Sustainable Bioenergy Solutions for Tomorrow

BEST WP4 TASK 4.5

Reconsideration of the reference situation for agro biomass production

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BEST WP4 TASK 4.5

- This task studies the impacts of reconsidering the land use reference situation for agro biomass production
  - The results are reported in these power point slides
  - The study included a literature review, discussions with experts (from MTT and Metla) on afforestation of fields, and a case study for grass biogas
- Partners: VTT, MTT, Metsägroup, Gasum
- Volume: 30 000 €
- Schedule: 11/2013-6/2014

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PART 1

Reconsideration of the land use reference situation when calculating GHG balances of agro-bioenergy

Kati Koponen and Sampo Soimakallio VTT

What does the reference land use mean?

- When we want to understand the total impacts of an action, we should compare the taken action to a reference situation without this action:
  - E.g. a particular system or decision should be reflected to a reference situation where the particular system or decision does not exist but the related function (e.g. energy service) is served, whenever appropriate, by other means.

- The state without the studied action is called a reference situation
  - Reference situation has also been referred as a baseline, reference case, reference scenario, counterfactual or shadow scenario (Canals et al. 2007; Helin et al. 2012; Johnson & Tschudi 2012).

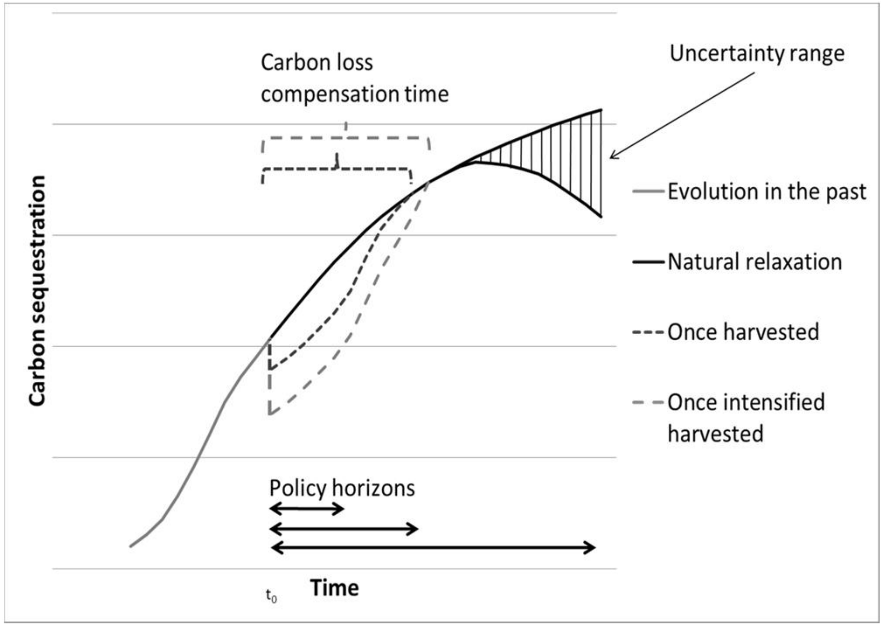
- Here we concentrate on the reference situation for a specific land use in the case of agro-bioenergy production

Example from forest bioenergy studies

- Recently, several studies have assessed the impacts of forest bioenergy by including a reference situation for land use.
  - E.g. McKechnie et al. 2011; Repo et al. 2011; e.g. Pingoud et al. 2012; Repo et al. 2012; Holtsmark 2013; Kallio et al. 2013

- These studies have included a reference situation for land use in which the studied biomass is not harvested → here called as natural regeneration reference

- The emission impact due to foregone carbon sequestration or relative carbon stock reduction is included in the analysis
  - Forgone carbon sequestration means the loss of “additional” carbon sequestration that would occur, if the forest was not harvested → The GHG emission reduction potential of forest bioenergy is reduced.

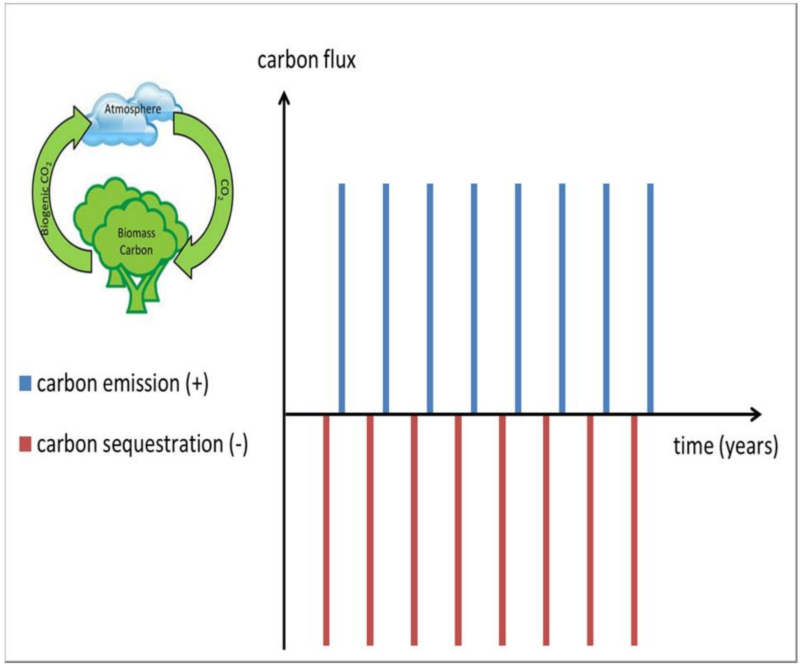


Carbon sequestration in a forest stand over time in various forest management options (Helin et al. 2013)

