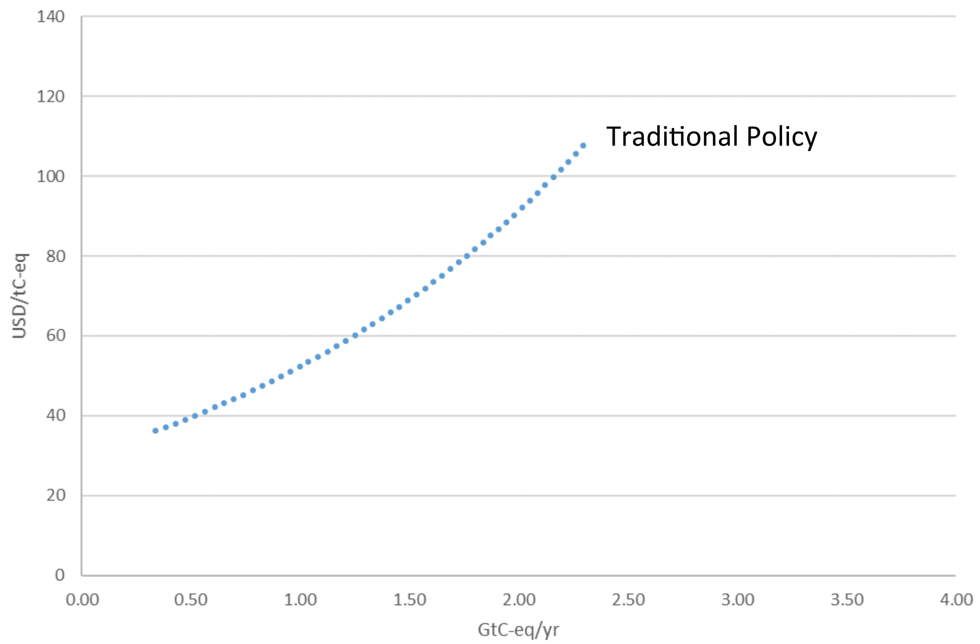


Figure 1: Estimated economic potential of forests in 2030

Results preview

IPCC, AR5, WG3:
Carbon prices up to 20 USD/tCO2 (73 USD/tC), potential of 1.64-21.45 tCO2 (0.45-5.85 tC-eq)

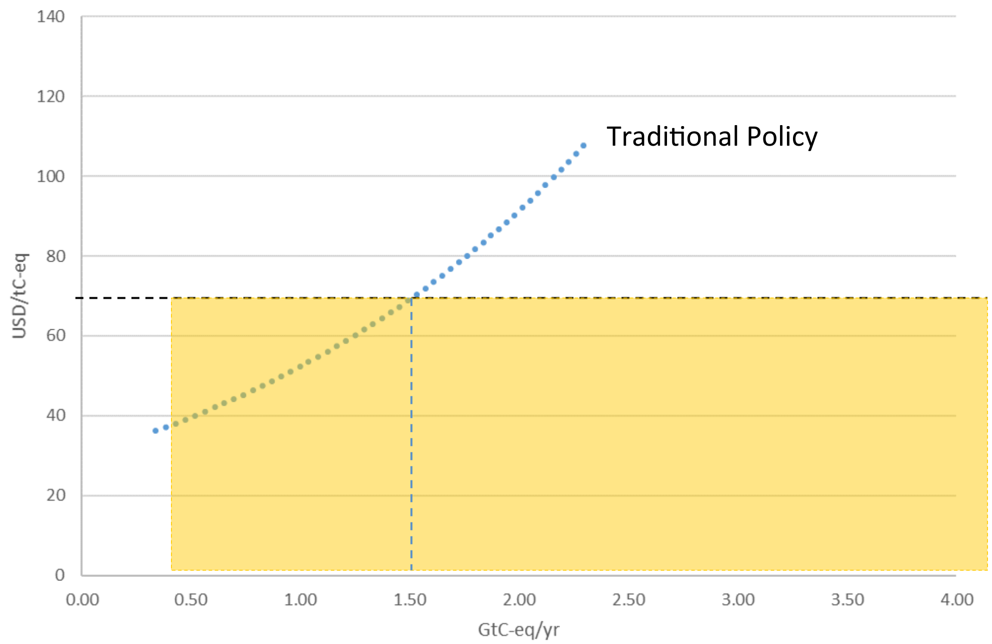


Figure 1: Estimated economic potential of forests in 2030

Results preview

- A global climate mitigation policy that considers only forest carbon sequestration <u>overestimates</u> forest mitigation potential.

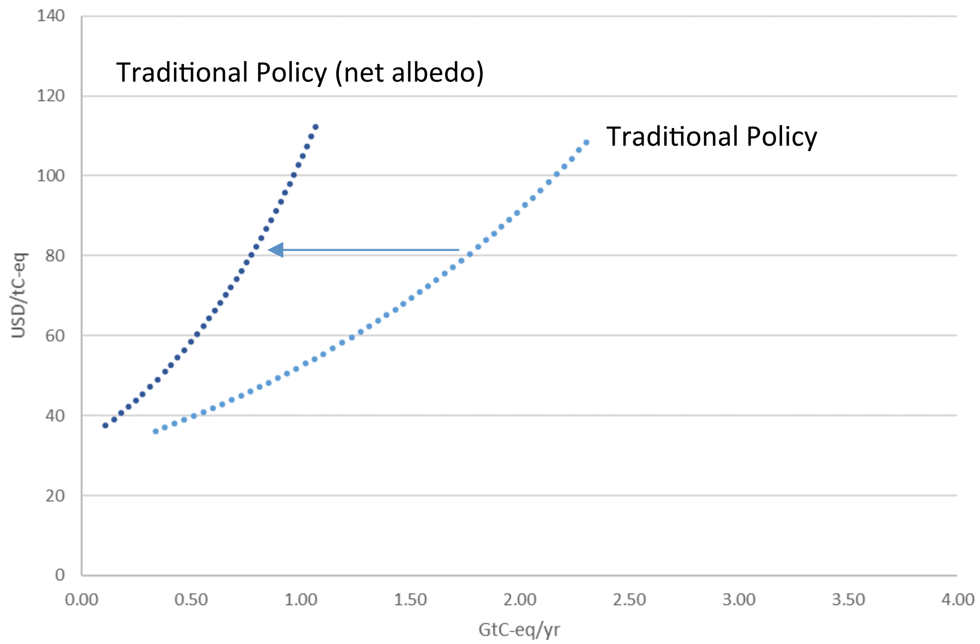


Figure 1: Estimated economic potential of forests in 2030

Results preview

- A global climate mitigation policy that considers only forest carbon sequestration overestimates forest mitigation potential.
- Under the same carbon price path, the Integrative policy provides <u>greater net global mitigation</u> in absolute terms.

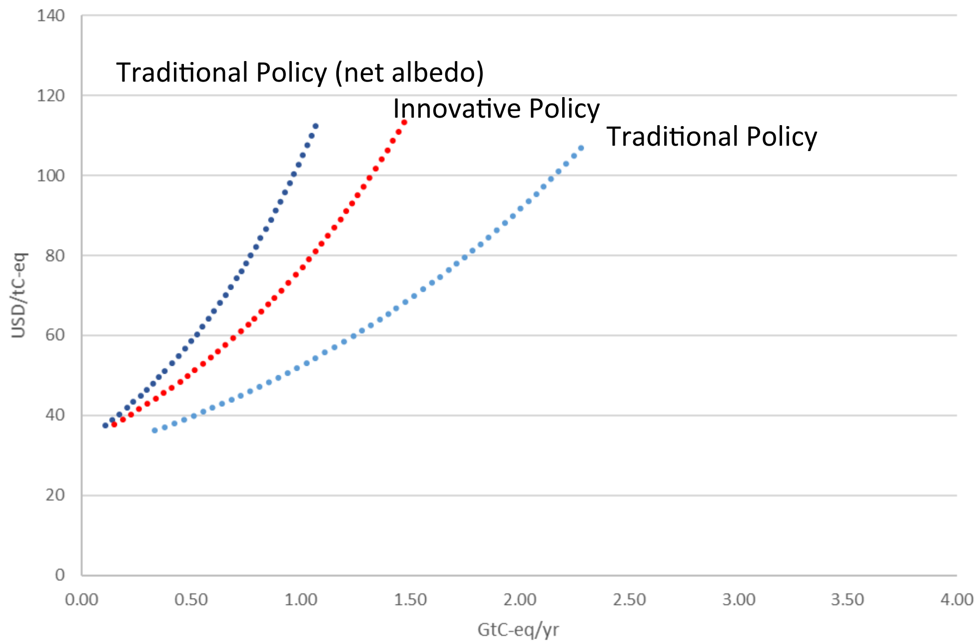


Figure 1: Estimated economic potential of forests in 2030

Literature review

Only stand-level or regional/local specific studies

Pricing the albedo effect leads to:

- shorter optimal rotations
    - Thompson et al. 2009; Sjolie et al. 2013; Lutz and Howarth, 2014; Lutz et al. 2016
- higher marginal costs of climate change mitigation in forestry
    - Thompson et al. 2009; Sjolie et al. 2013
- changes in the optimal forest mix
    - Matthies and Valsta 2016

Limitations of these studies:

- Don’t include land use change options
- Don’t consider market responses

Contribution

- First global economic analysis of forests mitigation potential with albedo.

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MODIS

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- Climate Policy simulated through alternative carbon price paths from DICE.

DICE

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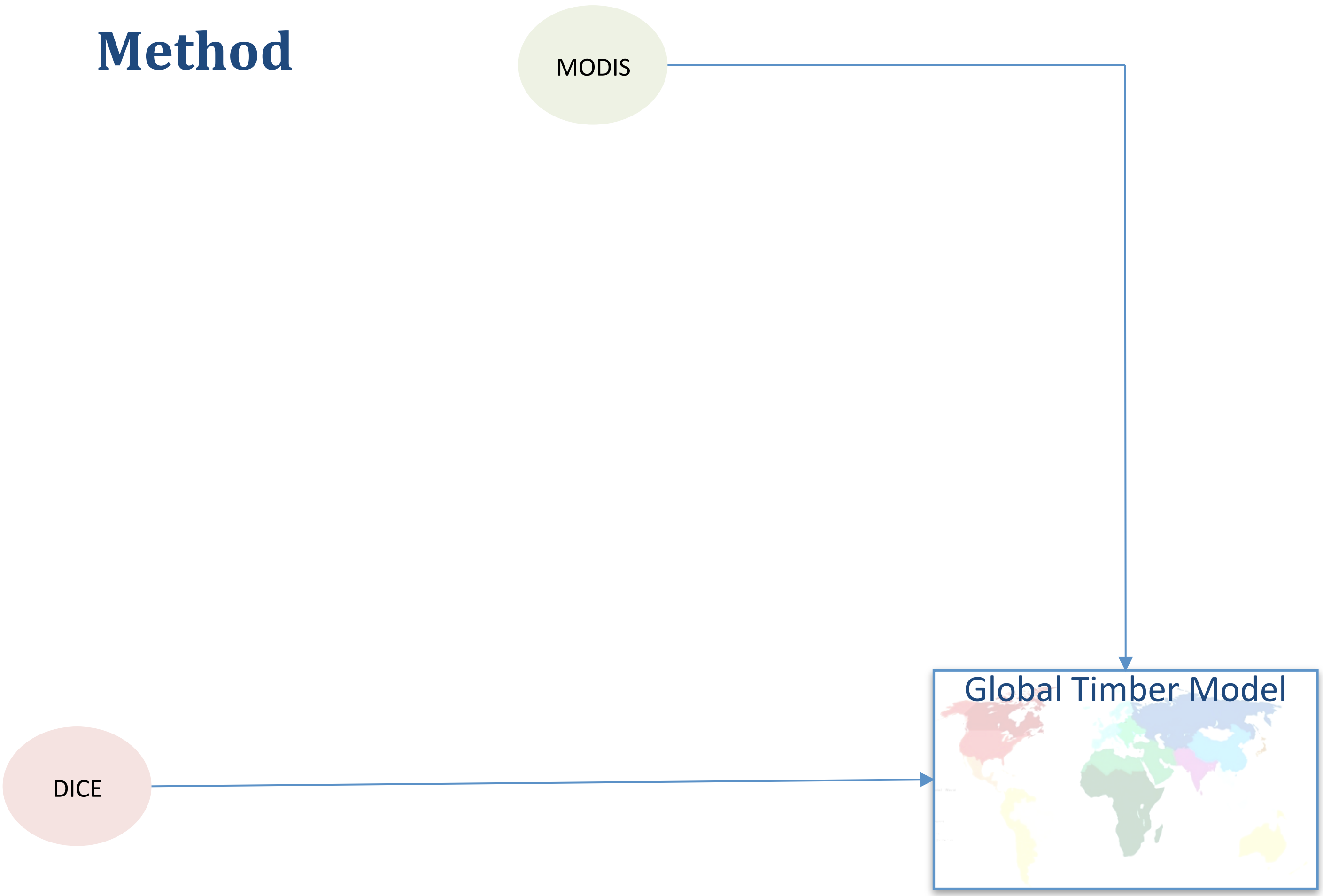
- First global economic analysis of forests mitigation potential with albedo.
- Global albedo estimates of dominant land uses from the NASA MODIS BRDF database (Jin Lab at UC Davis).
- Climate Policy simulated through alternative carbon price paths from DICE.
- Albedo info and carbon price are included in the Global Timber Model.

