

METHODOLOGY FOR IMPROVED FOREST MANAGEMENT IN BOREAL PRODUCTION FORESTS

Document Prepared by Övertorneå kommun

Title	Methodology for improved forest management in boreal production forests
Version	1.0
Date of Issue	6-July-2015
Type	Methodology
Sectoral Scope	14. AFOLU Project category: IFM Project type: LtHP
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Relationship to Approved or Pending Methodologies

Approved and pending methodologies under the VCS and approved GHG programs, which fall under the same sectoral scope and AFOLU project category, were reviewed to determine whether an existing methodology could be reasonably revised to meet the objective of this proposed methodology. Two methodologies were identified, and are set out in Table 1 below.

Table 1: Similar Methodologies

Methodology	Title	GHG Program	Comments
VM0005	Methodology for improved forest management: Conversion of low productive to high productive forest	VCS	This is also an IFM LtHP methodology, but it uses a project method for determining additionality and it is limited to evergreen tropical rainforest.
VM0034	Protocol for the Creation of Forest Carbon Offsets in British Columbia	VCS	This is a very broad methodology which includes ARR, REDD and IFM activities in the Province of British Columbia, Canada. The models and protocols included in methodology VM 0035 are calibrated for forest ecosystems in British Columbia, and do not include the Heureka Forestry Decision Support system for estimating tree carbon stock.

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1 SOURCES

The following have also informed the development of the methodology:

-) VCS Methodology VM 0012
-) CDM Tool for the demonstration and assessment of additionality
-) Good Practice Guidance for Land Use, Land-Use Change and Forestry
-) AFOLU Guidance regarding Calculating of the Long-Term Average Carbon Stock for IFM Projects with Harvesting
-) Sourcebook for Land Use, Land-Use Change and Forestry Projects (Pearson, Walker & Brown, 2005)
-) CDM A/R Methodological Tool, EB 58 Report, Annex 15 (Calculation of the number of sample plots for measurements within A/R CDM Project activities).

This methodology uses the latest versions of the following tools:

-) CDM Tool for the demonstration and assessment of additionality
-) AFOUL Non-Performance Risk Tool
-) Tool for testing significance of GHG emissions in A/R CDM Project activities

2 SUMMARY DESCRIPTION OF THE METHODOLOGY

Additionality and Crediting Method	
Additionality	Activity Method
Crediting Baseline	Project Method

This methodology facilitates the quantification of the net GHG benefits of Improved Forest Management projects that achieve carbon benefits from tree growth increasing forest management activities.

Project activities include fertilizations in young and middle-aged (about 20-70 year old, depending on site fertility index) conifer dominated forest.

The Baseline scenario is forest management according to common practice in conifer dominated forest in Sweden. The methodology uses an activity method (Option B, Financial viability, in the *VCS Standard*) for the demonstration of additionality.

All management activities must be carried out according to the framework of the Swedish Forestry Act in designated production forests.

The Project boundary includes above-ground and below-ground tree biomass carbon pools combined into a tree biomass pool. The tree biomass carbon pool is calculated from sample plot tree measurement data. The first measurement and carbon pool estimation is carried out the same year as the Project activity is performed (= year 0). This is the forest characteristics starting position for both the Baseline and the Project scenario. Total tree biomass carbon stock is estimated during the Project time until the final felling, using the Heureka Forestry Decision Support system, which is maintained by the Swedish University of Agricultural Sciences. Sample plots are re-measured every 5 years, and actual tree biomass carbon stock recalculated. The Project GHG benefit is calculated as the difference between Project and Baseline tree biomass carbon stocks.

As set out in the VCS standard, the crediting period must include the final harvesting and GHG credits will not be issued above the long term average Project GHG benefit.

3 DEFINITIONS

List of acronyms

G18	Site fertility index for Norway spruce
Heureka	Heureka Forestry Decision Support system
PU	Prediction unit
SDC	Swedish Forestry Data Centre ¹
SLU	Swedish University of Agricultural Sciences
TPG	Treatment program generator
T16-T26	Site fertility indexes for Scots pine

Definitions

Broadleaved tree

Any tree which has flat leaves and produces seeds inside of fruits.

¹ <http://www.sdc.se/default.asp?id=1007&ptid=>

Conifer dominated (>50%) forest

A forest stand where more than 50% of the tree basal area consists of conifer species

Final felling

The last harvest during a forest rotation, when all or almost all merchantable wood is harvested

Production forest

A forest where forestry is conducted

Project time

The duration of the project, from the time for project start until the time for final felling

Thinning

A thinning harvest with procurement of merchantable wood assortments

Tree biomass pool

Carbon pool consisting of below- and above-ground tree biomass

4 APPLICABILITY CONDITIONS

This methodology applies to Project activities resulting in increased tree growth and carbon sequestration in conifer production forests. Project activities include fertilizations in young and middle-aged (about 20-70 year old, depending on site fertility index) forest. The Project activities are described in more detail in Appendix C.

This methodology is applicable under the following conditions:

-) Conifer dominated (>50% of tree basal area) production forest in Sweden.
-) Site index T16-T26 and G18
-) Average tree height > 9 meter.
-) 1-3 fertilizations, with the first fertilization carried out no later than the following years before the earliest permitted age for final felling (FF), according to the Forestry Act:

<u>Site index</u>	<u>Years before lowest permitted age for FF</u>
T16	10
T18	10
T20	15
T22	15
T24	20
T26	20
G18	5

-) A statement from the Swedish Forest Agency must be used to show that the Project area is approved for wood product management.
-) Forest management has to be carried out within the framework of the Swedish Forestry Act.
-) Project start date is the date for the first fertilization.
-) Monitoring periods for tree biomass carbon stock calculations have to be 5 years.

Geographic boundary

The Project area is the area or areas of land on which the Project proponent will undertake the Project activities. The Project geographical area is to be defined by the Project proponent with maps and legal land description in the format specified in the latest version of the VCS standard.

Temporal boundaries

Project proponents must specify a Project crediting period as set out in the most recent version of the VCS Standard.

Carbon pools and emission sources

The carbon pools included in or excluded from the Project boundary are shown in Table 1 below. Carbon pools included in the Project boundary are restricted to the above- and below-ground tree biomass. Note that there are no optional pools, and that the included pools (above- and below-ground tree biomass) are combined into a tree biomass pool.

Table 1: Selected carbon pools

Source	Included?	Justification/Explanation
Above-ground tree biomass (included in tree biomass pool)	Yes	Required by VCS. Major carbon pool expected to increase from Baseline to Project scenario.
Above-ground non-tree biomass	No	Excluded by VCS. Minor carbon pool expected not to change from Baseline to Project scenario.
Below-ground tree biomass (included in tree biomass pool)	Yes	Optional by VCS. Minor carbon pool expected to increase from Baseline to Project scenario
Litter	No	Excluded by VCS. Minor carbon pool expected not to change from Baseline to Project scenario.
Dead wood	No	Optional by VCS. Minor carbon pool expected not to changes from Baseline to Project scenario.
Soil	No	Optional by VCS. Minor carbon pool expected not to change from Baseline to Project scenario.
Wood products	No	Optional by VCS. Major carbon pool subject to increase from Baseline to Project scenario, but verifiable information for this carbon pool is difficult to obtain. The methodology does not provide an approach for accounting for this carbon pool.