Agro-bioenergy studies

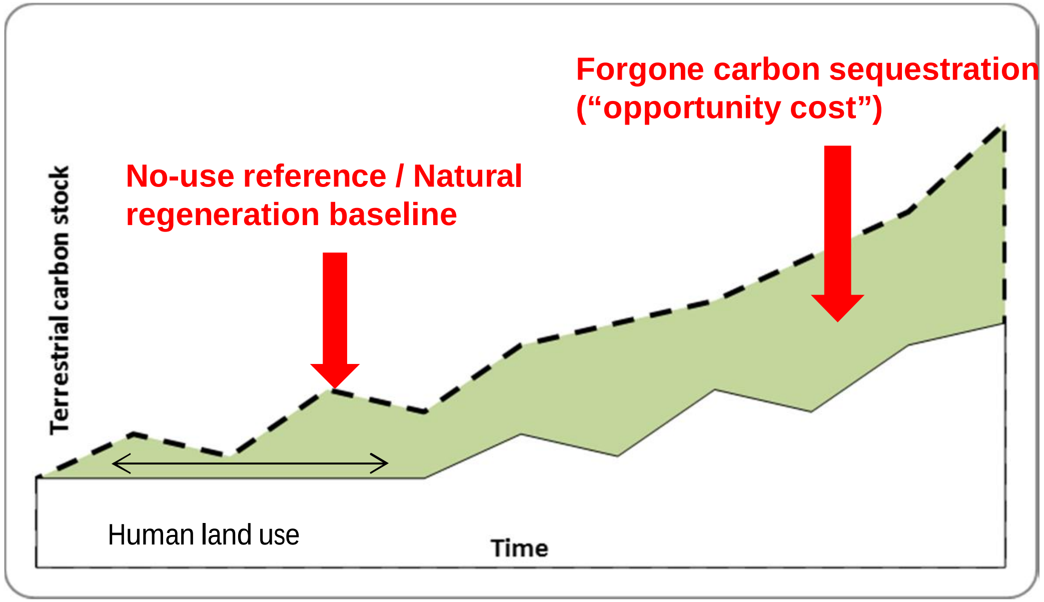
- For agro-bioenergy studies, the land use reference is often ignored, and thus only actual net emissions are accounted
- However, the consideration of land use reference situation is equally important for agro-bioenergy as for forest bioenergy.
- Even if agro-biomass can be considered carbon neutral over its rotation period (one or few years), it may not be climate neutral when the land use reference system is considered.

Carbon neutral agro-bioenergy: carbon emitted in one year is sequestered back in the next year

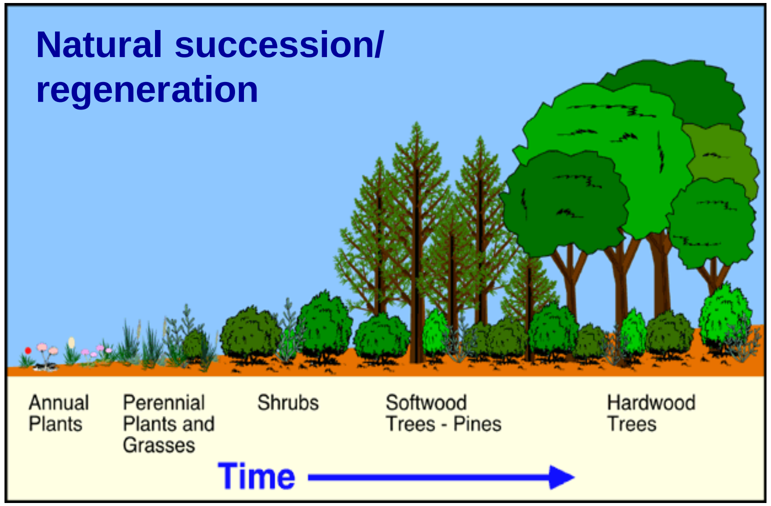


Human land use effects the ecosystem carbon stocks

- Often human land use keeps the carbon stocks lower than their natural levels:
  - “Natural ecosystems strive for maximal exergy, and human impact may disturb this striving by accidentally decreasing the exergy level or by permanently keeping it at a lower level in the case of land occupation” (Myus 2002)