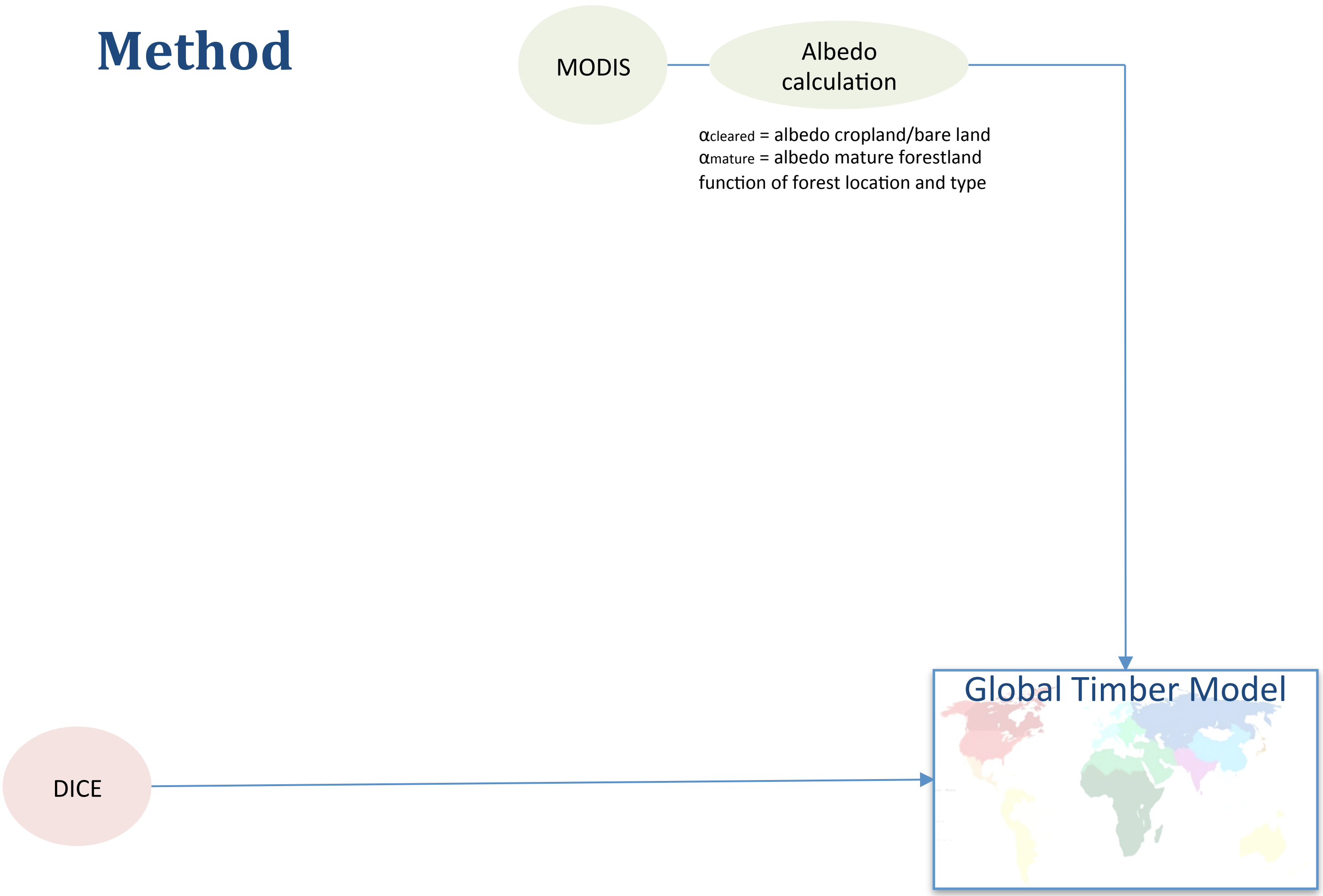
DICE

How?

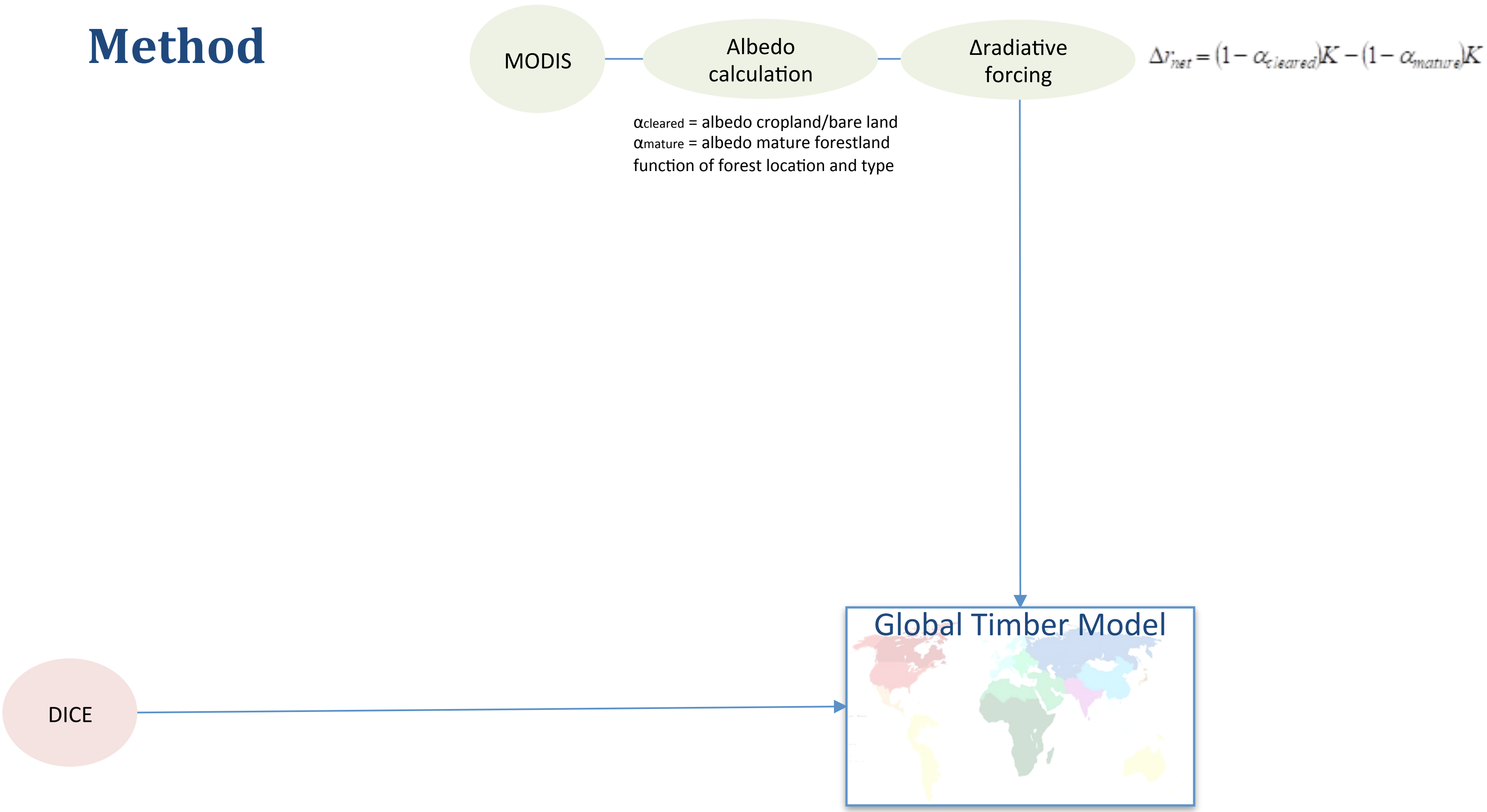
Method



Method


MODIS
Albedo calculation
αcleared = albedo cropland/bare land
αmature = albedo mature forestland
function of forest location and type
Global Timber Model
DICE

Method


MODIS
Albedo calculation
Δradiative forcing
$\Delta r_{net} = (1-\alpha_{cleared})K - (1-\alpha_{mature})K$
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α_{mature} = albedo mature forestland
function of forest location and type
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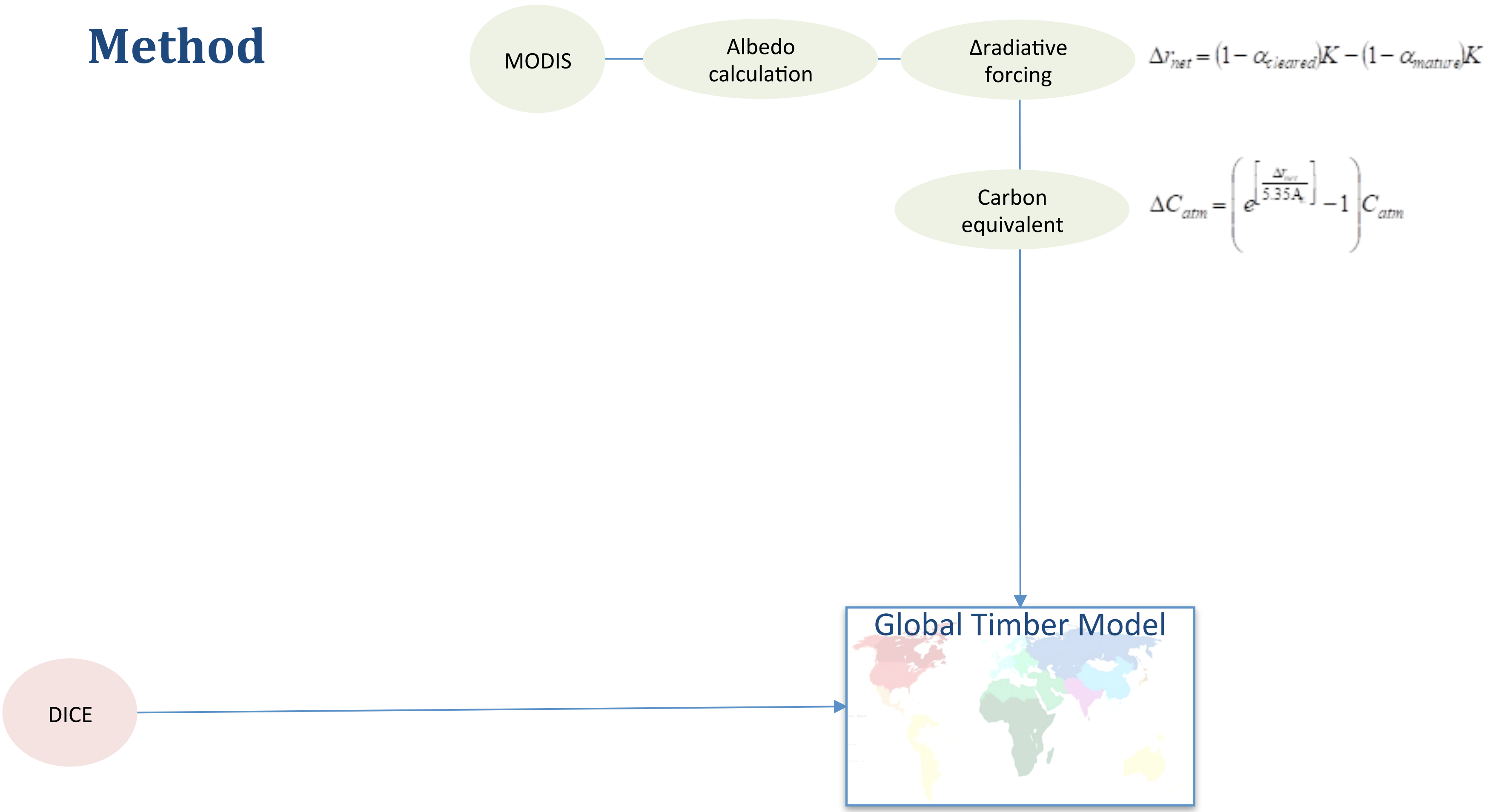
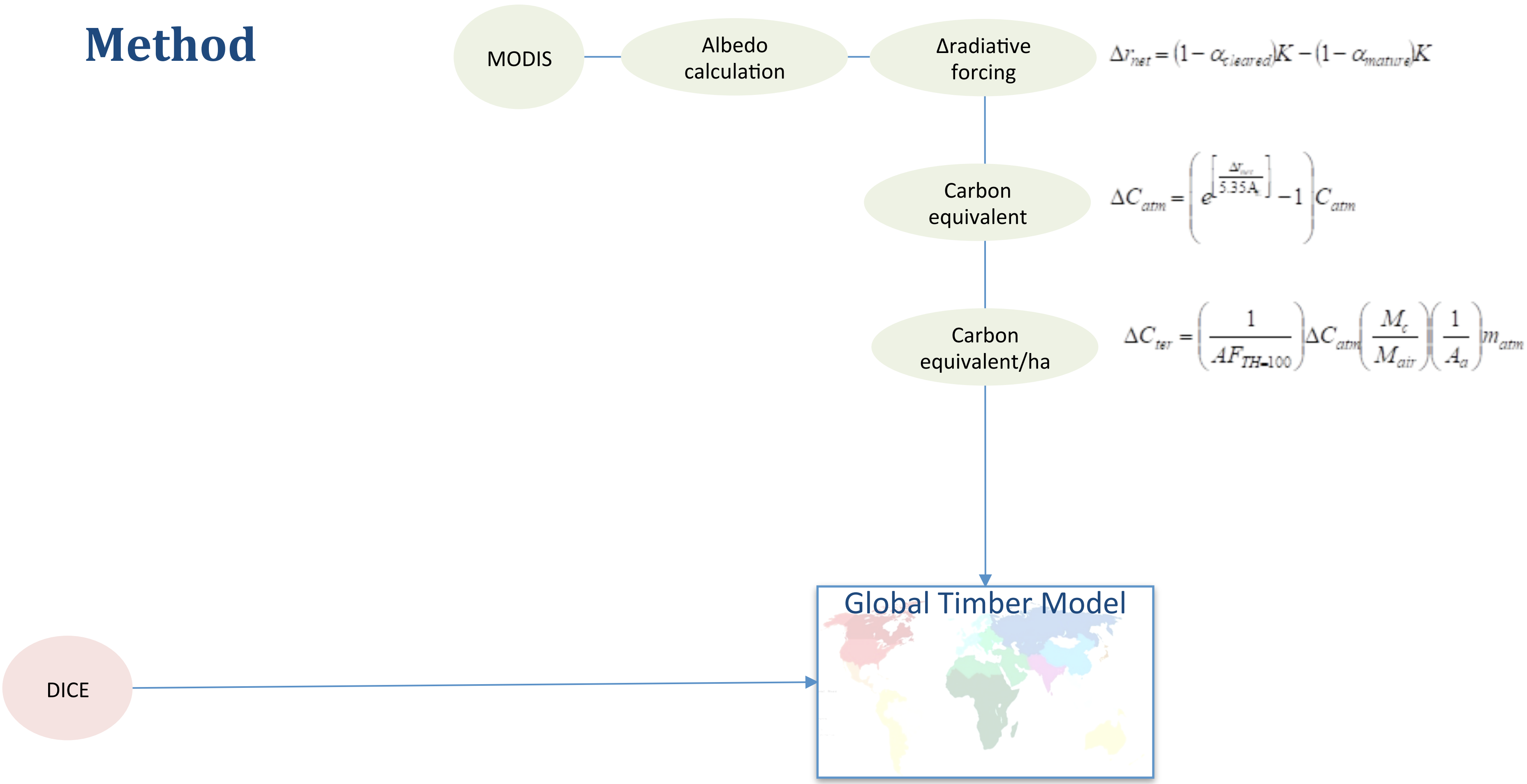