The carbon pool “Tree biomass” is created by merging the carbon pool of Above-ground tree biomass with the carbon pool of Below-ground tree biomass. The amount of C in the created new carbon pool is calculated as:

$$TBC = AGTBC + BGTBC, \text{ tonnes C} \quad (1)$$

Where

TBC = amount of carbon in the Tree Biomass Carbon pool, tonnes C

AGTBC = amount of carbon in the Above-Ground Tree Biomass Carbon pool, tonnes C

BGTBC = amount of carbon in the Below-Ground Tree Biomass Carbon pool, tonnes C.

The greenhouse gases included in or excluded from the Project boundary are shown in Table 2 below. Project proponents may use the Tool for testing significance of GHG emissions in A/R CDM Project activities to determine if GHG sources included in the Project boundary can be considered *de minimis*.

Table 2: GHG sources included in the Project boundary

Source		Gas	Included?	Justification/Explanation
Baseline	Fertilizer production, transport and application	CO ₂	Yes	Baseline may include fertilization
		CH ₄	Yes	Baseline may include fertilization
		N ₂ O	Yes	Baseline may include fertilization
		Other	None	
	Combustion of fossil fuel in vehicles / machinery	CO ₂	Yes	Baseline activities result in emissions due to usage of machinery and vehicles during the Project period.
		CH ₄	Yes	See above
		N ₂ O	Yes	See above
		Other	None	
Project	Fertilizer production, transport and application	CO ₂	Yes	Project activity includes fertilization
		CH ₄	Yes	See above
		N ₂ O	Yes	See above
		Other	None	
	Combustion of fossil fuel in vehicles / machinery	CO ₂	Yes	Project activities result in emissions due to usage of machinery and vehicles during the Project period.
		CH ₄	Yes	See above
		N ₂ O	Yes	See above
		Other	None	

6 BASELINE SCENARIO

This methodology uses a Project method for establishing the Baseline scenario. The Baseline scenario must consist of common practice reflecting what most likely would have occurred in the absence of the project.

To demonstrate the Baseline scenario for each Project stand, Project proponents must provide the following:

1. Documented evidence of the Project proponent's or the implementing partner's operating history, such as five years of management records, to provide evidence of normal historical practice within all the counties where the Project is to be carried out. Where the Project proponent or the implementing partner is a new owner or management entity and does not have a history of management practices within the Project area, records from the Swedish Forest Agency on management practice in the counties where the Methodology is to be applied can be used as evidence of normal historical practice.
2. Identification of alternative Baseline scenarios in conifer dominated forest stands that fulfill the site index requirements of the Applicability conditions. The alternative

Baseline scenarios must be based on the documented evidence on normal historical practice in point 1 above.

3. Identification of the most plausible of the alternative Baseline scenarios identified in point 2 above. The most plausible Baseline scenario for each Project stand is the management practice performed on the largest area of forest land in the county where the Project stand is located. For this purpose, the Project proponent must for each alternative Baseline scenario calculate the percentage of forest land, within all the counties where Project activities are to be carried out. Only conifer dominated forest stands that fulfill the site index requirements of the Applicability conditions are to be included.
4. Identification of the rotation period length for the Baseline scenario. The Baseline scenario average tree carbon stock during the Project time has to be modeled for alternative lengths of the rotation period, using Heureka simulations. The rotation period, giving the highest average tree carbon stock has to be used for the Baseline scenario model calculations in the Project.
5. A statement from the Swedish Forest Agency to establish that the Baseline scenario, adheres to the legal requirements in the area.
6. Evidence that the Baseline environmental management practice is not set below what's considered a minimum standard among similar landowners in the area. For this purpose, a statement from the Swedish Forest Agency on management practice in the area can be used.

The Baseline scenario for the Project will consist of the most plausible Baseline scenario that adheres to the legal requirements in the area and that is above the minimum standard environmental practice among similar landowners in the area.

In cases where the normal historical practice is below the standard environmental practice among similar landowner in the area, the baseline scenario will consist of the standard environmental practice among similar landowner in the area.

In cases where the normal historical practice and the standard environmental practice among similar landowner in the area do not adhere to the legal requirements, the baseline scenario will consist of the legal requirements in the area.

Project proponents must reassess Baseline as set out in the latest version of the VCS Standard.

7 ADDITIONALITY

This methodology uses an activity method for the demonstration of additionality. Project activities that meet the applicability conditions of this methodology (see section 4) and demonstrate regulatory surplus are deemed as additional.

Step 1: Regulatory Surplus

Project proponents must demonstrate regulatory surplus in accordance with the rules and requirements regarding regulatory surplus set out in the latest version of the *VCS Standard*.

Step 2: Positive List

The applicability conditions of this methodology represent the positive list. The Project must demonstrate that it meets all of the applicability conditions, and in so doing, it is deemed as complying with the positive list.

The positive list was established using the financial viability option (Option B in the *VCS Standard*) as set out in Appendix C.

8 QUANTIFICATION OF GHG EMISSION REDUCTIONS AND REMOVALS

This methodology is using the Heureka Forestry Decision Support system for estimating the total tree carbon stock. Heureka, which is maintained by the Swedish University of Agricultural Science, projects forest growth in five-year discrete time intervals. Therefore, for this methodology, the time index in the equations below is changed from the recommended one year (y) in the VCS Methodology Template, to a time period (t-(t+5)) of 5 years.

8.1 Baseline and Project Emissions

Baseline emissions are calculated as:

$$B_{(t-(t+5))} = B_{FC(t-(t+5))} \quad (2)$$

and Project emissions are calculated as:

$$PE_{(t-(t+5))} = PE_{FC(t-(t+5))} \quad (3)$$

where:

$BE_{(t-(t+5))}$ = Baseline emissions during years (t-(t+5)) (tCO₂e)

$BE_{FC(t-(t+5))}$ (tCO₂e) = Baseline emissions from fossil fuel combustion during years (t-(t+5))

$PE_{(t-(t+5))}$ = Project emissions during years (t-(t+5)) (tCO₂e)

$PE_{FC(t-(t+5))}$ = Project emission from fossil fuel combustion during years (t-(t+5)) (tCO₂e)

t = the start year of the five year period

t+5 = the end year of the five year period

t = year 0, 5, 10, 15...n, where n is the end year of the last 5-year period before the 5-year period, during which the final felling is estimated to be carried out.

8.2 Calculation of Baseline and Project Emissions from Fossil Fuel Combustion

The emissions from fossil fuel combustion for Baseline and Project activity occur from vehicles used during thinning, final felling and timber road transportation. For the Project activity, also the production and application of fertilizer result in emissions. For the Project activity, the actual harvesting volumes during each 5-year period are used for calculation of emissions from fossil fuel combustion. For Baseline, the Heureka simulated harvesting volume outputs are used for calculation of emissions from fossil fuel combustion.

For this purpose, an output option from the Heureka simulations, described in 8.8, showing the harvested tree volume, expressed in m³fub (m³ solid wood under bark) per hectare for timber (Heureka output option TimberVolumeTotal) and pulpwood (Heureka output option PulpVolumeTotal), is used.