Modified from original source: Milà i Canals et al. 2007



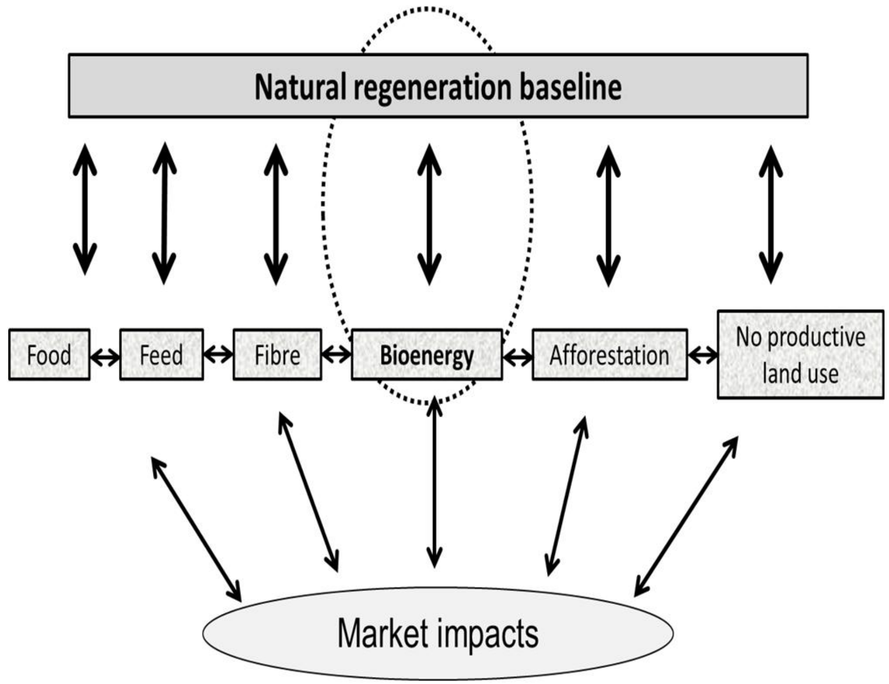
Modified from: Dr. Michael Pidwimy, University of British Columbia Okanagan

Possible reference situations

- In practice, the reference land use situation could be a competing or other likely land use such as food, feed or fibre production instead of energy.

- Capturing consequences of displacing some other function requires consideration of the indirect market-mediated impacts i.e. the displaced function has to be produced by some other means somewhere

- However, the change from some other land use to the studied land use does not reflect the impact of occupying land for the studied system, **thus natural regeneration baseline is only suitable for such purpose**.



How to define the natural regeneration baseline?

- One needs to determine, what happens to a land area when it is not used
- What type of natural regeneration can we assume?
  - Depends on the land type, region, climate conditions etc.
  - In Finland it is very probable that some kind of forest would grow to the land area → a carbon stock would be formed
    - This assumption is suitable especially for agricultural land, as in Finland almost all agricultural land has been cleared from forest land (Karhu et al. 2011), and thus it can be expected that they would become covered with forest again if left to natural regeneration. Also, Ramankutty and Foley (1999) state that for Finland and Sweden the potential natural vegetation would be temperate or boreal forest.
  - See the literature review in PART 2

Including the reference land use in the GHG-calculations of bioenergy

- A method to include the GHG-impact (here based on cumulative radiative forcing) due to the consideration of the natural regeneration reference land use into the GHG-balances of agro-bioenergy has been demonstrated by Koponen and Soimakallio (2014) based on Pingoud et al. (2012).

→ The cumulative radiative forcing due to the bioenergy system (including the natural regeneration baseline) can be compared to the cumulative radiative forcing of fossil carbon

  - This way, an emission indicator similar to the GWP factors (e.g. for CH_4 and N_2O) can be calculated for biogenic carbon (we call it RGWP = relative global warming potential)
  - With the RGWP, an emission factor for the biogenic carbon can be calculated and added to the GHG-balance of agro-bioenergy products
  - See PART 3 for a case example

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PART 2

LITERATURE REVIEW: Natural afforestation of old-fields – determining the natural regeneration reference situation

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Contents of the literature review

- In this part, the available literature related to the natural afforestation of former Finnish agricultural lands is reviewed.
- Most of the studies are relatively old and their main focus has been in the occurrence of individual species and vegetation types.
- The studied areas have not been monitored for a long enough time to have developed into mature forests.
- There is no quantitative data available on the biomass accumulation during the afforestation process.

Reference situation/ UNEP-SETAC guideline on global land use impact assessment on biodiversity and ecosystem services in LCA (2013)

- Müller-Wenk & Brandao 2010: Climatic impact of land use in LCA—carbon transfers between vegetation/soil and air. Int J Life Cycle Assess 15:172-182

Table 2 Relaxation times and imputable mean carbon stay in air for main types of transformation in main biomes

Biome and type of preceding transformation (data source for carbon backflow rates in parentheses)	Carbon transfer (t C/ha)	Annual carbon backflow (t C/ha year)	Relaxation time (year)	Mean carbon stay in air (year)
Tropical forest: relaxation after forest-to-cropland transformation (WBGU 1998:55)	150.75	2.45	62	31
Tropical forest: relaxation after forest-to-pastureland transformation (WBGU 1998:55)	120	1.85	65	32.5
Tropical forest: relaxation after forest-to-artificial land transformation (WBGU 1998:55)	150.75	2.45	62	31+25
Temperate forest: relaxation starting after forest-to-cropland transformation (WBGU 1998:55)	135	1.83	74	37
Temperate forest: relaxation after forest-to-pastureland transformation (WBGU 1998:55)	100	1.35	74	37
Temperate forest: relaxation after forest-to-artificial land transformation (WBGU 1998:55)	135	1.83	74	37+50
Boreal forest: relaxation after forest-to-cropland transformation (WBGU 1998:55)	150	0.63	238	119
Boreal forest: relaxation after forest-to-pastureland transformation (WBGU 1998:55)	64	0.48	133	67
Boreal forest: relaxation after forest-to-artificial land transformation (WBGU 1998:55)	150	0.63	238	119+100
Trop. grassland: relaxation after grassland-to-cropland transformation (IPCC 2000, Table 4.4)	58	0.6	97	48
Trop. grassland: relaxation after grassland-to-artificial land transformation(IPCC 2000, Table 4.4)	58	0.6	97	48+25
Temp. grassland: relaxation after grassland-to-cropland transformation (IPCC 2000, Table 4.4)	66	0.6	110	55
Temp. grassland: relaxation after grassland-to-artificial land transformation (IPCC 2000, Table 4.4)	66	0.6	110	55+50