MODIS
Albedo calculation
Δradiative forcing
$\Delta r_{net} = (1-\alpha_{cleared})K - (1-\alpha_{mature})K$
Carbon equivalent
$\Delta C_{atm} = \left(e^{\left[\frac{\Delta r_{net}}{5.35A}\right]} - 1\right) C_{atm}$
Global Timber Model
DICE

Method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Carbon equivalent/ha
$\Delta C_{ter} = \left(\frac{1}{AF_{TH-100}} \right) \Delta C_{atm} \left(\frac{M_c}{M_{air}} \right) \left(\frac{1}{A_a} \right) m_{atm}$
Global Timber Model
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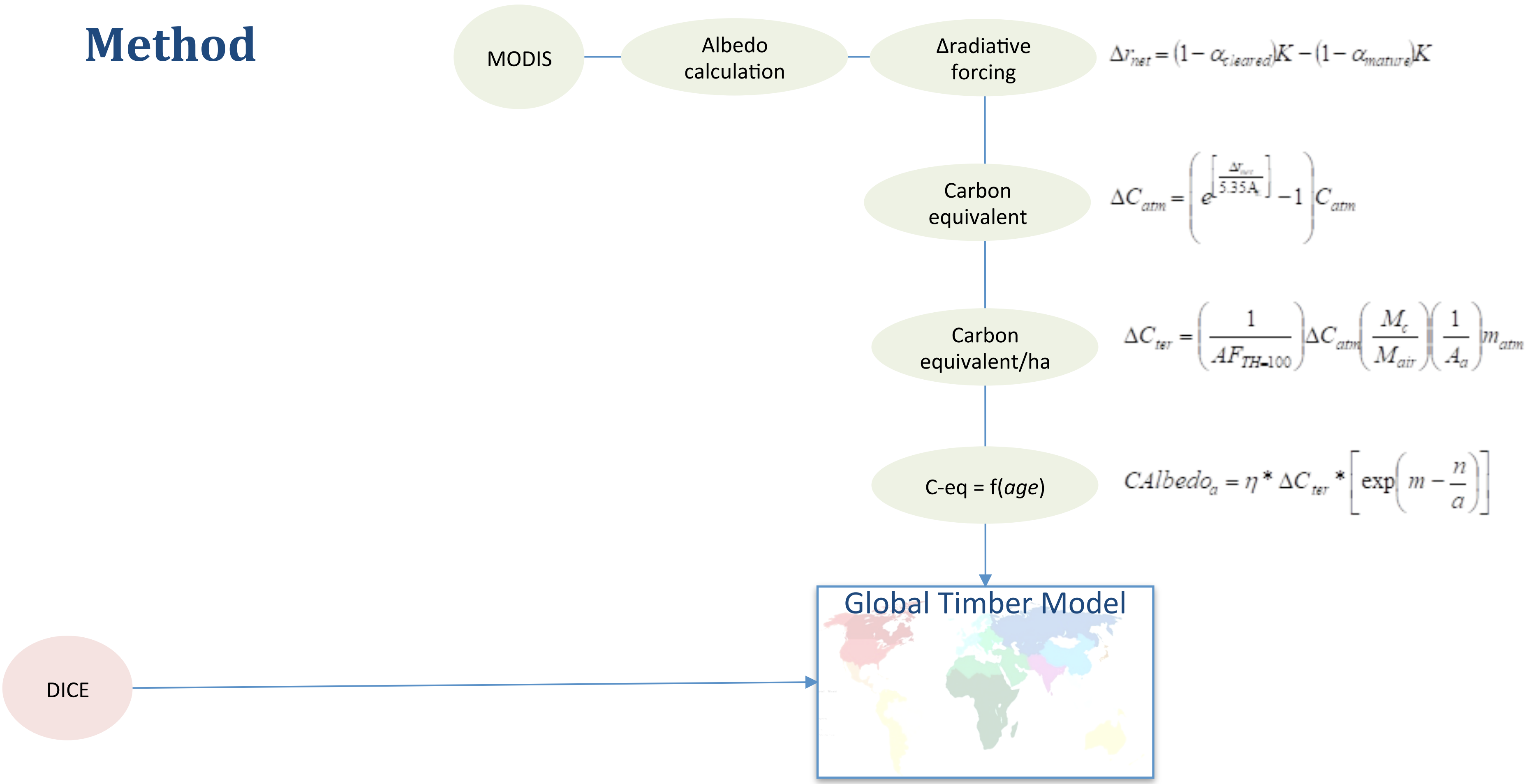

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C-eq = f(*age*)
$CAlbedo_a = \eta * \Delta C_{ter} * \left[\exp\left(m - \frac{n}{a} \right) \right]$
Global Timber Model
DICE

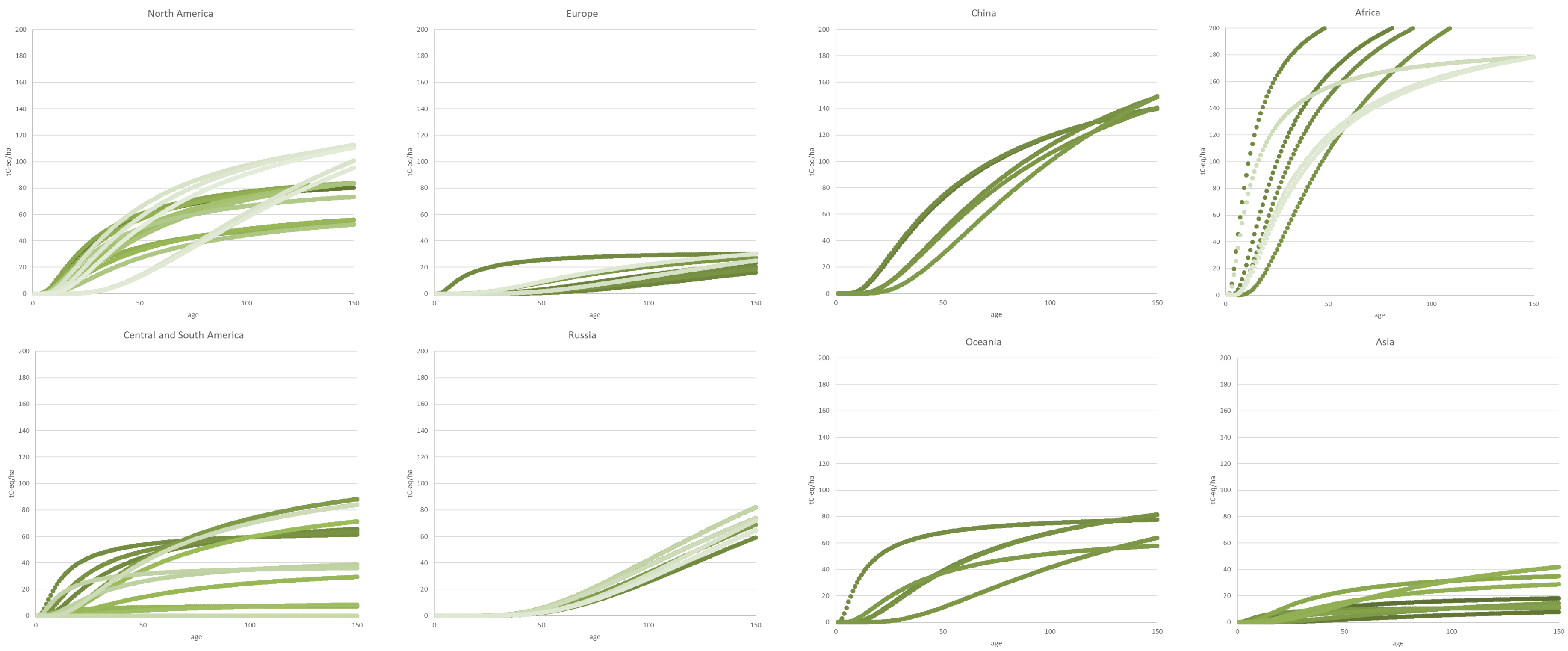
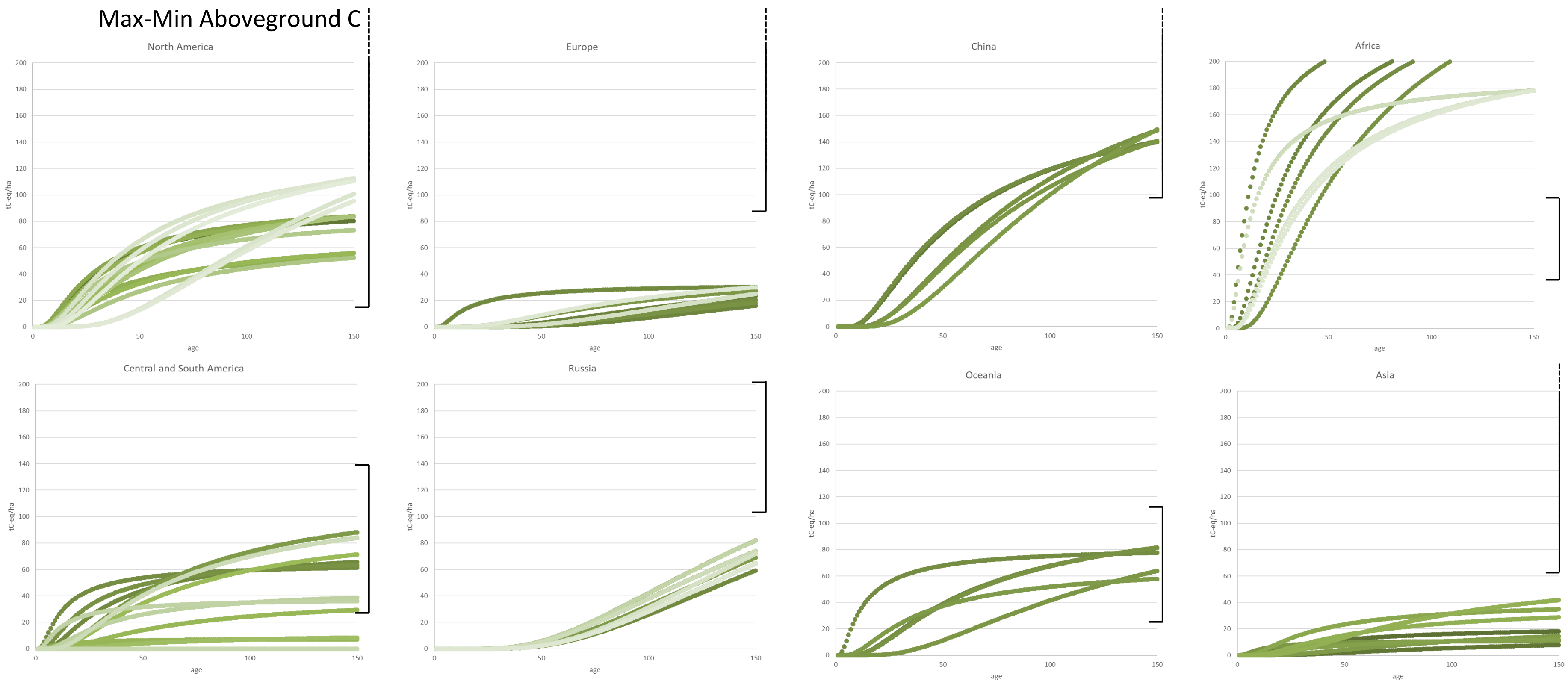