Based on this, the total harvested volume of timber and pulpwood for thinning and final felling during each 5 year period of the Project time is calculated as:

$$\text{Bthtimbvol}_{(t-(t+5))} = \text{Bthtimbvol/ha}_{(t-(t+5))} * \text{AREA, m}^3\text{fub} \quad (4)$$

$$\text{Bthpulpvol}_{(t-(t+5))} = \text{Bthpulpvol/ha}_{(t-(t+5))} * \text{AREA, m}^3\text{fub} \quad (5)$$

$$\text{Bfftimbvol}_{(t-(t+5))} = \text{Bfftimbvol/ha}_{(t-(t+5))} * \text{AREA, m}^3\text{fub} \quad (6)$$

$$\text{Bffpulpvol}_{(t-(t+5))} = \text{Bffpulpvol/ha}_{(t-(t+5))} * \text{AREA, m}^3\text{fub} \quad (7)$$

for Baseline, and

$$\text{Pthtimbvol}_{(t-(t+5))} = \text{Pthtimbvol/ha}_{(t-(t+5))} * \text{AREA, m}^3\text{fub} \quad (8)$$

$$\text{Pthpulpvol}_{(t-(t+5))} = \text{Pthpulpvol/ha}_{(t-(t+5))} * \text{AREA, m}^3\text{fub} \quad (9)$$

$$\text{Pfftimbvol}_{(t-(t+5))} = \text{Pfftimbvol/ha}_{(t-(t+5))} * \text{AREA, m}^3\text{fub} \quad (10)$$

$$\text{Pffpulpvol}_{(t-(t+5))} = \text{Pffpulpvol/ha}_{(t-(t+5))} * \text{AREA, m}^3\text{fub} \quad (11)$$

for Project activity,

where:

$\text{Bthtimbvol/ha}_{(t-(t+5))}$ and $\text{Bthpulpvol/ha}_{(t-(t+5))}$ are the Heureka output harvested timber and pulpwood volumes/ha for Baseline after thinning and $\text{Bfftimbvol/ha}_{(t-(t+5))}$ and $\text{Bffpulpvol/ha}_{(t-(t+5))}$ are the corresponding volumes/ha after final felling.

$\text{Pthtimbvol/ha}_{(t-(t+5))}$, $\text{Pthpulpvol/ha}_{(t-(t+5))}$, $\text{Pfftimbvol/ha}_{(t-(t+5))}$ and $\text{Pffpulpvol/ha}_{(t-(t+5))}$ are the actually harvested volumes/ha after thinning and final felling for the Project activity.

t = year 0, 5, 10...n, where n is the end year of the 5-year period before the 5-year period, during which the final felling is carried out.

AREA is the Project area in hectare

The emissions from fuel combustion related to the management operations are calculated for each 5 year period as:

$$BE_{FC(t-(t+5))} = BE_{th(t-(t+5))} + BE_{ff(t-(t+5))} + BE_{trpt(t-(t+5))} \quad (tCO_2e) \quad (12)$$

$$PE_{FC(t-(t+5))} = PE_{th(t-(t+5))} + PE_{ff(t-(t+5))} + PE_{trpt(t-(t+5))} + PE_{fz(t-(t+5))} \quad (tCO_2e) \quad (13)$$

Where

$BE_{th(t-(t+5))}$ = Baseline emissions during thinning operations (tCO₂e)

$BE_{ff(t-(t+5))}$ = Baseline emissions during final felling operations (tCO₂e)

$BE_{trpt(t-(t+5))}$ = Baseline emissions from road transport of harvested timber and pulpwood(tCO₂e)

$PE_{th(t-(t+5))}$ = Project emissions during thinning operations (tCO₂e)

$PE_{ff(t-(t+5))}$ = Project emissions during final felling operations (tCO₂e)

$PE_{trpt(t-(t+5))}$ = Project emissions from road transport of harvested timber and pulpwood (tCO₂e)

$PE_{fz(t-(t+5))}$ = Project emissions from fertilizer production and application (tCO₂e)

The emissions caused by management operations during each 5 year period after project start (year t =0) are calculated as:

$$BE_{th(t-(t+5))} = (B_{thtimbvol(t-(t+5))} + B_{thpulpvol(t-(t+5))}) * 2.59 * 0.002213267 \quad (tCO_2e) \quad (14)$$

$$BE_{ff(t-(t+5))} = (B_{fftimbvol(t-(t+5))} + B_{ffpulpvol(t-(t+5))}) * 1.55 * 0.002213267 \quad (tCO_2e) \quad (15)$$

$$BE_{trpt(t-(t+5))} = (B_{thtimbvol(t-(t+5))} + B_{fftimbvol(t-(t+5))}) * 0.022 * Dist_{timb} * 0.002213267 + \\ (B_{thpulpvol(t-(t+5))} + B_{ffpulpvol(t-(t+5))}) * 0.022 * Dist_{pulp} * 0.002213267 \quad (tCO_2e) \quad (16)$$

$$PE_{th(t-(t+5))} = (P_{thtimbvol(t-(t+5))} + P_{thpulpvol(t-(t+5))}) * 2.59 * 0.002213267 \quad (tCO_2e) \quad (17)$$

$$PE_{ff(t-(t+5))} = (P_{fftimbvol(t-(t+5))} + P_{ffpulpvol(t-(t+5))}) * 1.55 * 0.002213267 \quad (tCO_2e) \quad (18)$$

$$PE_{trpt(t-(t+5))} = (P_{thtimbvol(t-(t+5))} + P_{fftimbvol(t-(t+5))}) * 0.022 * Dist_{timb} * 0.002213267 + \\ (P_{thpulpvol(t-(t+5))} + P_{ffpulpvol(t-(t+5))}) * 0.022 * Dist_{pulp} * 0.002213267 \quad (tCO_2e) \quad (19)$$

$$PE_{fz(t-(t+5))} = AREA * Apprate * 0.472 / 150 \quad (tCO_2e) \quad (20)$$

where

t= year 0, 5, 10, 15...n, where n is the end year of the last 5-year period before the 5-year period, during which the final felling is estimated to be carried out.

2.59 = fuel consumption for thinning tree harvesting and terrain transport², liter/ m³sub.

² <http://www.skogforsk.se/kunskap/kunskapsbanken/2013/Bransleforbrukningen-hos-skogsmaskiner-201211/>

1.55 = fuel consumption for final felling tree harvesting and terrain transport¹, liter/ m³fub.

0.002213267= emissions of CO₂, CH₄ and N₂O from diesel fuel combustion³, tCO₂e/liter diesel.

0.022 = Fuel consumption per km road transport distance⁴, l/m³fub.

Disttimb = One way distance for road transport of harvested timber, km.

Distpulp = One way distance for road transport of harvested pulpwood, km.

0,472 = GHG emissions from fertilizer production, transport and application (application rate 150 kg N/ha), tCO₂e/ha⁵.

Apprate = Fertilizer application rate, kg N/hectare.

8.3 Leakage

According to the AFOLU requirements, there are three types of leakage:

- 1) Market leakage occurs when Projects significantly reduce the production of a commodity causing a change in the supply and market demand equilibrium that results in a shift of production elsewhere to make up for the lost supply.
- 2) Activity-shifting leakage occurs when the actual agent of deforestation and/or forest or wetland degradation moves to an area outside of the Project boundary and continues its deforestation or degradation activities elsewhere.
- 3) Ecological leakage occurs in WRC Projects where a Project activity causes changes in GHG emissions or fluxes of GHG emissions from ecosystems that are hydrologically connected to the Project area.