Early phases of secondary succession, fields with annual crops

1. year: crop plants, annual weeds and ruderals (Hokkanen & Raatikainen 1977, Kiirikki 1993)

2. year → grasses and other perennial species that favor open habitats (Hokkanen & Raatikainen 1977, Törmälä 1982, Prach 1985)
   - *Deschampsia cespitosa* (nurmilauha)- communities on organic soils moister than the average (Hokkanen & Raatikainen 1977)
   - *Anthoxanthum odoratum* (tuoksusimake)- communities developed in on coarse mineral soils drier than the average (Hokkanen & Raatikainen 1977)

~13. year → *Filipendula ulmaria* (mesiangervo) on moist soils (Törmälä 1982)

Early phases of secondary succession, former ley/hay fields

1. year: Typical hay species *Phleum pretense* (timotei) and *Trifolium pretense* (puna-apila) In former hay/ley fields, (Hokkanen & Raatikainen 1977, Silfverberg 1980, Kiirikki 1993)

2.-5. year → *Anthoxanthum odoratum* type in mineral soils and *Deschampsia cespitosa* –type in organic soils (Hokkanen & Raatikainen 1977)

→ 22. year: some sample plots still dominated by grasses and forbs (Kiirikki 1993)

Factors affecting natural afforestation in Finland

- Soil chemical properties
  - In nutrient rich soils, grasses soon develop a dense vegetation, which inhibits establishment of woody plants reproducing by seed (Prach 1985)
  - Afforestation is enhanced on nutrient and humus poor sites (Silfverberg 1980, Prach 1985) and organic soils (Hytönen 1995)

- Soil moisture
  - On moist soils, dense populations of tall growing herbaceous species (*Filipendula ulmaria*) often develop, inhibiting the establishment of woody species (Kalela 1961, Silfverberg 1980, Törmälä 1982)

- Landscape properties
  - Establishment of trees is enhanced by open ditches, that create openings into the otherwise homogenous vegetation (Kalela 1961, Silfverberg 1980)

Factors affecting natural afforestation in Finland

- Climate
  - In southern Finland, broad-leaved trees (*Betula, Alnus, Populous tremula* and *Salix caprea*), are most common (Kalela 1961, Kiirikki 1993)

- Preceding crop
  - In former hay/ley fields, the establishment of woody species is hindered compared to fields that have been in annual crop production before the abandonment, due to the strong competition for water, light and nutrients (Kalela 1961, Silfverberg 1980, Hytönen 1995)
  - Former pastures were the sites most weakly afforested (Kalela1961)
  - Perennial weeds present at the beginning of secondary succession easily become dominant (Hokkanen and Raatikainen 1977, Silfverberg 1980)

Factors affecting natural afforestation in Finland

- Field size
  - The shade caused by forest edges makes the field layer vegetation lower and sparser, which promotes the growth of woody plants (Silfverberg 1980, Jukola-Sulonen 1983, Prach 1985)

- Features of tree species
  - Birch (*Betula pendula* or *B. pubescens*) usually the first to arrive and establish (Kalela 1961, Prach 1985, Hytönen 1995)
  - Also other broad-leaved species (*Alnus, Populus tremula, Salix caprea*), present (Kalela 1961), but have a minor importance nationally (Hytönen 1995), *Alnus* and *Populus* due of their vegetative reproduction (Silfvergerg 1980)
  - Pine (*Pinus sylvestris*) and spruce (*Picea abies*) don't establish until a later stage of the succession (Kalela 1961, Hytönen 1995)
  - The poorest chances to establishment have those species whose seeds are relatively heavy and few in number (*Fraxinus, Acer*) and that are spread by animals (*Sorbus*) (Silfverberg 1980)

Factors enhancing natural afforestation in other countries

- Soil chemical properties:
  - Peat and sand soils, that are more nutrient poor than finer textured soils: Sweden, Latvia, Czech Republic (Karlsson 1994, Prach et al. 2001, Ruskule et al. 2012)
- Landscape properties (Italian prealp region of Friuli, Giudi & Piussi 1993)
  - Stone heaps and walls (less competition with herbaceous vegetation), Italian prealp region of Friuli
  - Past crop trees (e.g. producing fruits, seeds or fodder).
- Preceding crop
  - Annual crops (soil preparation, absence of vegetation cover): Sweden (Karlsson 1994), Latvia (Ruskule et al. 2012), Czech Republic (Kopecky & Vojta 2009)
- Field size
  - Favourable conditions at forest edges (Ruskule et al. 2012), not due to the short distance to the seed stand