Figure 2: Regional changes in albedo C-eq (tC-eq/ha) as a function of forest age



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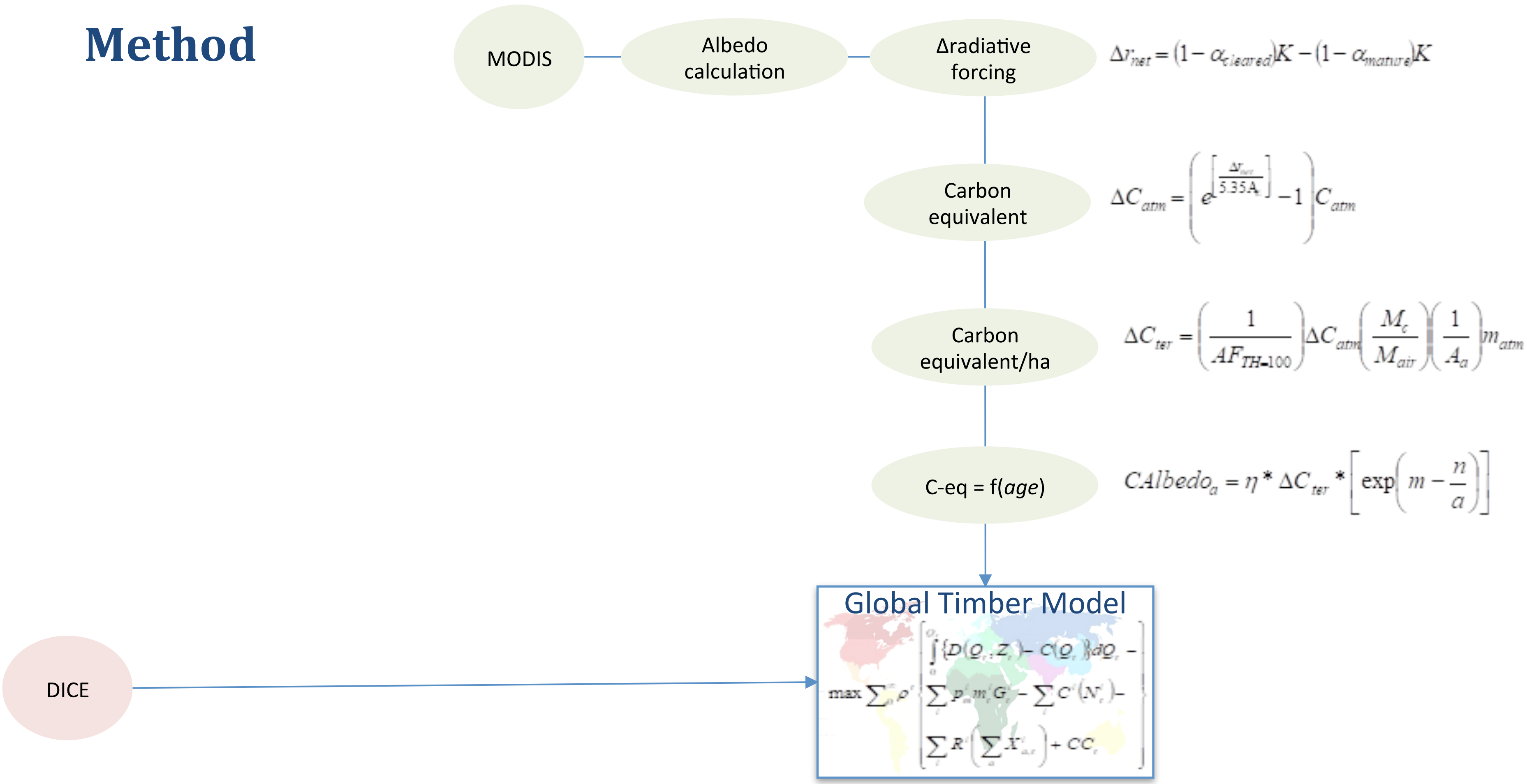
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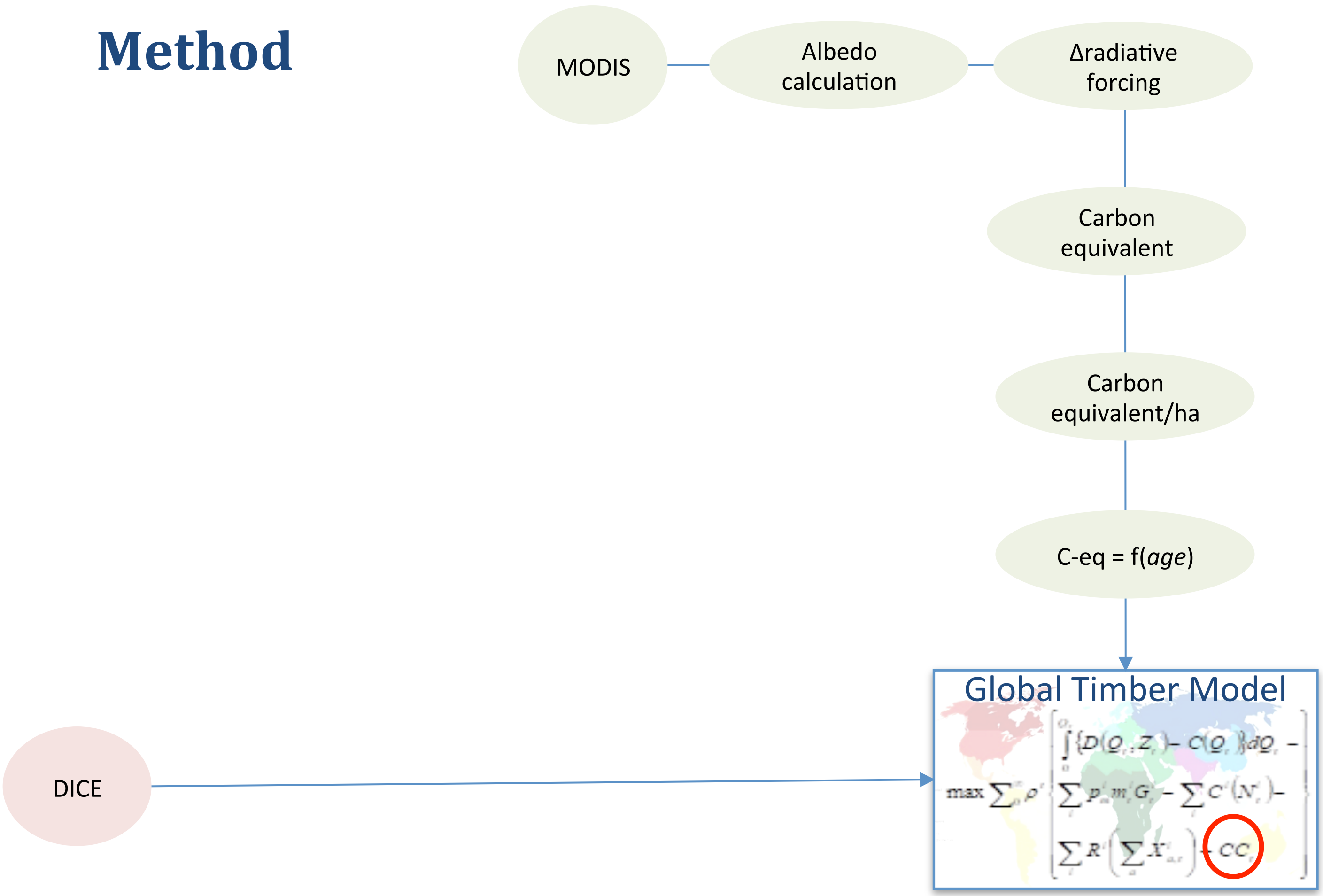
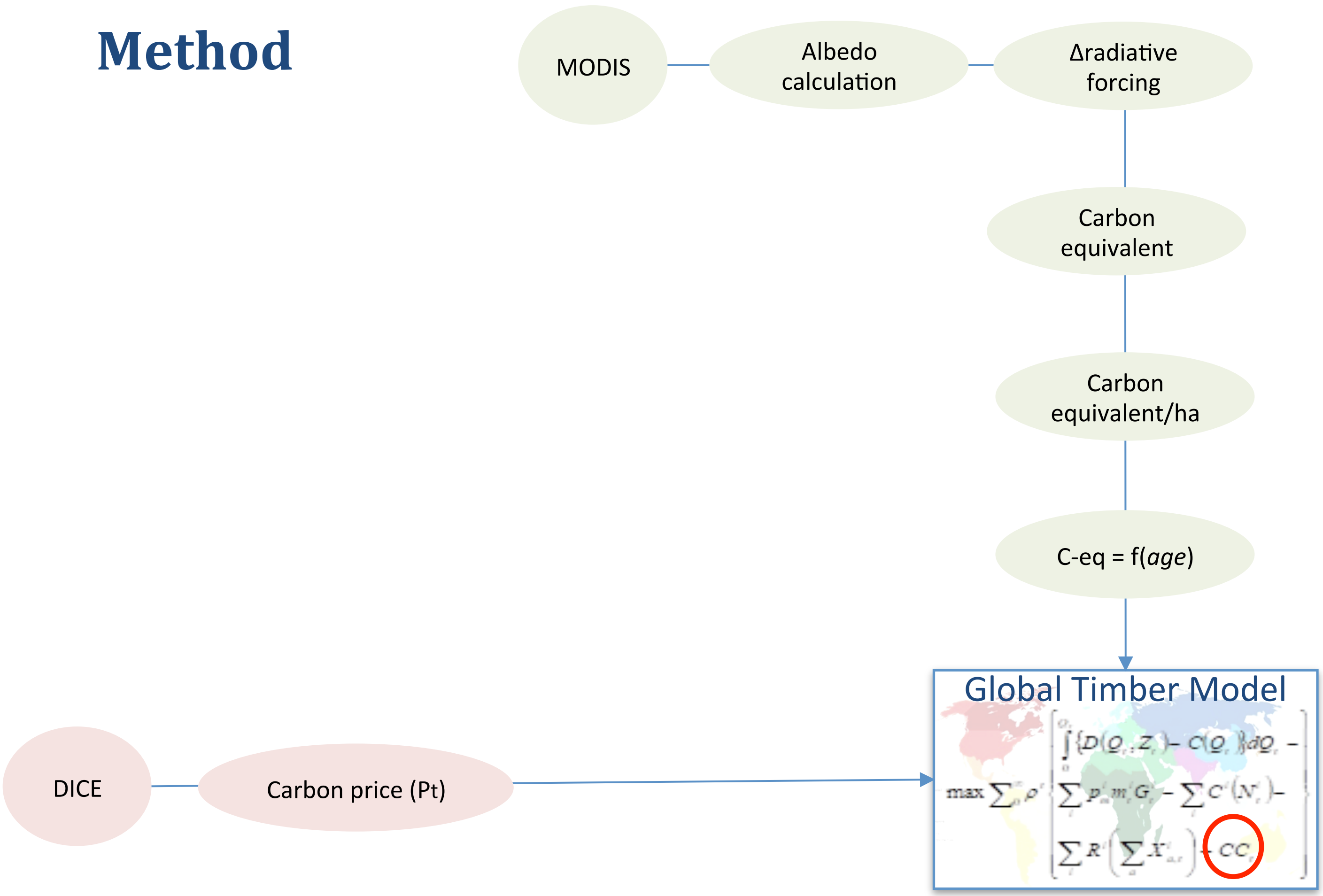
Global Timber Model
DICE