Leakage in IFM Projects is predominately attributable to market leakage. However, under the applicable conditions of this methodology, the Project activities do not result in decreased harvest amounts. The Project activities increase the production of raw materials and hence there is no loss in supply and no shift of production elsewhere.

³ Swedish Nature Protection Agency

⁴ <http://www.skogforsk.se/contentassets/e9e9b5945de643aea2cbf4cb19e7fe81/arbetsrapport-624-2006.pdf>

⁵ Frank Brentrup, Yara Research Centre Hanninghof.
Eriksson, E et al: Integrated carbon analysis of forest management practices and wood substitution. Can.J For. Res. 37 (2007).
Mats Olsson, SLU: Personal communication.
Loviken, G: Föryngring och gödsling av skogsmark ur ett livscykkelanalytiskt perspektiv. SLU, Umeå 1994

According to the AFOLU requirements the market leakage discount factor can therefore be set to 0%.

This methodology is not applicable to Project activities stopping deforestation and/or forest or wetland degradation.

8.4 Net GHG Emission Reduction and Removals

Net GHG emission reductions and removals are calculated as follows:

$$E_{(t-(t+5))} = B_{(t-(t+5))} - P_{(t-(t+5))} + PR_{(t-(t+5))} - BR_{(t-(t+5))} \quad (21)$$

Where:

$ER_{(t-(t+5))}$ = Net GHG emissions reductions and removals in years (t-(t+5)) (tCO₂e)

$BE_{(t-(t+5))}$ = Baseline emissions in years (t-(t+5)) (tCO₂e)

$PE_{(t-(t+5))}$ = Project emissions in years (t-(t+5)) (tCO₂e)

$BR_{(t-(t+5))}$ = Baseline removals in years (t-(t+5)) (tCO₂e)

$PR_{(t-(t+5))}$ = Project removals in years (t-(t+5)) (tCO₂e)

8.5 Baseline and Project Activity Removal Calculation

Baseline and Project activity removals during years (t-(t+5)) are calculated as:

$$BR_{(t-(t+5))} = TBC_{BR(t-(t+5))} * 44/12 \text{ (tCO}_2\text{e)} \quad (22)$$

and

$$PR_{(t-(t+5))} = TBC_{PR(t-(t+5))} * 44/12 \text{ (tCO}_2\text{e)}, \text{ respectively} \quad (23)$$

Where:

$BR_{(t-(t+5))}$ = Baseline removal during years (t-(t+5)) (tCO₂e)

$PR_{(t-(t+5))}$ = Project removal during years (t-(t+5)) (tCO₂e)

$TBC_{BR(t-(t+5))}$ = Baseline tree biomass carbon stock change during years (t-(t+5)), tonnes C

$TBC_{PR(t-t+5)}$ = Project tree biomass carbon stock change during years (t-(t+5)), tonnes C

44/12 = Factor for conversion of amount of C to amount of CO₂.

8.6 Tree Biomass Carbon Stock Change Calculation

Baseline and Project activity removal are calculated with the Stock-difference method, described in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories Volume 4, Agriculture, Forestry and Other Land Use, using the following proposed equation type:

$$C_{av(t-t+5)} = (C_{(t+5)} - C_t) / ((t+5) - t); \quad (24)$$

Where:

$C_{av(t-t+5)}$ = average annual change in carbon stock (removal) during time (t-(t+5)), tonnes C y⁻¹

C_t = carbon stock at year t, tonnes C

$C_{(t+5)}$ = carbon stock at year t+5, tonnes C

t = the start year of the time period

t+5 = the end year of the time period.

The total removal, expressed as tree carbon stock change, is achieved if equation (24) is changed to:

$$C_{(t-t+5)} = (C_{(t+5)} - C_t), \text{ tonnes C} \quad (25)$$

Where:

$C_{(t-t+5)}$ = total carbon stock change between years t and t+5, tonnes C.

In accordance with this, the total Tree Biomass carbon stock change (removal) for Baseline and Project activity between years t and t+5 is calculated as:

$$TBC_{BR(t-t+5)} = (TBC_{BR(t+5)} - TBC_{BRt}), \text{ tonnes C} \quad (26)$$

$$TBC_{PR(t-t+5)} = (TBC_{PR(t+5)} - TBC_{PRt}), \text{ tonnes C} \quad (27)$$

and consequently, the GHG removal benefit for Project activity during years t-(t+5) is calculated as:

$$TBC_{PRbenefit(t-t+5)} = TBC_{PR(t-t+5)} - TBC_{BR(t-t+5)}, \text{ tonnes C} \quad (28)$$

Where for (26), (27) and (28):

$TBC_{BR(t-t+5)}$ = Tree Biomass carbon stock change during years t to t+5 for Baseline, tonnes C

$TBC_{PR(t-(t+5))}$ = Tree Biomass carbon stock change during years t to (t+5) for Project activity, tonnes C

TBC_{BRt} = Tree Biomass carbon stock at year t for Baseline, tonnes C

$TBC_{BR(t+5)}$ = Tree Biomass carbon stock at year t+5 for Baseline, tonnes C

TBC_{PRt} = Tree Biomass carbon stock at year t for Project activity, tonnes C

$TBC_{PR(t+5)}$ = Tree Biomass carbon stock at year t+5 for Project activity, tonnes C

$TBC_{PRbenefit;(t-(t+5))}$ = Difference in tree biomass carbon stock change between Project and Baseline during years t to (t+5), tonnes C.

8.7 Estimation of Tree Biomass Carbon Stock

The carbon stock of the Tree Biomass carbon pool is estimated, using the following built-in functions in the Heureka system (http://heurekaslu.org/wiki/Biomass_functions) and for the following tree biomass fractions:

-) stem above stump
-) bark
-) branches, leaves/needle
-) stump, including roots (stump height is defined as 1% of the tree height).

The biomass content of trees (dry matter ton/ha) is estimated according to Petersson (1999) and Repola (2008) (for leave biomass of broadleaved trees), and stump, including below-ground root biomass with diameter > 2 mm, according to Petersson & Ståhl (2006). Since Petersson (1999) is not a peer-reviewed publication, the functions are presented in Appendix E. The same biomass functions as for birch are used for other broadleaved trees. In these cases, the calculated biomass weight is adjusted for the wood density of each species, in relation to the wood density for birch. The carbon content of the tree biomass dry matter is set to 50% (West 2009).

The biomass estimation allometric functions are of the following type:

$$\ln(Y_{\text{fraction}}) = 0 + 1 \cdot x_1 + 2 \cdot x_2 + 3 \cdot x_3 + \dots + n \cdot x_n + \ln(\epsilon), \quad (29)$$

where

$\ln(Y_{\text{fraction}})$ = tree fraction biomass dry weight

fraction = tree biomass fraction

0 - n = function parameters

x_1 - x_n = variables

$\ln(\epsilon)$ = a random variable with expected value 0.