Time needed for natural afforestation in Finland

Area	Reference	Phase	Time needed (years)	Preceding crop	Soil
Whole country	Prach 1985	establishment of woody species	15	diverse	diverse
Whole country	Prach 1985	establishment of climax woody species	35-50	diverse	diverse
Whole country	Hytönen 1995	täystiheä taimikko	reasonable time	non-ley	organic
Jyväskylä region	Törmälä 1982	establishment of woody species	more than 13	not specified	fine sand, moist
Suonenjoki	Jukola-Sulonen 1983	shrub and tree layer	more than 9	hay	hietamoreeni
Suonenjoki	Jukola-Sulonen 1983	continuous shrub and tree layer	more than 26	hay	hietamoreeni
Lohja	Kiirikki 1993	a closed layer of trees, average height 13 meters	some sample plots at 22	hay	not reported
Lohja	Koponen 1967	grass-herb forest vegetation	less than 35-40	not specified	not reported
Porkkala	Kalela 1961	established birch seedlings	2	non-ley	diverse

Time needed for natural afforestation in other countries

Country, area	Reference	Phase	Time needed (years)
Latvia	Ruskule et al. 2012	a closed canopy tree cover	15-20
Russia, Moscow region	Korotkov et al. 2001	birch forest	20
Germany, Northwest (moist soil, former hay field)	Rosenthal 2010	tree colonization	at least 23
Italy, prealps (Friuli)	Giudi & Piussi 1993	a dense woodland cover	a few decades
England	Harmer 2000	a complete canopy cover	20-30
England	Gibson 2010	canopy closure	more than 15
USA, New Jersey	Bartha et al. 2003	establishment of woody species	16
Europe & eastern North America	Flinn & Vellend 2005	development of a dense thicket of shrubs and trees	30–40
Europe & eastern North America	Flinn & Vellend 2005	a closed tree canopy	60–80

Russia, Moscow region (Korotkov et al. 2001)