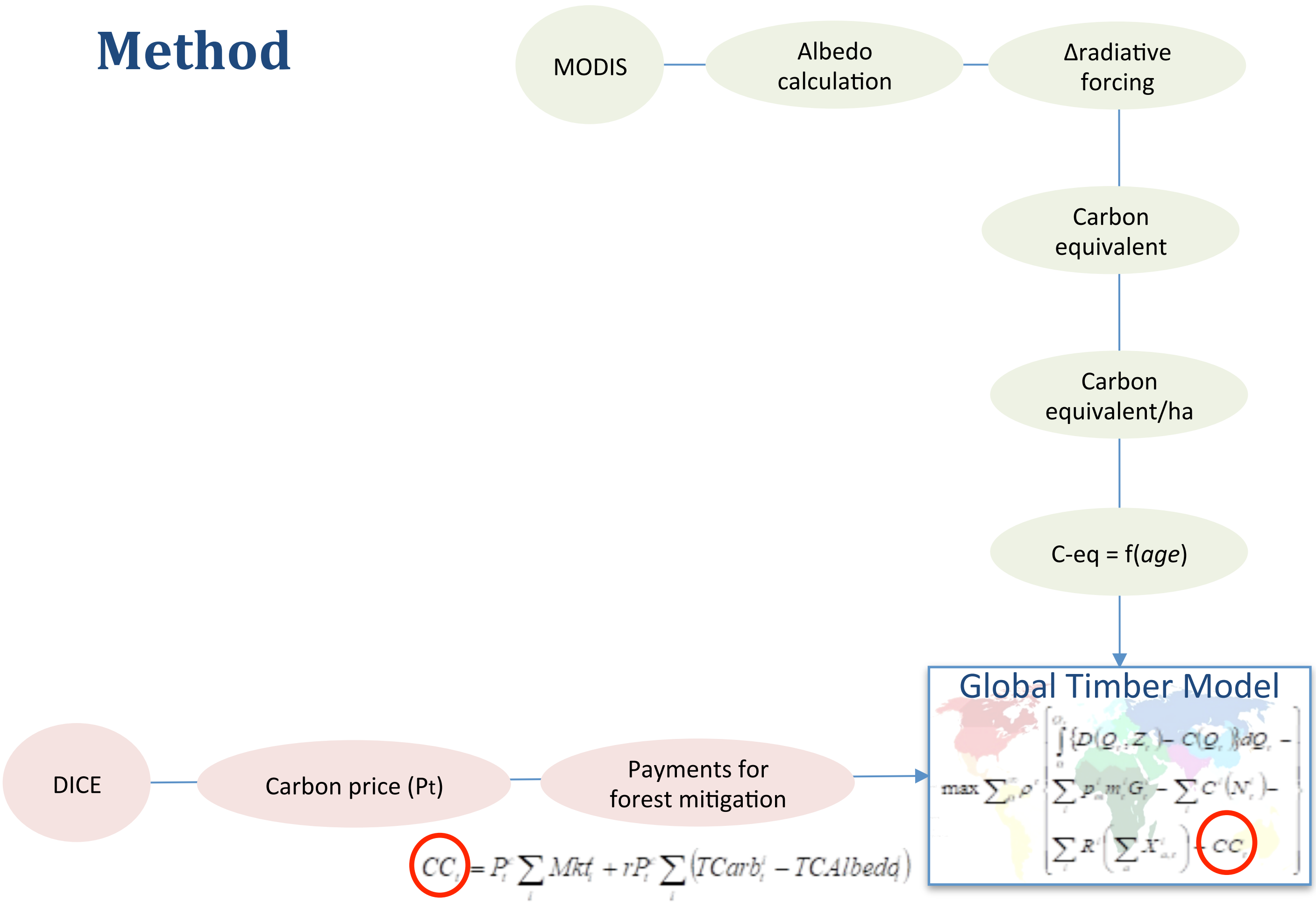
Method


MODIS
Albedo calculation
Δradiative forcing
Carbon equivalent
Carbon equivalent/ha
C-eq = f(*age*)
Global Timber Model
DICE

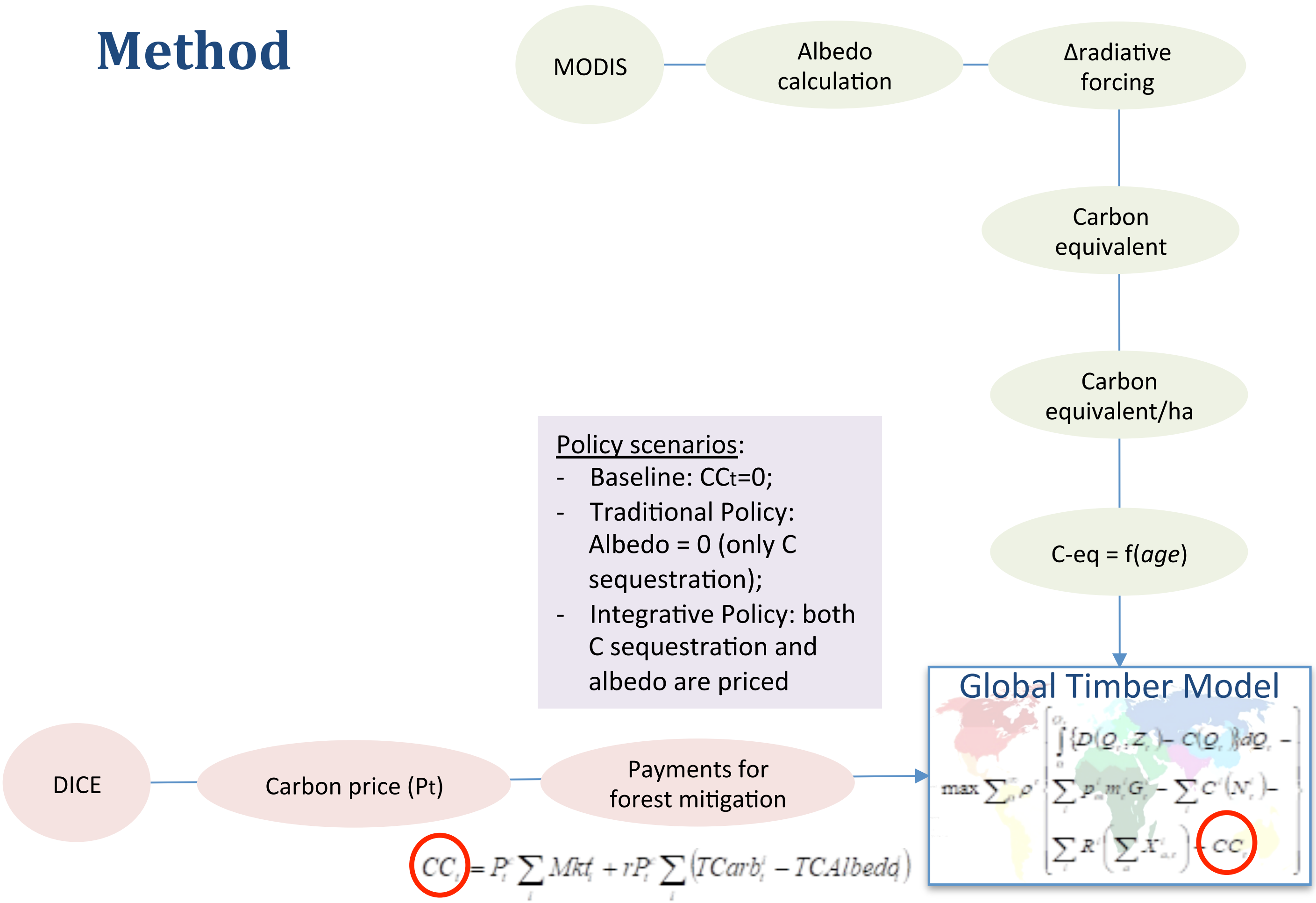
Method


MODIS
Albedo calculation
Δradiative forcing
Carbon equivalent
Carbon equivalent/ha
C-eq = f(age)
Global Timber Model
DICE
Carbon price (Pt)

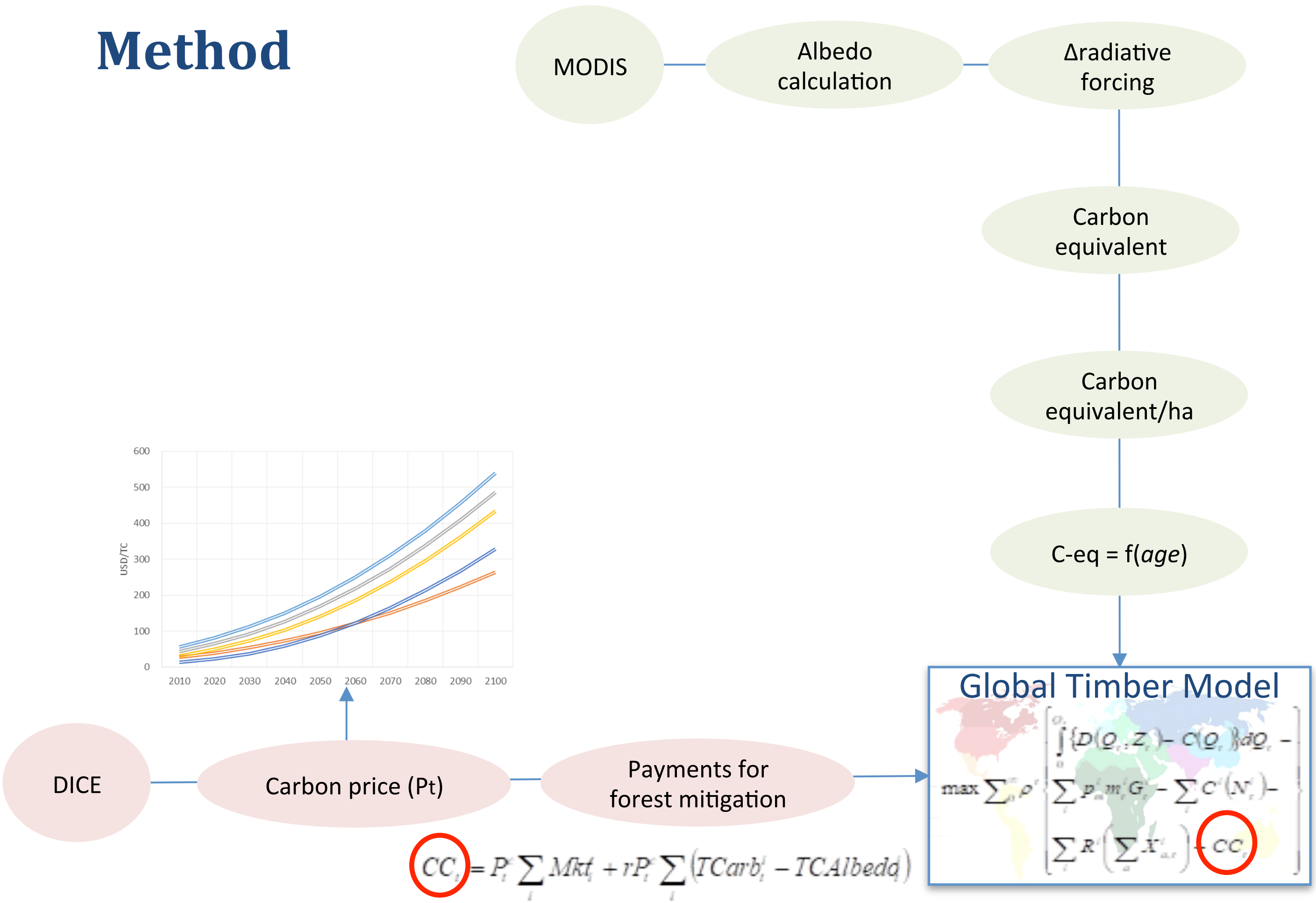
Method


MODIS
Albedo calculation
Δradiative forcing
Carbon equivalent
Carbon equivalent/ha
C-eq = f(age)
Global Timber Model
DICE
Carbon price (Pt)
Payments for forest mitigation