8.8 Tree Biomass Carbon Stock Estimation during the Project Time with Heureka

Tree carbon stock per hectare for Baseline and Project at Project start ($TBC_{BRt\ ha}$ and $TBC_{PRt\ ha}$, respectively, for year $t=0$; $TBC_{BRt\ ha} = TBC_{PRt\ ha}$) is calculated by Heureka, using input data from site and sample plot tree measurements and biomass functions for calculation of Tree Biomass and carbon stock per hectare. These measurements have to be carried out within a time frame of 60 days before and 60 days after the Project start.

The subsequent tree growth is then simulated using the Heureka system, with growth models coupled with a management program including 1-3 thinnings and a final harvest at the Project end. The thinning schedules presented by the Swedish Forest Agency⁶ are applied. The applied thinning grade in % of the tree basal area and the stand age at final felling at Project end, have to be in accordance with the common practice Baseline scenario, identified according to Section 6. For the Project activity, a certain fertilization policy growth model in Heureka is used, in which time for fertilizations and amount of fertilizer are optional. The fertilization effect is calculated according to Petterson (1994) (also recited in Elfving, 2009, p.78)⁷ and is expressed as tree volume growth increase, and is allocated to the trees by assuming that the height growth to diameter growth ratio is not affected by the fertilization effect. The simulation model creates a biomass carbon stock output for calculation of the estimated tree carbon stock per hectare for Baseline ($TBC_{BR(t+5)\ est\ ha}$) and Project ($TBC_{PR(t+5)\ est\ ha}$) every 5 years after Project start until the final felling, on which the calculation of the expected long time average Project GHG benefit (LA) is based. The Heureka system and examples of management programs are described more in detail in Appendix B and C.

8.9 Heureka Output of Tree Carbon Stock

For the purpose of this methodology, the Heureka output variables Carbon AboveGround (CAG) and Carbon_StumpAndRoots (CSAR), expressed as ton C/ha, are used. The variable CAG includes the biomass carbon in all parts of the tree, except for the stump and roots. The variable CSAR includes the biomass carbon in the stump and all roots down to a diameter of 2 mm. The variable Tree Biomass Carbon (TBC) is then calculated as:

$$TBC = CAG + CSAR, \text{ tons C/ha.} \quad (30)$$

The calculated total tree carbon stock at Project start (year $t=0$) is calculated as:

$$TBC_{BRt} = TBC_{BRt\ ha} * AREA, \text{ tons C} \quad (31)$$

⁶ Swedish Forest Agency 1985. (In Swedish) Thinning schedules for northern Sweden 8p, and Thinning schedules for southern Sweden. 8p

⁷[http://heurekaslu.org/mw/images/9/93/Heureka_prognossystem_\(Elfving_rapportutkast\).pdf](http://heurekaslu.org/mw/images/9/93/Heureka_prognossystem_(Elfving_rapportutkast).pdf)

$$TBC_{PRt} = TBC_{PRt\ ha} * AREA, \text{ tons C} \quad (32)$$

Where

TBC_{BRt} = Calculated tree carbon stock for Baseline at year 0, tonnes C

TBC_{PRt} = Calculated tree carbon stock for Project at year 0, tonnes C

$TBC_{BRt\ ha}$ = Calculated tree carbon stock for Baseline at year 0, tonnes C/ hectare

$TBC_{PRt\ ha}$ = Calculated tree carbon stock for Project at year 0, tonnes C/ hectare

AREA= Project area, hectare.

The estimated total tree carbon stock at year t+5 is for each value of t calculated as:

$$TBC_{BR(t+5)\ est} = TBC_{BR(t+5)\ est\ ha} * AREA, \text{ tons C} \quad (33)$$

$$TBC_{PR(t+5)\ est} = TBC_{PR(t+5)\ est\ ha} * AREA, \text{ tons C} \quad (34)$$

and expressed in terms of GHG removal as:

$$BRem_{(t+5)} = TBC_{BR(t+5)\ est} * 44/12 \text{ (tCO}_2\text{e)} \quad (35)$$

$$PRem_{(t+5)} = TBC_{PR(t+5)\ est} * 44/12 \text{ (tCO}_2\text{e)} \quad (36)$$

and

The long-term average net change in carbon stock LC is calculated as:

$$LC = \sum_{t=0}^n (PRem_{(t+5)} - BRem_{(t+5)}) / \text{nobs (tCO}_2\text{e)} \quad (37)$$

Where

LC = Long-term average net change in carbon stock (tCO₂e)

$BRem_{(t+5)}$ = Carbon stock in the Baseline scenario at year t+5 (tCO₂e).

$PRem_{(t+5)}$ = Carbon stock in the Project scenario at year t+5 (tCO₂e).

nobs = the number of points of time for which the summarized change in carbon stock is calculated.

The number of buffer credits to be withheld, when GHG credits are issued is based on the net change in carbon stock, according to 4.7.1 in the AFOLU Requirements.

8.10 Calculation of Long-Term Average GHG Benefit

According to VCS AFOLU Requirements, the expected long-term average GHG benefit (LA) of the Project has to be calculated for the planned Project time.

For this methodology, the following equation and variables are used for calculation of LA:

$$LA = \sum_{t=0}^n ((BE_{(t+5)} - PE_{(t+5)}) + (PRem_{(t+5)} - BRem_{(t+5)})) / nobs \text{ (tCO}_2\text{e)} \quad (38)$$

Where:

LA = Expected long-term average GHG benefit (tCO₂e).

BE_(t+5) = To date GHG emissions generated in the Baseline scenario at year (t+5) (tCO₂e).

BE_(t+5) is calculated and expressed in section 8.1 as BE_{(t-(t+5))}, which is the cumulative emissions during the time period t-(t+5).

PE_(t+5) = To date GHG emissions generated in the Project scenario at year (t+5) (tCO₂e).

PE_(t+5) is calculated and expressed in section 8.1 as PE_{(t-(t+5))}, which is the cumulative emissions during the time period t-(t+5).

BRem_(t+5) = GHG removal (=carbon stock) in the Baseline scenario at year t+5 (tCO₂e).

(Calculated in equation (35)).

PRem_(t+5) = GHG removal (=carbon stock) in the Project scenario at year t+5 (tCO₂e).

(Calculated in equation (36)).

nobs = the number of points of time for which the summarized GHG benefit is calculated.

The long-term average GHG benefit is the maximum number of credits that the Project can issue.

8.11 Verification and Recalculation of Project Tree Carbon Stock and LA

The 5 year interval tree carbon stock estimated by Heureka for the Project activity (TBC_{PR(t+5)}_{est} in equation (34), has to be verified after 5 or 10 years through a recalculation, based on data from a repeated sample plot tree measurement. The deviation between the previously estimated and the calculated tree carbon stock is used for correction of the Heureka estimated tree carbon stock during the remaining Project time, as described in 8.13. A renewed calculation of LA according to equation (38) is also required, based on the corrected tree carbon stock values. The Baseline tree carbon stock values used for calculation of LA are always the Heureka estimated tree carbon stock (TBC_{BR(t+5)}_{est} in equation (33)).

8.12 Reporting results

In the above calculations, emission reductions and carbon stock increases (removal) are expressed with + sign, whereas emission increases and carbon stock decreases are expressed with – sign, in accordance with Chapter 5 of the IPCC 2006 Guidelines.