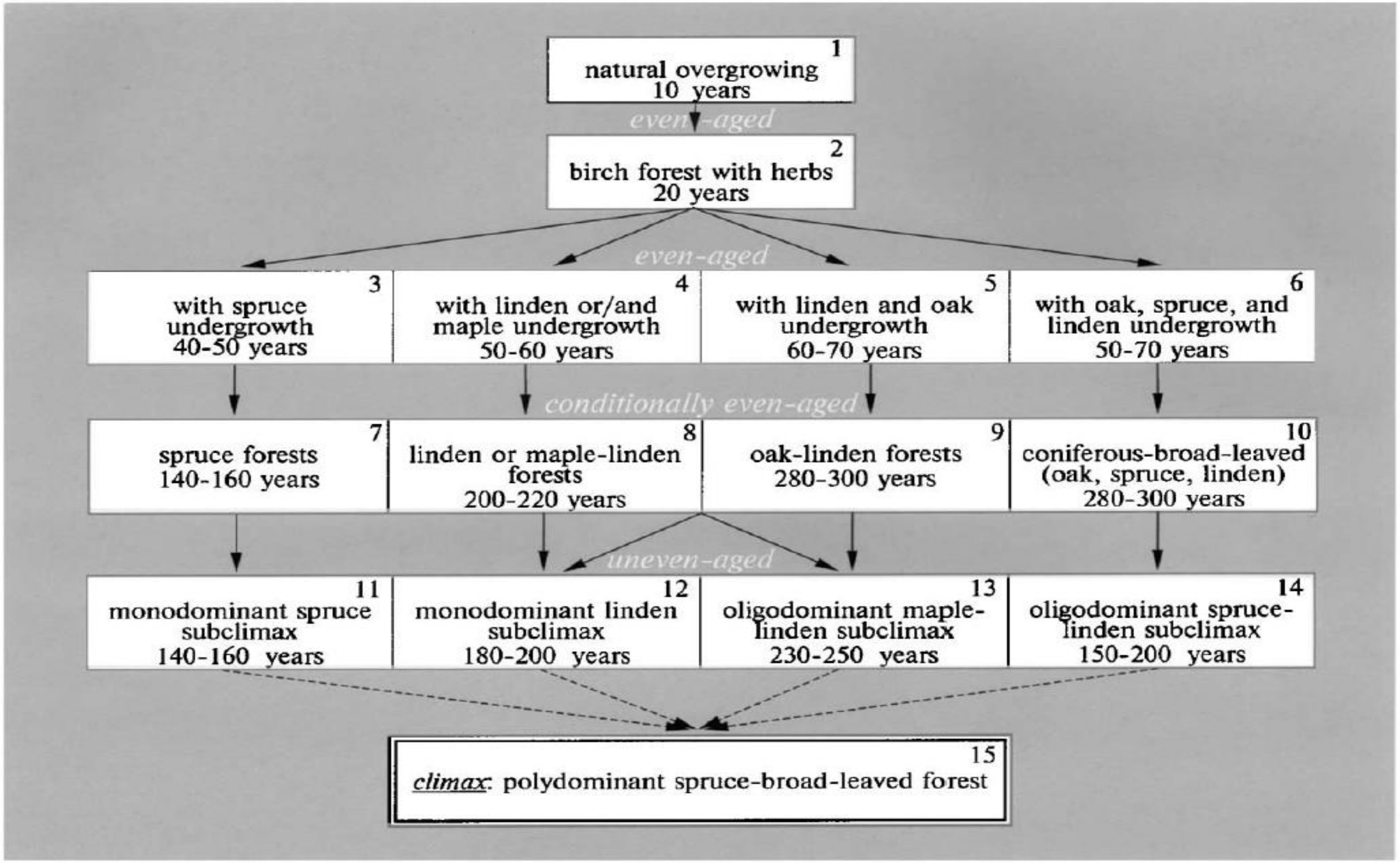

Fig. 1. Ideal course of succession through forest types (after-tillage series) in the Prioksko-Terrasnyi Biosphere Reserve, Moscow Region, Russia.

Time needed to reach certain growth stages in Finland (years), summary

Preceding crop: annual						
Soil	Site	Crop plants, annual weeds and ruderals	Grass-dominated vegetation type	Establishment of woody species	Closed canopy layer	Establishment of climax species
General	general	1	2	15		35-50
	south	1	2		≤ 35-40	
	non-ley, south	1	2	2		
Coarse mineral	moist, central	1	2	> 13		
Organic	general	1	2		reasonable time	

Preceding crop: ley/ hay					
Soil	Site	Ley species	Grass-dominated vegetation type	Establishment of woody species	Closed canopy layer
General	ley, south	1	2-5		≥ 22
Coarse mineral	ley	1	2-5	> 9	> 26

Effect of soil type on plant growth

- Nutrient levels are higher in former field soils than in forest soils and forest growth is thus likely to be faster on old-fields, once the trees have established.
- In estimating the growth potential, the yield production potential of agricultural plants on different soil types can be used.
- Mean barley yield in Finland between 1995-2013 is 3386 kg/ha (Tike)
- A more optimal yield level for the years 2006-2013 by soil texture can be estimated by the results of official variety trials (Laine et al. 2014)

Soil texture	Share of field area (%, Viljavuuspalvelu 2014)	Barley yield (kg/ha, Laine et al. 2014)
Coarse mineral	62	5947
Clay	28	5556
Organic	11	5732

Conclusions from the literature review

- The results of the literature review were discussed with the specialists from MTT and Metla.

- The study seemed to include all the available Finnish literature on the issue.

- However, no numerical data is available on the biomass accumulation of forests established naturally on old-fields.

- The establishment of trees seems to be very slow especially on former ley fields, but the subsequent forest growth can be expected to be fast.

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PART 3

CASE EXAMPLE:
GHG-impacts of biogas from grass, when natural regeneration land use reference is included

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Case example

- The total GHG emission impact of grass biogas system is studied, by taking into account also the emission impact due to the consideration of natural regeneration baseline
  - The emissions due to forgone carbon sequestration are added to the life cycle emission of grass biogas production chain (see illustration at slide 8).

- The RWGP methodology presented in PART1 is used.

Assumptions for the calculation

- Sinkko et al. 2012 calculated the life cycle emissions of grass biogas system according to the European Union sustainability criteria (RED methodology, EU 2009) and ended up to an emission factor of 36gCO_2-eg./MJ (when all biogas was used for transportation, heat used in biogas plant was produced with wood chips, electricity was from national grid, and all the emission were allocated to biogas). This emission factor is used as a basis for the analysis.

- The yield of grass is considered to vary from 3350 to 7500 kg_dm/year (lower yield according to Agricultural Statistics (TIKE) and higher yield an expert opinion by MTT)
  - Scenario with higher yield (7500) = grass max
  - Scenario with lower yield (3350) = grass min

- The carbon content of grass ($C_{feedstock}$) and the lower heating value (LHV) are assumed be similar to those of straw (46%, 13.5MJ/kg_dm, respectively) (Alakangas, 2000).

- The RGWP factors are calculated for three different time scales: 20, 50 and 100 years (RGWP20, RGWP50, RGWP100).

Assumption for the natural regeneration reference

- Three natural regeneration reference states are modelled
  - RG1=maximum growth
  - RG2=medium growth
  - RG3=minimum growth

- The assumption made from the literature review is, that on a grass land, the natural regeneration (e.g. growth of trees) can be first slow.
  - This is because in the beginning the shadow is slowing down the take off of other plants.

  On the other hand, when the growth begins, it can be fast as the grass lands are rich of nutrients.

- Forest growth data from the MOTTI model (http://www.metla.fi/metinfo/motti/index-en.htm) was used as a starting point, and the growth curves were modified to correspond the indications of the literature review.

Challenges related to soil carbon

- In addition to the vegetation growth, also the accumulation of soil carbon in the natural regeneration scenario should be evaluated. This is challenging due to lack of knowledge of carbon stock development and uncertainties related to the soil carbon accumulation.

    - The soil carbon accumulation could be modelled with models such as YASSO (http://www.syke.fi/projects/yasso) or evaluated based on the IPCC inventory principles on soil carbon.