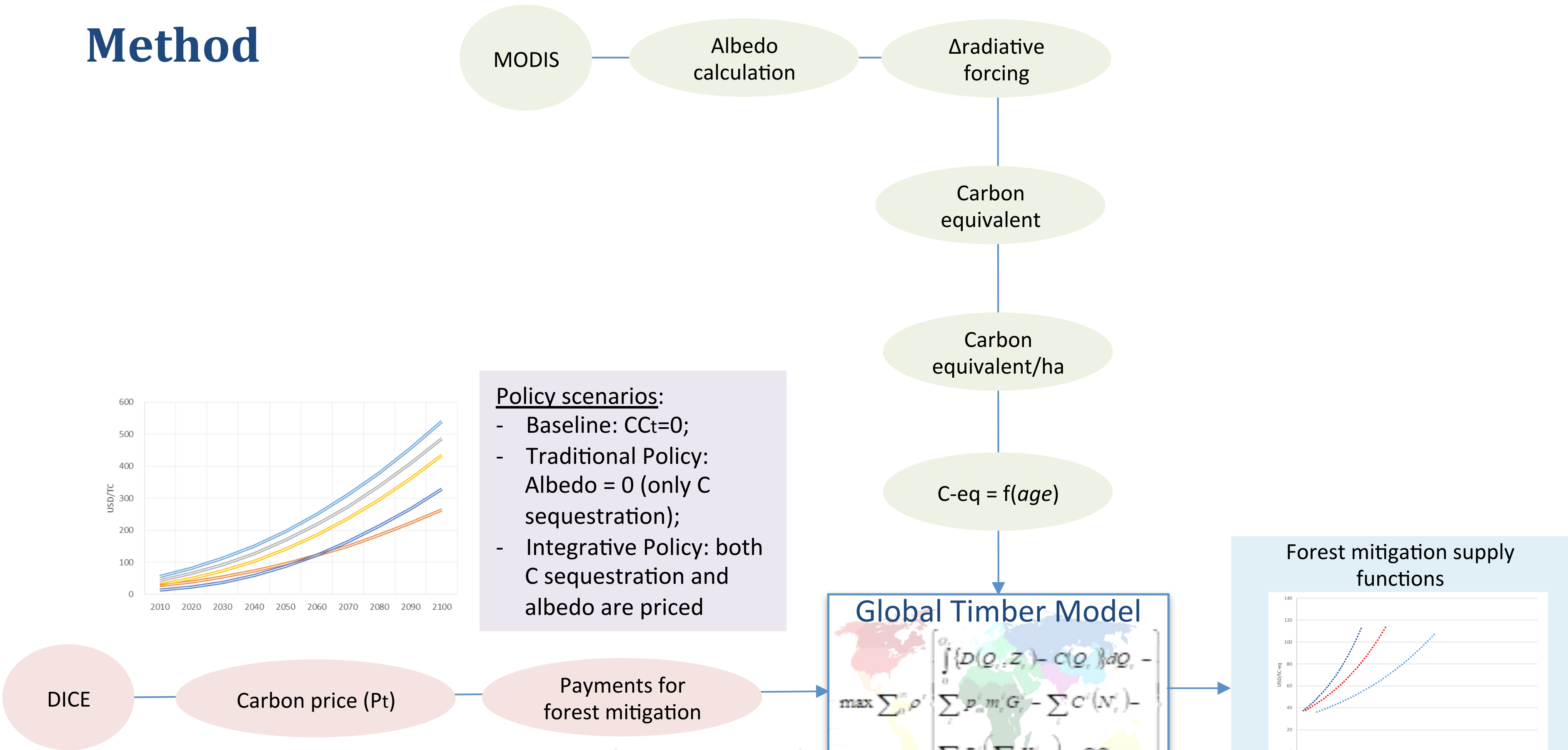
Method


MODIS
Albedo calculation
Δradiative forcing
Carbon equivalent
Carbon equivalent/ha
C-eq = f(age)
Policy scenarios:
- Baseline: CCt=0;
- Traditional Policy: Albedo = 0 (only C sequestration);
- Integrative Policy: both C sequestration and albedo are priced
Global Timber Model
DICE
Carbon price (Pt)
Payments for forest mitigation
CC = P Σ Mkt + rP Σ (TCarb − TCAlbedo)

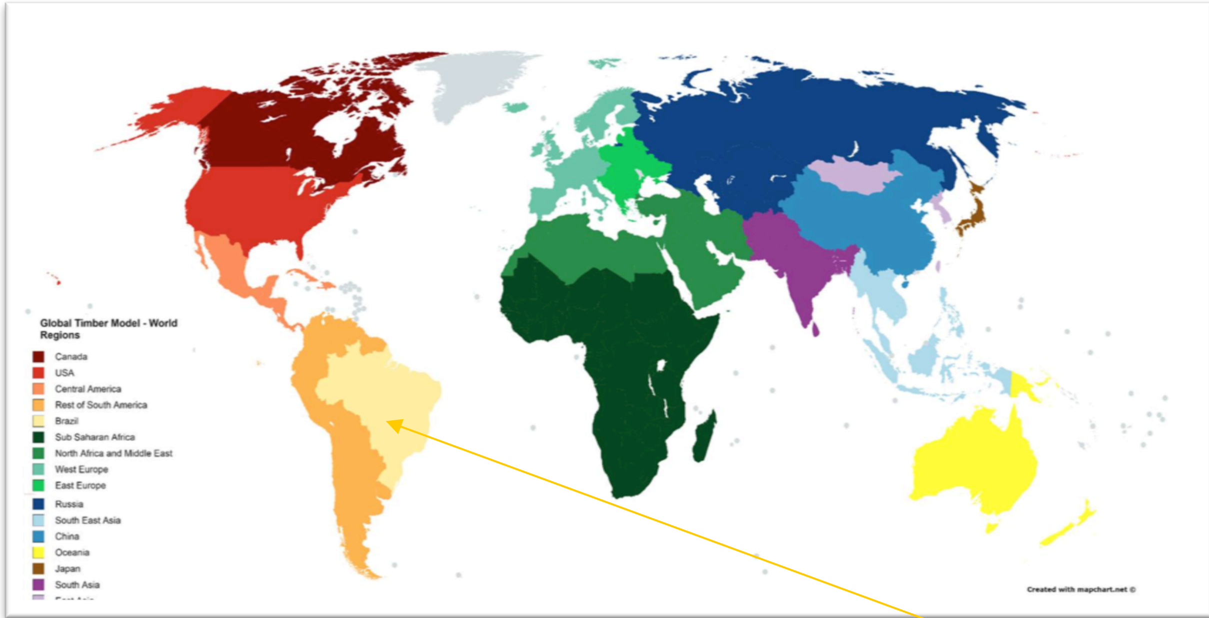
Method


MODIS
Albedo calculation
Δradiative forcing
Carbon equivalent
Carbon equivalent/ha
C-eq = f(age)
Global Timber Model
USD/TC
600
500
400
300
200
100
0
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100
DICE
Carbon price (Pt)
Payments for forest mitigation

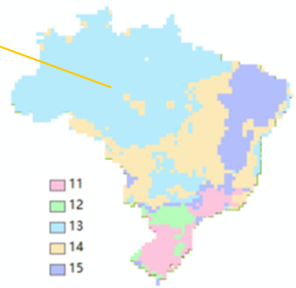
Method



$$CC_t = P_t \sum_i Mkt_i + R_t \sum_i (TCarb_i - TCAlbedo_i)$$



Global analysis



Traditional Policy: changes in C stock pools

- The Traditional Policy creates the incentive to convert land to forest, to grow forest more quickly and to extend the rotation of forests.

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- The conversion of more land to forest, the increase in management intensity and the more extended forest rotation wrt the No Policy scenario produce an increase in aboveground, soil and market carbon.

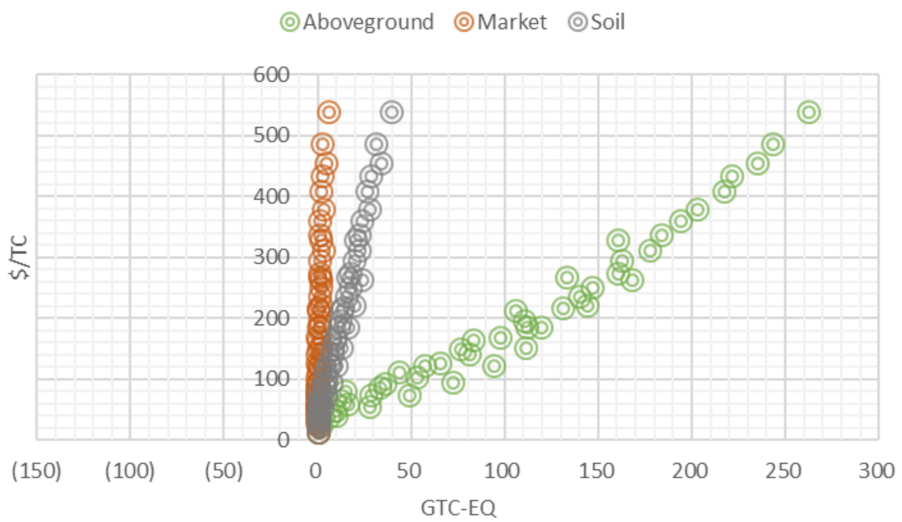

Figure 4: Changes in carbon stock in the three carbon pools and changes in albedo carbon-equivalent in Gt C under Traditional Policy relative to the No Policy scenario

Traditional Policy: changes in C stock pools

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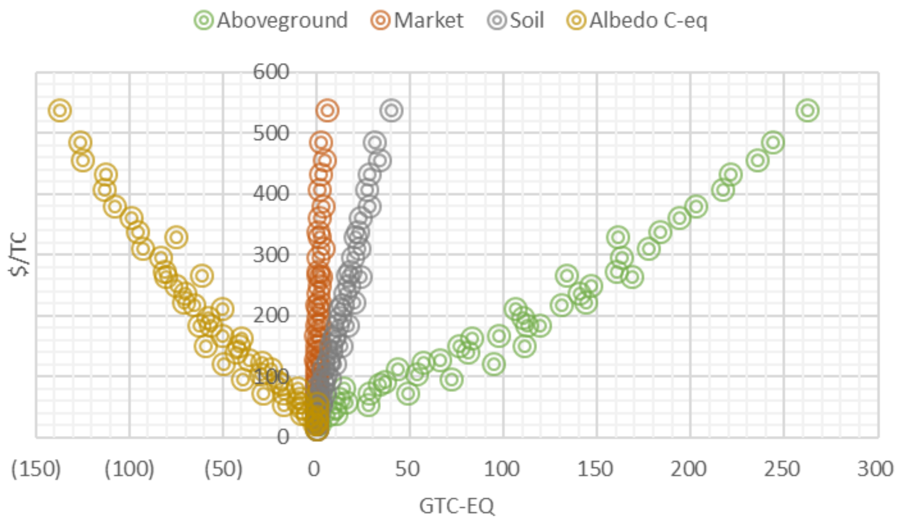
- The conversion of more land to forest, the increase in management intensity and the more extended forest rotation wrt the No Policy scenario produce an increase in aboveground, soil and market carbon.
- These actions increase the amount of carbon sequester in forest and also affect land albedo.



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Innovative Policy: changes in C stock pools

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- Global average carbon benefits of forest actions are greater than the corresponding negative climate impacts of changes in albedo
- Above, soil and market carbon increase wrt the No Policy scenario.

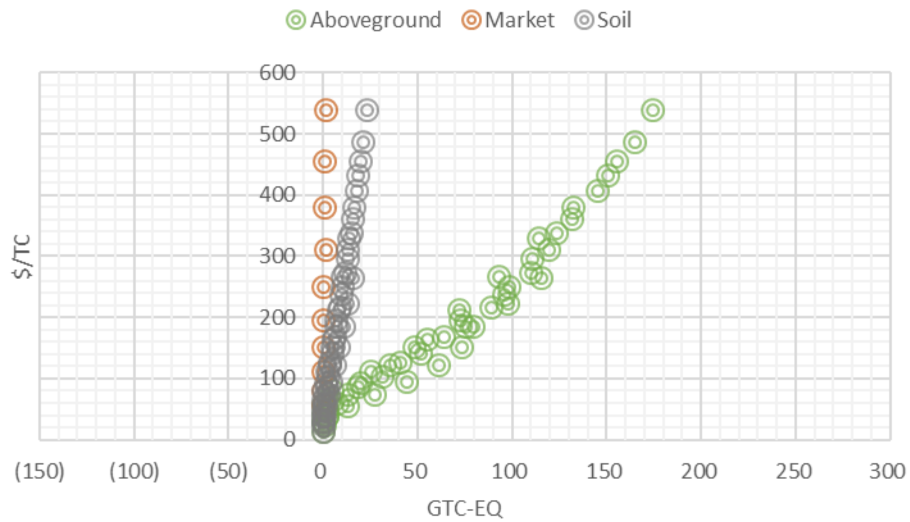
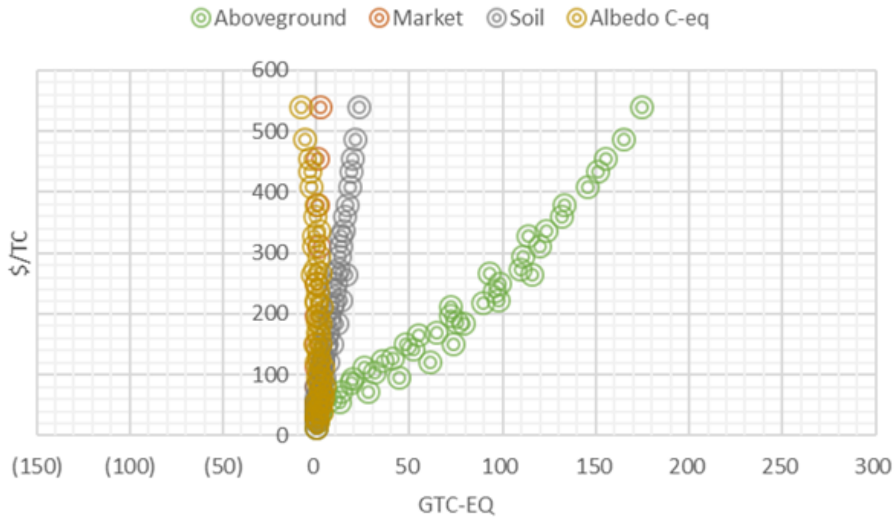


Figure 5: Changes in carbon stock in the three carbon pools and changes in albedo carbon-equivalent in Gt C under Traditional Policy relative to the No Policy scenario

Innovative Policy: changes in C stock pools

- Global average carbon benefits of forest actions are greater than the corresponding negative climate impacts of changes in albedo
- Above, soil and market carbon increase wrt the No Policy scenario.
- To minimize the effects of albedo, the policy re-allocates forests in regions where albedo effects are smaller, changes forest management shortening rotation and reduces global land conversion to forest relative to the Traditional policy.