However, emission reductions and carbon stock increases (removal) have to be expressed with – sign and emission increases and carbon stock reductions have to be expressed with + sign, when results are reported, according to 3.1.7 of the IPCC 2003 Good Practice Guidance for Land Use, Land Use Change and Forestry.

8.13 Uncertainty Handling

The estimation of tree carbon stock changes as base for Project GHG benefit calculation may be associated with uncertainties or errors of different kind:

- a. Measurement and data handling errors
- b. Sampling errors
- c. Growth prediction model errors
- d. Confidence deduction
- e. Rotation period length

It is of utmost importance that necessary measures according to the guidelines below are taken by the Project proponent, in order to keep these possible uncertainties and errors at a reasonable low level, when carrying out the different Project activities:

- a. All measurements and data handling routines have to be carried out according to the guidelines in chapter 9.3.4. Only measurement device with an accuracy not less than what is used by The Swedish National Forest Inventory, is approved for this Methodology.
- b. Sampling errors are errors in estimation of total tree biomass carbon stock, depending on that tree measurements are only carried out on a limited number of sample plots. In this methodology, however, it is not possible to achieve carbon stock estimates at the sample plot level, as an output from the Heureka system, for carrying out calculations of the sampling errors. However, the same original sample plot tree measurement data at Project start are used for tree biomass carbon stock predictions for both Baseline and Project, which means that the sampling error will not influence the carbon stock difference (GHG benefit) between Project and Baseline. Furthermore, only permanent sample plots are used to, as far as possible, avoid sampling errors between measurements from different points of time.

As an indirect tool to reduce the sampling error, means for estimation of appropriate number of sample plots at Project start for a desired confidence interval for the mean tree basal area are presented in 9.3.5.1.

- c. The Heureka growth model is by default run in a deterministic mode. Of course, tree growth and tree mortality is a highly stochastic process. Elfving (2009) concludes that the variation coefficient in predicted growth with Heureka can be expected to be about 20 % (see Appendix D). In Fahlvik et al. (2014) it was also shown that the

prediction errors did not increase with the time horizon length used in the growth predictions. To correct for the above described and expected errors, a correction factor for the Heureka estimated Project tree carbon stock has to be calculated at each verification occasion. This correction factor is calculated as:

$$\text{CORR TBC}_{\text{PR}(t+5)} = \text{TBC}_{\text{PR}(t+5) \text{ calc}} / \text{TBC}_{\text{PR}(t+5) \text{ est}} \quad (39)$$

Where:

$\text{CORR TBC}_{\text{PR}(t+5)}$ = the Project tree carbon stock correction factor for verification year t+5.

$\text{TBC}_{\text{PR}(t+5) \text{ est}}$ = the Heureka estimated Project tree carbon stock at year t+5, tonnes C

$\text{TBC}_{\text{PR}(t+5) \text{ calc}}$ = the Heureka calculated Project tree carbon stock at year t+5, based on tree measurement data from the same year, tonnes C.

The correction factor is then used for recalculation of the Heureka estimated Project tree carbon stock for the remaining Project period as:

$$\text{TBC}_{\text{PR}(t+5) \text{ est corr}} = \text{TBC}_{\text{PR}(t+5) \text{ est}} \times \text{CORR TBC}_{\text{PR}(t+5)} \quad (40)$$

t = year 0, 5, 10, 15...n, where n is the end year of the 5-year period before the 5-year period, during which the final felling is estimated to be carried out.

Where

$\text{TBC}_{\text{PR}(t+5) \text{ est corr}}$ = the corrected Project carbon stock at year t+5, tonnes C

$\text{TBC}_{\text{PR}(t+5) \text{ est}}$ = see above

$\text{CORR TBC}_{\text{PR}(t+5)}$ = see above

The corrected carbon stock values for the Project activity, according to equation (40), are then used for a renewed calculation of the Long time average Project GHG benefit in accordance with equation (38), and the number of credits available for issue.

It is not possible to apply a similar correction for the Heureka estimated Baseline carbon stock, since there are no unfertilized sample plots available for repeated tree measurements.

- d. According to VCS Standard 2.4.1, accuracy should be pursued as far as possible, but the hypothetical nature of baselines, the high cost of monitoring of some types of GHG emissions and removals, and other limitations make accuracy difficult to attain in many cases. In these cases, conservative assumptions, values and procedures should be applied to ensure that net GHG emission reductions or removals are not overestimated. Such an overestimation of the net GHG emission reduction or removal will occur in this methodology, if the Heureka estimated Baseline carbon stock is underestimated.

The Heureka prediction error for tree biomass carbon stock for a certain point of time is similar as the above mentioned Heureka prediction error for tree growth. It may also be assumed that the Heureka predicted tree biomass carbon stock values are normally distributed around the true value, and that the standard deviation from the true value (m) therefore is $0.2 \cdot m$ (variation coefficient = 20%). According to the normal distribution, 90% of the predictions lie within an interval of $m \pm 1.2816 \cdot 0.2 \cdot m$, i.e., within an interval of $\pm 25.6\%$ of the true value for the Heureka predicted tree biomass carbon stock. This means that the probability of not to underestimate the Baseline tree biomass carbon stock with Heureka with more than 25.6% of the estimated value, is 95%. Since this confidence interval exceeds $\pm 15\%$, a confidence deduction of the overall emission reduction and net GHG removal has to be carried out with a factor of 0,943 according to the requirements in the CDM Meth Panel Thirty Second Meeting Report, Annex 14.

- e. Onsite carbon stock is influenced by the rotation period length. To ensure that this uncertainty is taken into consideration in a conservative way, the Project proponent has to calculate and use the rotation period that gives the highest average tree carbon stock for the Baseline scenario model calculations in the Project, according to Section 6, point 4.

9 MONITORING

The purpose of the monitoring program is to reliably monitor changes in carbon stocks in a cost-effective way and to compare the measured carbon stocks against modelled carbon stocks for the Project scenario. Based on this, prior to each verification, an uncertainty factor is calculated and used for correction of the modelled tree carbon values related to the calculation of VCU's. A Project monitoring report on the results of implementation of the monitoring plan has to be produced for each monitoring period prior to verification.

9.1 Data and Parameters Available at Validation

Data / Parameter	GPS coordinates
Data unit	-
Description	Project forest stand GPS coordinates, expressed according to the Swedish systems SWEREF99TM or RT90
Equations	Geographical location input variable to the Heureka model
Source of data	Normally available from forest stand characteristics data bases. Otherwise registered in the field.
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	GPS coordinates are the most commonly used variables for identifying the geographical location of forest stands. The GPS coordinates are registered in the field at the center of the Project forest stand, using a GPS signal receiving device and expressed according to either SWEREF99TM or RT90.
Purpose of Data	Calculation of Baseline and Project emission and removal
Comments	

Data / Parameter	Site index H100
Data unit	M
Description	Average height of the 100 tallest trees at the age of 100 years for Scots pine and Norway spruce. A measure of site fertility.
Equations	Input site characteristics variable to the Heureka model
Source of data	Normally available from forest stand characteristics data
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	The H100 site fertility index system is applied as standard in forestry. The site fertility index is specific for Scots pine, spruce. Almost all production forest sites are fertility classified according to this standard. If site index is missing, it has to be determined according to methods described in the last version of the Field Instruction Manual for The Swedish National Forest Inventory, Swedish University of Agricultural Sciences
Purpose of Data	Determination of Baseline and Project emission and removal
Comments	