    - However, the uncertainty due to soil carbon accumulation can be also thought to be included in the overall uncertainty of the natural regeneration reference. (This has been assumed in this study.)

    - In general the agricultural land use decreases the soil carbon stocks whereas forest growth increases them. Therefore it could be possible that consideration of the soil carbon would increase the GHG impacts between the studied land use and the natural regeneration scenario.

Assumption for the natural regeneration reference

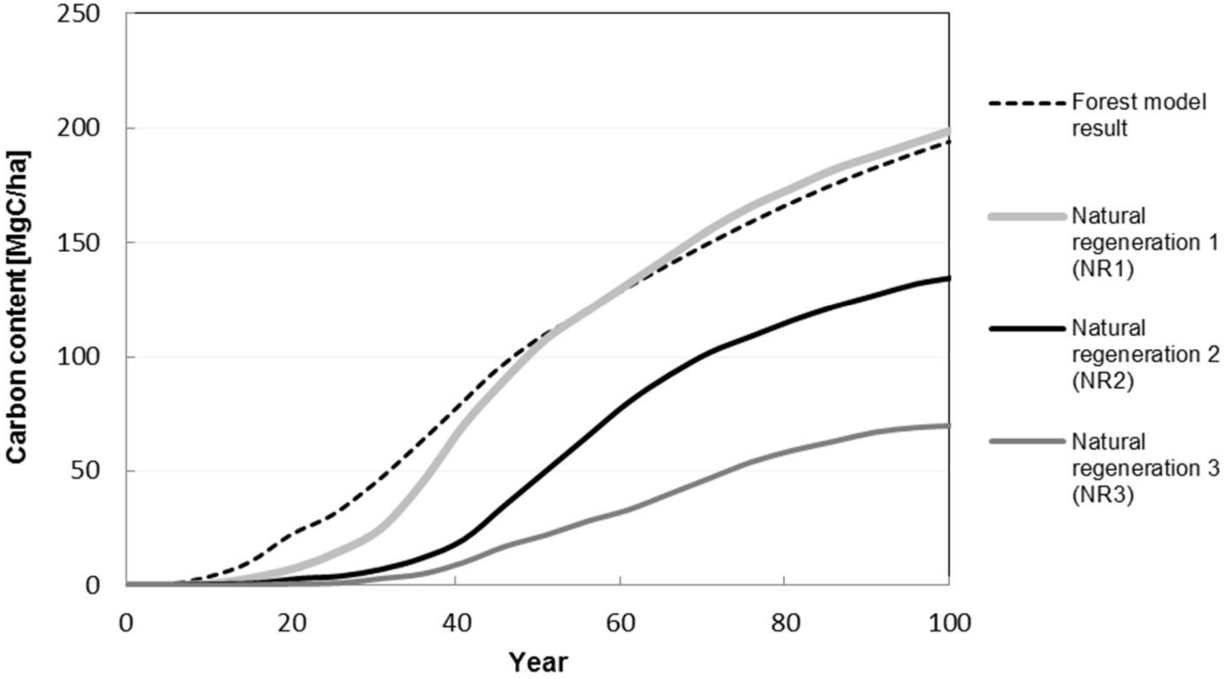


Figure presents the carbon stock accumulation in the three modelled natural regeneration reference scenarios. The scenarios illustrate the uncertainty of the carbon stock development in the state of natural regeneration.

Calculation of RGWP factors

- The RGWP factors were calculated by using the REFUGE 3 model (presented by Pingoud *et al.* (2012)), which calculates the atmospheric concentrations and radiative forcing for CO_2, CH_4, and N_2O.

- The climate impact of a biomass carbon unit pulse (equation 1) is expressed in proportion to the climate impact of the equivalent virtual fossil carbon unit pulse (equation 2), and a relative global warming potential (RGWP) is calculated (equation 3). The method is future orientated, as only the decisions and actions made from now on are relevant in climate change mitigation (Pingoud et al., 2012).

$$AGWP_{bio} = \int_0^T RF\left(S_{bio}(t)\right)dt, \qquad (1)$$

where $S_{bio}(t)$ is the atmospheric CO_2 concentration due to the biomass carbon unit pulse, defined by comparing the agro-bioenergy and baseline scenarios. It presents a net emission due to biomass growth, combustion, and forgone carbon sequestration due to postponed state of natural regeneration