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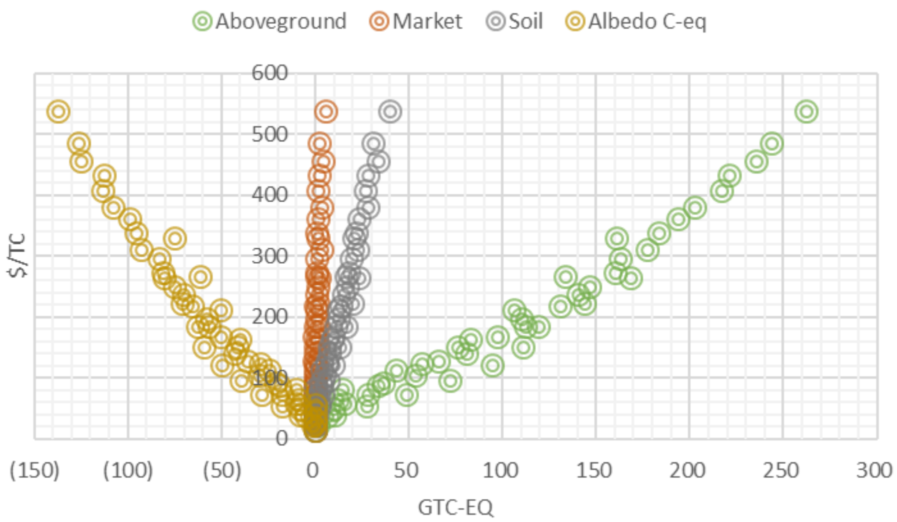
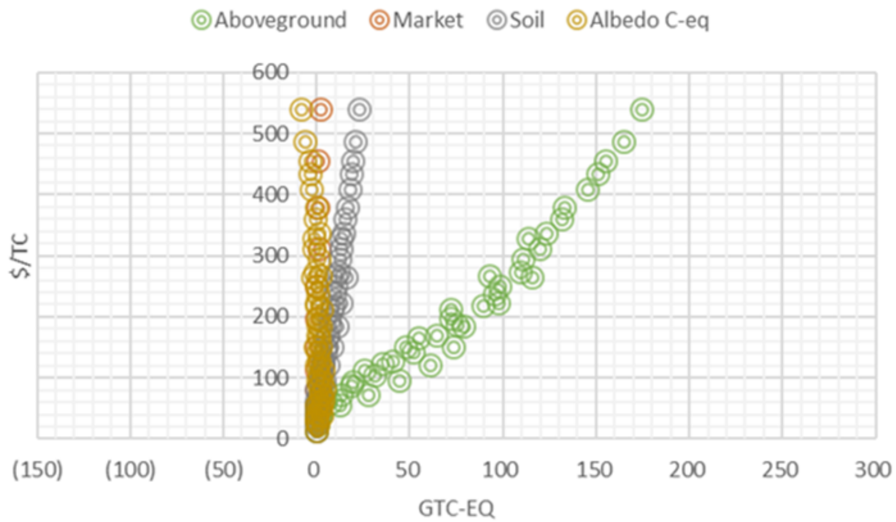
Traditional Policy



Innovative Policy



Forest global mitigation supply functions

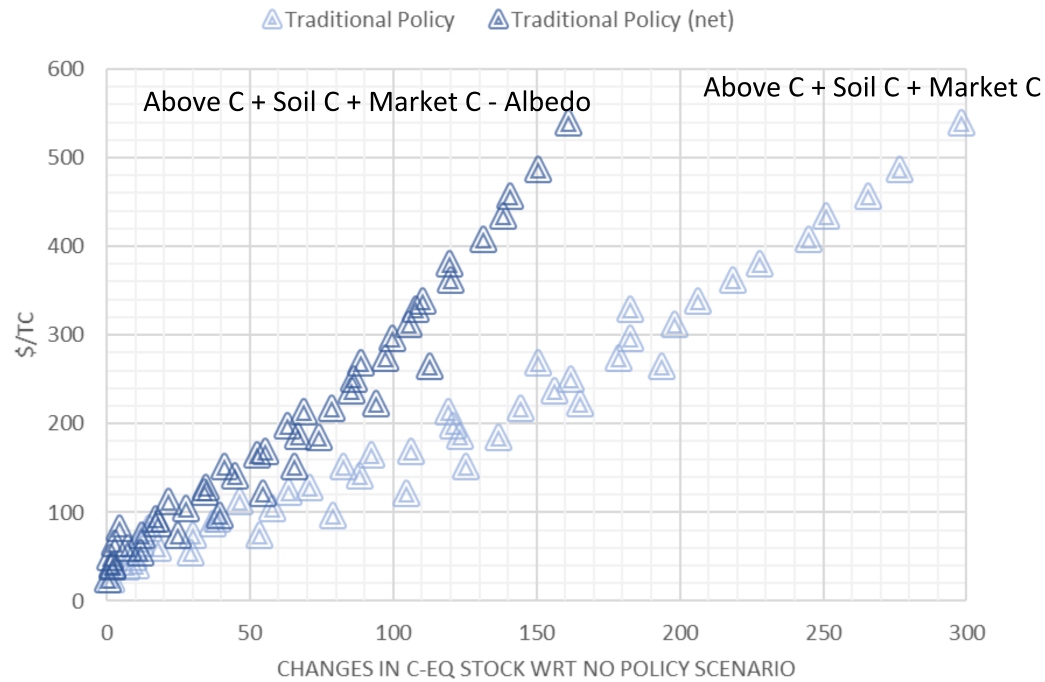
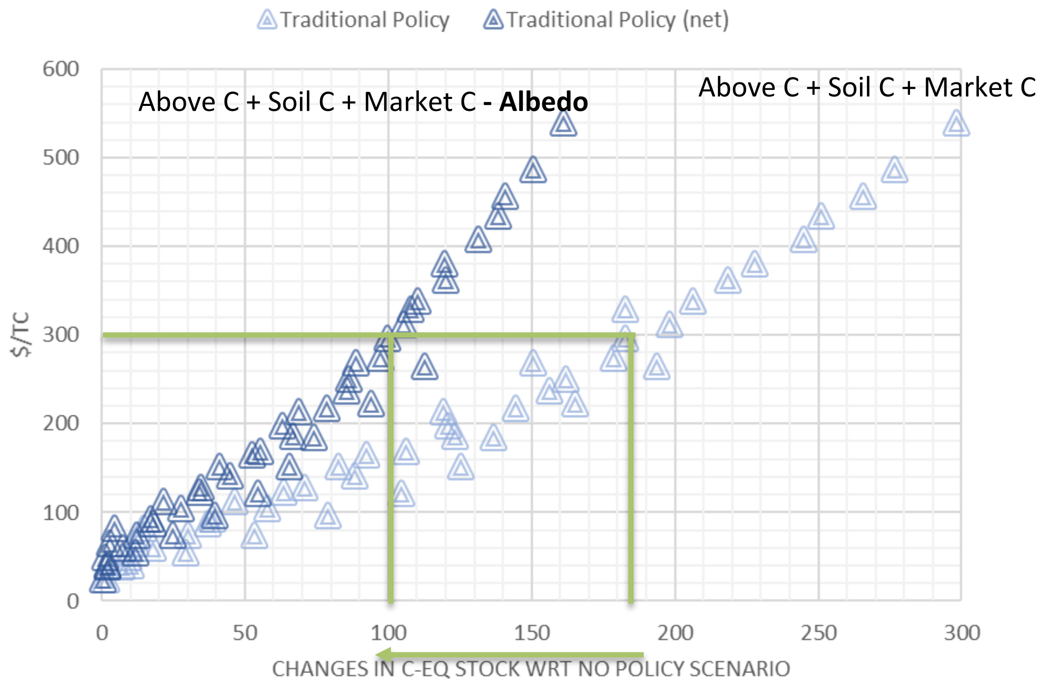


Figure 6: Changes in forest climate mitigation potential in C-eq for different carbon prices under the Traditional Policy regime (light blue), the Traditional Policy (net) which accounts ex post for albedo (dark blue) and the Integrative Policy regime (red) which prices both forest sequestration and albedo relative to the No Policy scenario

Forest global mitigation supply functions

- Results show that for all the carbon prices tested a policy that ignores the albedo consequences of forest-based activities underestimates marginal costs.



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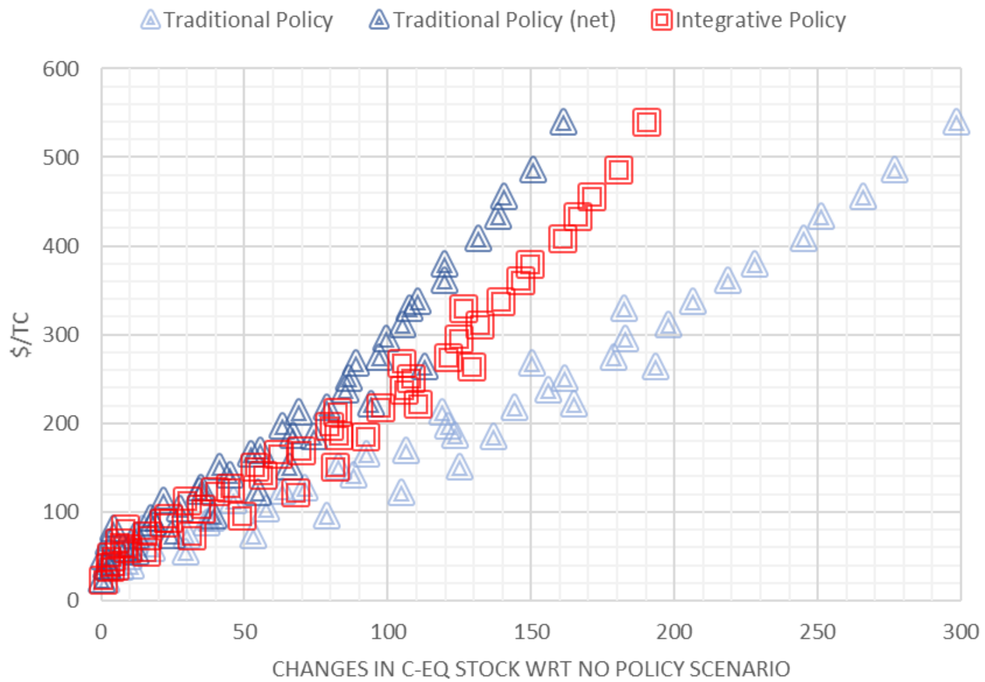
Forest global mitigation supply functions

- Results show that for all the carbon prices tested a policy that ignores the albedo consequences of forest-based activities underestimates marginal costs.

- Results show that the Integrative Policy is cheaper, or more efficient, than a policy that does not include albedo in the pricing formula.



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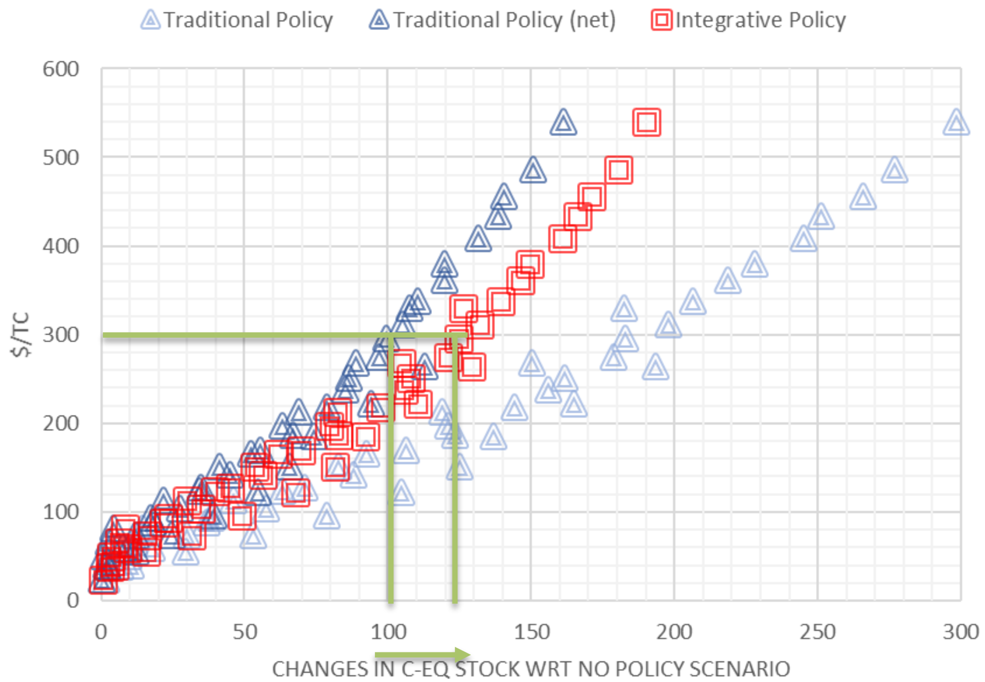