Data / Parameter:	Soil moisture class
Data unit	N/A
Description	Input site characteristics variable to the Heureka model
Equations	
Source of data	Normally available from forest stand characteristics data
Value applied	N/A
Justification of choice of data or description of measurement methods and	The soil moisture class is an input variable to the Heureka system. If soil moisture class is missing for the Project stand, it has to be determined according to methods described in the last version of the Field Instruction Manual for The Swedish National Forest Inventory, Swedish University of Agricultural Sciences
Purpose of Data	Determination of Baseline and Project emission and removal
Comments	Soil moisture classes are described in Appendix F

Data / Parameter:	Vegetation type class
Data unit	N/A
Description	Input site characteristics variable to the Heureka model
Equations	
Source of data	Normally available from forest stand characteristics data bases.
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	The vegetation type class is an input variable to the Heureka system. If the vegetation type class is missing for the Project stand, it has to be determined according to methods described in the last version of the Field Instruction Manual for The Swedish National Forest Inventory, Swedish University of Agricultural Sciences
Purpose of Data	Determination of Baseline and Project emission and removal
Comments	Vegetation type classes are described in Appendix F

9.2 Data and Parameters Monitored

Data / Parameter:	Apprate
Data unit:	kg N/hectare
Description:	Applied amount of fertilizer N at each fertilization
Equations	20, and 1 and 2 in Appendix A
Source of data:	Delivered amount of fertilizer N to the Project area minus remaining amount after fertilization, divided by the variable AREA
Description of measurement methods and procedures to be applied:	Manual counting of delivered fertilizer sacks to the Project stand and emptied and remaining filled sacks after fertilization. GPS tracking of application vehicle movement during fertilizer application.
Frequency of monitoring/ recording:	At each fertilization event
QA/QC procedures to be applied:	Control of fertilized Project AREA from GPS tracking records of vehicle movement. Repeated counting of emptied and remaining filled fertilizer sacks after fertilization,
Purpose of data	Determination of Project and Baseline emission and removal
Calculation method:	<p>$Apprate = (Delfz - Remfz) / Area$, where</p> <p>Delfz= delivered amount of fertilizer to the forest stand, kg N and</p> <p>Remfz= remaining amount of fertilizer after fertilization, kg N and</p> <p>Area = Area of the Project activity forest stand, ha</p>
Comments	

Data / Parameter:	Area
Data unit:	hectare
Description:	Area of the Project activity forest stand
Equations	4-11, 20, 31-34
Source of data:	Digitalized Project activity area boundaries
Description of measurement methods and procedures to be applied:	GPS coordinates and/or remote sensing and/or inventory records using appropriate digital area estimation software. Determined with an accuracy of +- 10 m
Frequency of monitoring/ recording:	At Project start after that the Project activity is carried out. Re-measured if Project area become changed
QA/QC procedures to be applied:	Control of fertilized Project AREA from GPS tracking records of fertilization vehicle at Project start.
Purpose of data	Determination of Baseline and Project emission and removal
Calculation method:	N/A
Comments	

Data / Parameter	Db
Data unit:	cm
Description:	Tree diameter on bark at 1,3 m height above ground
Equations	
Source of data:	Sample plot tree monitoring
Description of measurement methods and procedures to be applied:	Measured with an electronic caliper in, with simultaneous computer recording. The measurement point on the stem, where the caliper ruler has to be positioned at measurement, has to be permanently marked with, e.g., water resistant paint.
Frequency of monitoring/recording	Measured at Project start and then at 5 or 10 year interval
QA/QC procedures to be applied	The caliper has to be calibrated each day before measurements. After each work day, control of that no Db values are missing or having erroneous values (< 4 cm or > 60 cm), has to be carried out. Re-measured on 10% randomly selected sample plots at each measurement occasion.
Purpose of data	Determination of Baseline and Project emission and removal
Calculation method	
Comments	

Parameter:	Tree species
Data unit:	Pine, Spruce, Birch, Other broadleaved species
Description:	Species is recorded for each diameter measured tree
Equations	Used in biomass estimation functions and growth functions
Source of data:	Sample plot monitoring tree data.
Description of measurement methods and procedures to be applied:	Ocular determination of the specie of each measured tree
Frequency of monitoring/record	Recorded at Project start and then at 5 or 10 year interval
QA/QC procedures to be applied:	Tree species check at each measurement occasion on the same 10% randomly selected sample plots as for Db.
Purpose of data:	Determination of Baseline and Project emission and removal
Calculation method	N/A
Comments	

Data / Parameter:	Tree height
Data unit:	m
Description:	Tree height above ground
Equations	
Source of data:	Sample plot tree monitoring
Description of measurement methods and procedures to be applied:	Measured with an electronic height measurement device in m, with an average accuracy of +/- 0,1 m.
Frequency of monitoring/recording:	Measured at Project start and at 5 or 10 year interval
QA/QC procedures to be applied:	Daily calibration of device. After each work day, control of that no Tree height values are missing or having erroneous values (< 1,3 m or > 40 m), has to be carried out. Re-measured at each measurement occasion on the same 10% randomly selected sample plots as for Db.
Purpose of data:	Determination of Baseline and Project emission and removal
Calculation method	N/A
Comments	

Parameter:	Disttimb
Data unit:	km
Description:	Distance from Project area to sawmill
Equations	Equations 16 and 19
Source of data:	SDC services option "Transportation accounting"
Description of measurement methods and procedures to be applied:	According to SDC routines for measurements, calculation and presentation in the "Transportation accounting" services .
Frequency of monitoring/record	Calculated for each 5 year period during the Project time.
QA/QC procedures to be applied:	According to SDC routines for QA/QC.
Purpose of data:	Determination of Baseline and Project emission
Calculation method	N/A
Comments	

Parameter:	Distpulp
Data unit:	Km
Description:	Distance from Project area to pulp mill
Equations	Equations 16 and 19
Source of data:	SDC services option "Transportation accounting"
Description of measurement methods and procedures to be applied:	According to SDC routines for measurements, calculation and presentation in the "Transportation accounting" services.
Frequency of monitoring/record	Calculated for each 5 year period during the Project time.
QA/QC procedures to be applied:	According to SDC routines for QA/QC.
Purpose of data:	Determination of Baseline and Project emission
Calculation method	N/A
Comments	

Data / Parameter:	Bthtimbvol/ha(t-(t+5))
Data unit:	m ³ f u b/hectare (m ³ solid wood under bark per hectare)
Description:	Harvested timber volume/ha from thinning for Baseline during years t-(t+5)
Equations	4
Source of data:	Harvested timber volume output from Heureka simulation of stand development and thinning harvests during the Project time for Baseline
Description of measurement methods and procedures to be applied:	Heureka output option TimberVolumeTotal, is used for achieving output of harvested timber volume/ha.
Frequency of monitoring/record	Calculated for each 5 year period during the Project time.
QA/QC procedures to be applied:	
Purpose of data:	Determination of Baseline emissions
Calculation method	N/A
Comments	