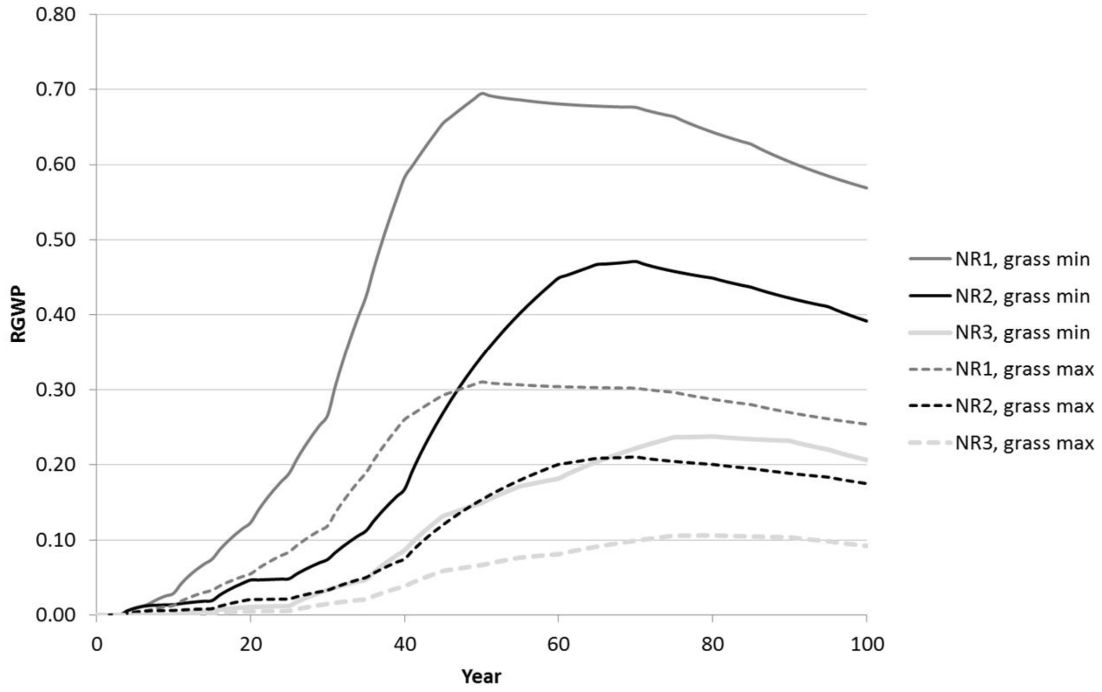
$$AGWP_{fos} = \int_0^T RF\left(S_{fos}(t)\right)dt, \qquad (2)$$

where $S_{fos}(t)$ is the atmospheric CO_2 concentration due to the equivalent virtual fossil carbon unit pulse with no dynamic removal mechanism by growing vegetation. It should be noted that the particular fossil emission is a virtual reference and not an emission of combustion of certain real fossil fuel. It is used to describe the same amount of fossil carbon compared to the biogenic carbon from biomass combustion.

$$RGWP(T) = \frac{AGWP_{bio}(T)}{AGWP_{fos}(T)}. \qquad (3)$$

Results: RGWP factors

- The RGWP factors tell the emission impact of biogenic carbon compared to fossil carbon over the time scale studied.
    - RGWP=1
      → impact similar to fossil
    - 0 < RGWP < 1
      → emissions impact lower than fossil
    - RGWP < 0
      → no emission impact (emission saving)



CO_2 impacts due to lost additional carbon sequestration

- The emission impact is calculated by:

$$Biomass\ CO_2\ impact = \frac{C_{feedstock}}{LHV} \times \frac{44}{12} \times \mathrm{RGWP}$$

where $C_{feedstock}$ is the mass-based carbon content and *LHV* is the lower heating value of the particular biomass feedstock (see slide 31). Factor 44/12 is used to convert C to CO_2.

- The RGWP factors and the CO_2 impacts are presented in the table for each scenario.

Scenario	RGWP 20	RGWP 50	RGWP 100
NR1, grass max	0.05	0.31	0.25
NR2, grass max	0.02	0.15	0.18
NR3, grass max	0.00	0.07	0.09
NR1, grass min	0.12	0.69	0.57
NR2, grass min	0.05	0.34	0.39
NR3, grass min	0.01	0.15	0.21
CO2 impact	**gCO_2/MJ**	**gCO_2/MJ**	**gCO_2/MJ**
NR1, grass max	7	39	32
NR2, grass max	3	19	22
NR3, grass max	1	8	12
NR1, grass min	15	87	71
NR2, grass min	6	43	49
NR3, grass min	1	19	26

Total emissions

- When the CO_2 impacts due to forgone carbon sequestration are added to the life cycle GHG emissions of grass biogas, the total emission impact is found out.

- The results depend significantly on the assumptions of the natural regeneration baseline and the yield of grass.

- The emission impact due to lost additional carbon sequestration can be between 1 and 70% of total emissions depending on the scenario.
  - The emission impact is more important in longer time scales, as the carbon accumulation in the natural regeneration baseline increases over time.

Time scale Total emission	20a gCO_2/MJ	50a gCO_2/MJ	100a gCO_2/MJ
NR1, grass max	43	75	68
NR2, grass max	39	55	58
NR3, grass max	37	44	47
NR1, grass min	51	123	107
NR2, grass min	42	79	85
NR3, grass min	37	55	62

Conclusions

- The emission impact due to lost additional carbon sequestration can be significant, but depends on the assumptions made on the carbon stock development in the natural regeneration reference, and on the yield of grass.
  - The uncertainty of the dynamic baseline for land use is significant, but could be reduced when a specific production chain and land area are studied.

- The natural regeneration baseline should be included to understand the impacts of land occupation, when the consequences of displacing competing land use is not in the focus (no ILUC impacts are included).

- This way the results for purposely grown agro bioenergy requiring land occupation are more comparable with the results for forest bioenergy (where the natural regeneration reference is applied).

- The results propose that the climate impacts of agro-bioenergy might be significantly higher than calculated by only accounting actual net emissions.

References PART 3:

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