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Net mitigation per hectares

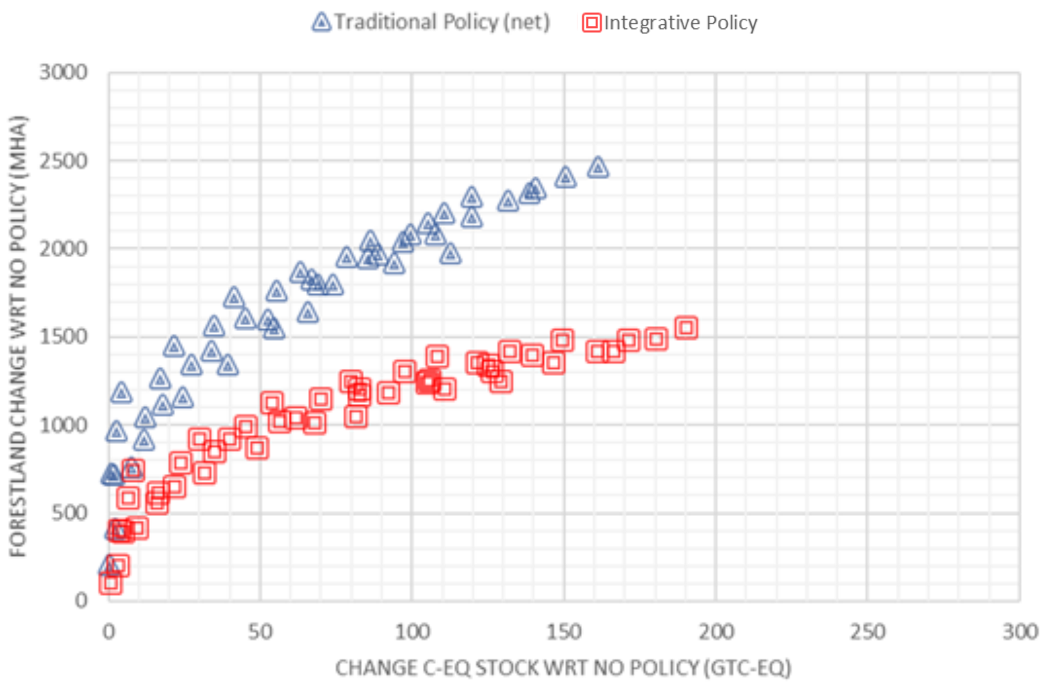
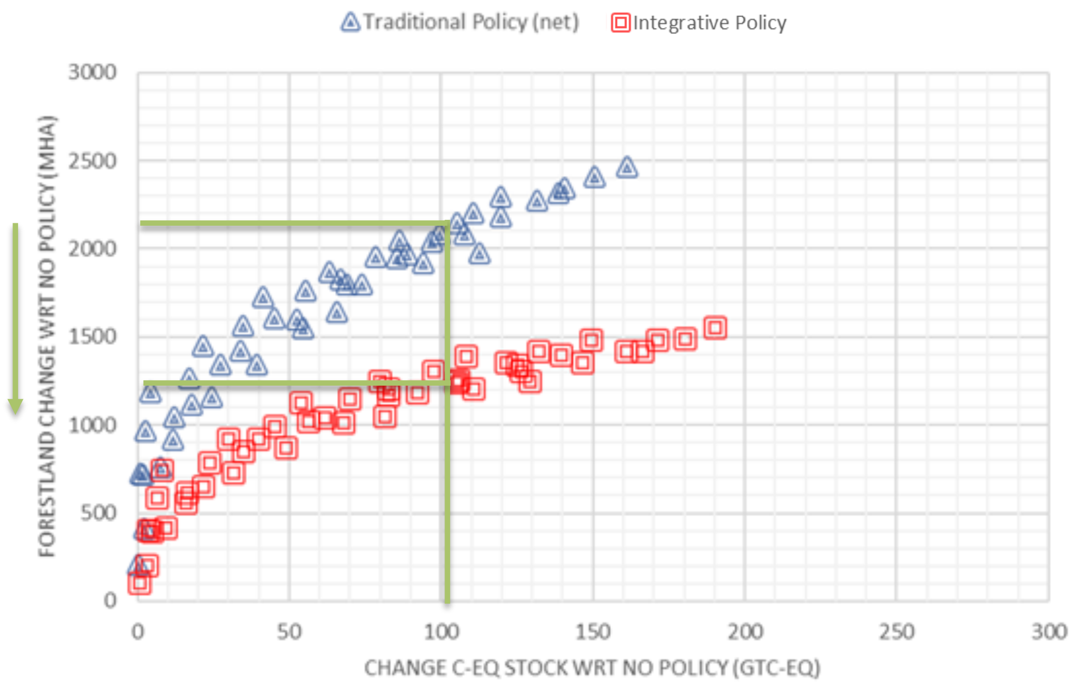


Figure 7: Net mitigation per changes in forestland (in million hectares) under the Traditional Policy (blue) and the Integrative Policy (red) relative to the No Policy scenario

Net mitigation per hectares

- The Integrative Policy is less intrusive than the Traditional Policy : it requires less land to be converted to forestland for the same level of net mitigation.

- To achieve a net mitigation of 100 GtC-eq, it will require 740 million hectares (Mha) more if the pricing formula ignores albedo.



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Regional marginal mitigation functions

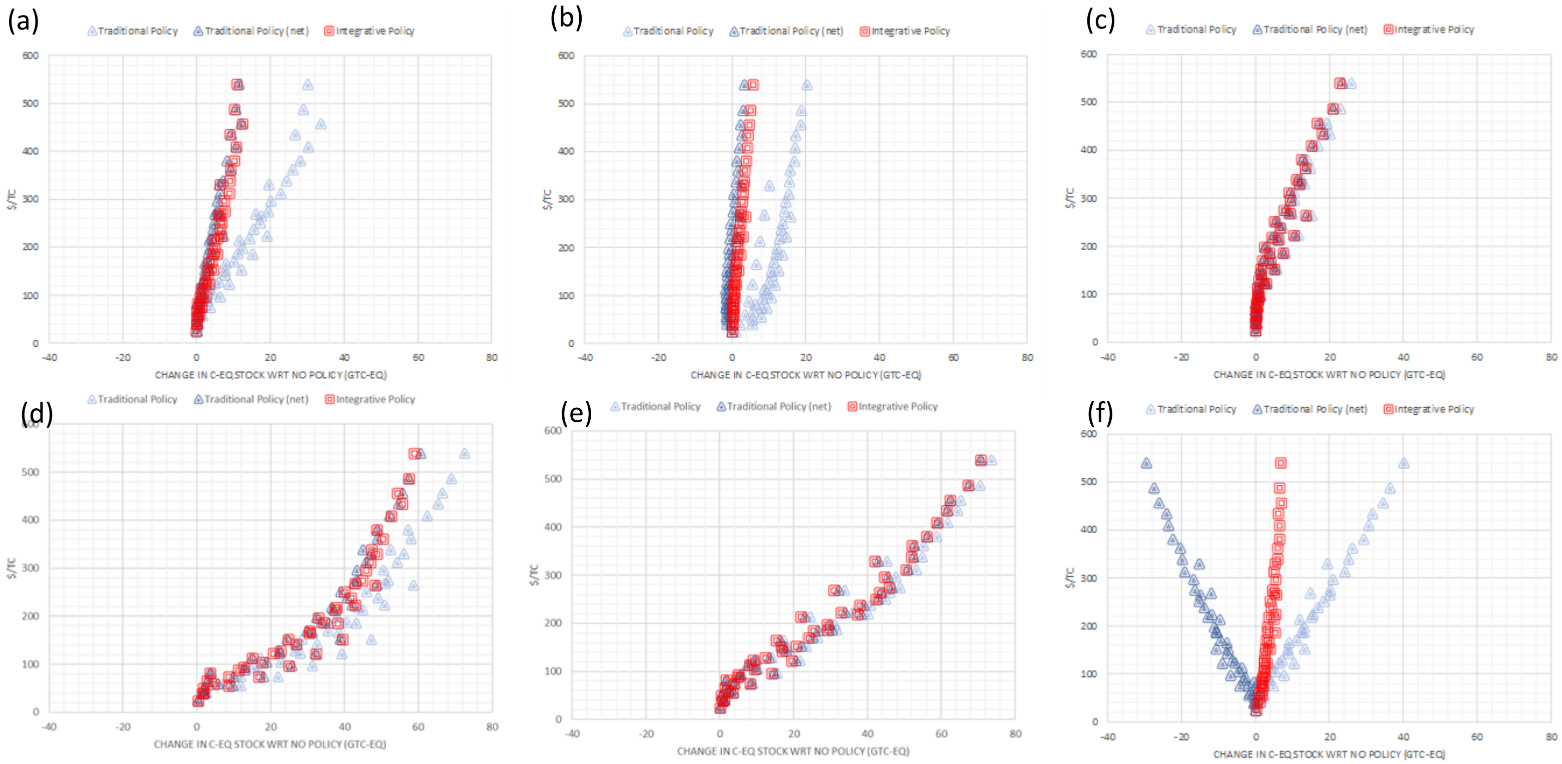

Figure 8: Cumulative C-eq sequestration functions in selected regions (a) North America; (b) Russia; (c) Europe; (d) Central and South America; (e) South East Asia and (f) Africa

Conclusions

- First global economic analysis of forests climate mitigation potential with timber production, carbon sequestration, and surface albedo regulation.
- By ignoring changes in albedo due to changes in land cover and land management the Traditional Policy produces an inefficient allocation of resources (land) and higher mitigation costs.
- By incorporating both carbon sequestration and albedo into pricing (Integrative Policy), the policy re-allocates forests and management to mitigate the effects of albedo.
- Forest mitigation costs were found to vary significantly across world regions.
  - Under the Integrative Policy scenario, mitigation becomes much more expensive in Canada, Russia and Africa while it remains almost unchanged in the other areas.

Next steps

- The study ignored possible changes in evapotranspiration and the interactions with albedo.
  - This aspect is important for tropical forests where evaporative cooling effect is most pronounced.
- Results suggest that it might be more cost-effective to do more climate mitigation in other sectors (e.g. energy) than in the forestry sector.
  - link the forestry model with albedo to an IAM to assess the implications of pricing albedo on the mitigation potential of other sectors.
- The study did not include wood demand for energy production in the forestry model.
- Climate change effects on the growth of forests, changes in dieback rate and changes in biomes could alter the results.

Thank you!

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Empirical estimates: net C sequestration

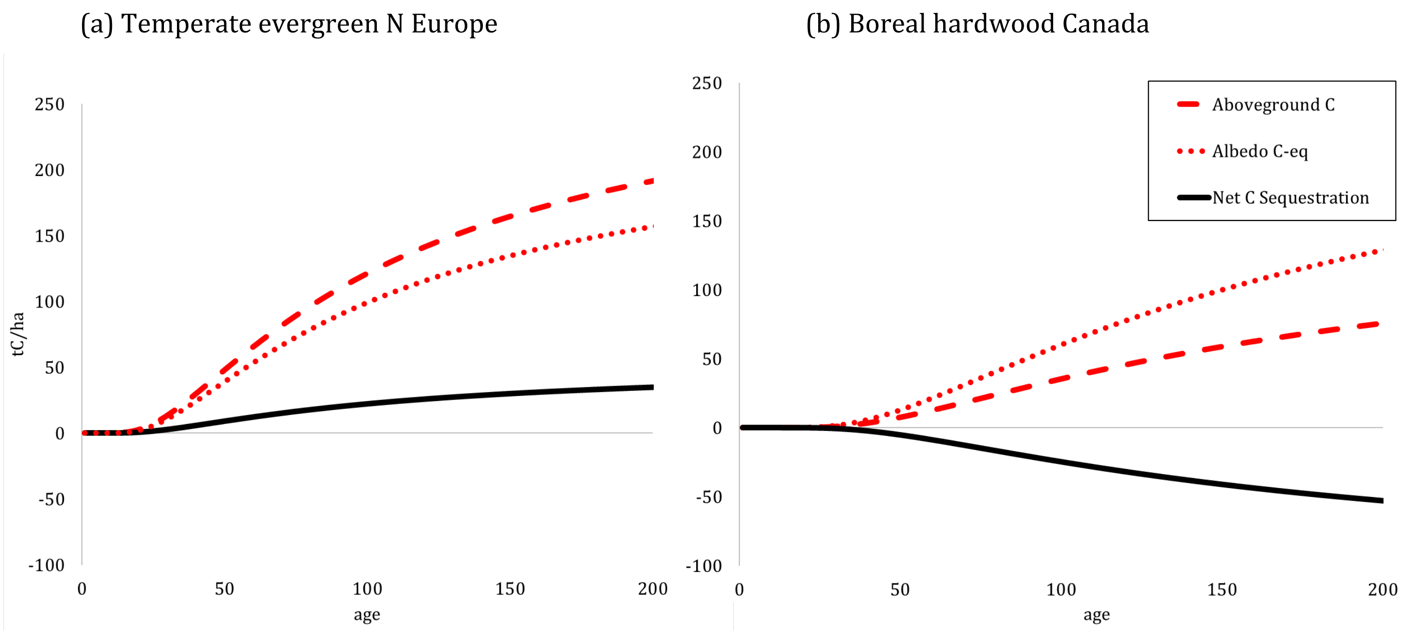

Figure 3: Forest carbon sequestration, carbon-equivalent albedo and net carbon sequestration in tC per ha for (a) Temperate evergreen N Europe and (b) Boreal hardwood Canada at different timber age