Data / Parameter:	Bthpulpvol/ha(t-(t+5))
Data unit:	m ³ f u b/hectare (m ³ solid wood under bark per hectare)
Description:	Harvested pulpwood volume from thinning for Baseline during years t-(t+5)
Equations	5
Source of data:	Harvested pulpwood volume output from Heureka simulation of stand development and thinning harvests during the Project time for Baseline
Description of measurement methods and procedures to be applied:	Heureka output option PulpVolumeTotal, is used for achieving output of harvested thinning pulpwood volume/ha.
Frequency of monitoring/record	Calculated for each 5 year period during the Project time.
QA/QC procedures to be applied:	
Purpose of data:	Determination of Baseline emissions
Calculation method	N/A
Comments	

Data / Parameter:	Bfftimbvol/ha(t-(t+5))
Data unit:	m ³ f u b/hectare (m ³ solid wood under bark per hectare)
Description:	Harvested timber volume from final felling for Baseline during years t-(t+5)
Equations	6
Source of data:	Harvested timber volume output from Heureka simulation of stand development and final felling harvest during the Project time for Baseline
Description of measurement methods and procedures to be applied:	Heureka output option TimberVolumeTotal, is used for achieving output of harvested timber volume/ha from final felling.
Frequency of monitoring/record	Calculated for each 5 year period during the Project time
QA/QC procedures to be applied:	
Purpose of data:	Determination of Baseline emissions
Calculation method	N/A
Comments	

Data / Parameter:	Bfftpulpvol/ha(t-(t+5))
Data unit:	m ³ f u b/hectare (m ³ solid wood under bark per hectare)
Description:	Harvested pulpwood volume from final felling for Baseline during years t-(t+5)
Equations	7
Source of data:	Harvested pulpwood volume output from Heureka simulation of stand development and final felling harvest during the Project time for Baseline
Description of measurement methods and procedures to be applied:	Heureka output option PulpVolumeTotal, is used for achieving output of harvested pulpwood volume/ha from final felling.
Frequency of monitoring/record	Calculated for each 5 year period during the Project time
QA/QC procedures to be applied:	
Purpose of data:	Determination of Baseline emissions.
Calculation method	N/A
Comments	

Data / Parameter:	$P_{thtimbvol/ha}(t-(t+5))$
Data unit:	m^3 f u b/hectare (m^3 solid wood under bark per hectare)
Description:	Harvested timber volume from thinning for Project scenario during years t-(t+5)
Equations	8
Source of data:	SDC service option "Measurement accounting"
Description of measurement methods and procedures to be applied:	According to SDC routines for measurements, calculation and presentation in the "Measurement accounting" services.
Frequency of monitoring/record	Calculated for each 5 year period during the Project time
QA/QC procedures to be applied:	According to SDC routines for QA/QC.
Purpose of data:	Determination of Project emissions
Calculation method	N/A
Comments	

Data / Parameter:	$P_{thpulpvol/ha}(t-(t+5))$
Data unit:	m^3 f u b/hectare (m^3 solid wood under bark per hectare)
Description:	Harvested pulpwood volume from thinning for Project during years t-(t+5)
Equations	9
Source of data:	SDC service option "Measurement accounting"
Description of measurement methods and procedures to be applied:	According to SDC routines for measurements, calculation and presentation in the "Measurement accounting" services.
Frequency of monitoring/record	Calculated for each 5 year period during the Project time
QA/QC procedures to be applied:	According to SDC routines for QA/QC.
Purpose of data:	Determination of Project emissions
Calculation method	N/A
Comments	

Data / Parameter:	Pfftimbvol/ha (t-(t+5))
Data unit:	m ³ f u b/hectare (m ³ solid wood under bark per hectare)
Description:	Harvested timber volume from final felling for Project during years t-(t+5)
Equations	10
Source of data:	SDC service option "Measurement accounting"
Description of measurement methods and procedures to be applied:	According to SDC routines for measurements, calculation and presentation in the "Measurement accounting" services.
Frequency of monitoring/record	Calculated for each 5 year period during the Project time
QA/QC procedures to be applied:	According to SDC routines for QA/QC.
Purpose of data:	Determination of Project emissions
Calculation method	N/A
Comments	

Data / Parameter:	Pffpulpvol/ha (t-(t+5))
Data unit:	m ³ f u b/hectare (m ³ solid wood under bark per hectare)
Description:	Harvested pulpwood volume from final felling for Project during years t-(t+5)
Equations	11
Source of data:	SDC service option "Measurement accounting"
Description of measurement methods and procedures to be applied:	According to SDC routines for measurements, calculation and presentation in the "Measurement accounting" services.
Frequency of monitoring/record	Calculated for each 5 year period during the Project time
QA/QC procedures to be applied:	According to SDC routines for QA/QC.
Purpose of data:	Determination of Project emissions
Calculation method	N/A
Comments	

9.3 Description of Monitoring Plan

The monitoring plan includes procedures for:

-) Monitoring spatial inventory change
-) Field plot measurements of tree carbon stock
-) Monitoring standard operation
-) Quality control and data storage

9.3.1 Spatial Inventory Change Monitoring

Project proponents have to annually update and document spatial changes in the forest inventory data or Project activity area. Such changes might be caused by harvests, fires, wind- and snow-break.

9.3.2 Field Plot Measurements of Tree Carbon Stock

The objective of the field plot measurements is to determine tree carbon stock at Project start and the statistical accuracy of the modelled carbon stock during Project duration. The input to the tree carbon stock models are tree measurements at the Project start (year 0), when the Project activity is carried out, on permanent sample plots for both the Baseline and the Project scenario. These measurements have to be carried out within a time frame of 60 days before and 60 days after the Project start. The tree measurements and carbon stock calculations are then repeated at 5 year intervals until all credits are issued, after which measurement intervals may be increased to 10 years until the final felling. The calculated carbon stock values are compared against the associated modelled values for determination of the error (deviation) in the modelled value. This error value is then used for calculation of a correction factor, described in Chapter 8.14. Further useful information about appropriate carbon stock estimation methods may be found in “Sourcebook for Land Use, Land-Use Change and Forestry Projects” (Pearson, Walker & Brown, 2005) and in (Pearson, Brown & Birdsey, 2007).

9.3.3 Sample Plot Type, Size, Number and Distribution

Permanent circular sample plots with radius 7 m, marked on a map and with geo-reference and all measured trees marked, are recommended for this Methodology. In stands, not previously thinned, the sample plots are systematically distributed in advance on a map over the whole Project activity stand area. The location of the first sample plot is randomly chosen. From this starting position, the other sample plots are then systematically distributed over the whole area. The GPS coordinates for all plot centers are recorded for determination of plot positions during field work.

To ensure that the Project tree biomass carbon stock is determined at a reasonable high level of significance, the appropriate number of sample plots has to be calculated. For this purpose, an introductory survey of the variation in sample plot tree basal area within the Project activity stand area has to be carried out in order to determine the coefficient of variation for the mean basal area.

According to the VCS Standard, a significance level for which the deviation is less than 10% from the true sample plot mean value at a 90% confidence level may be appropriate. Under these conditions, a reasonable sample plot number in well managed and even-aged boreal conifer forests should be 10-15 plots/project

A description of how an appropriate number of sample plots for a certain desired statistical confidence level can be calculated may be found in the CDM A/R Methodological Tool, EB 58 Report, Annex 15 (Calculation of the number of sample plots for measurements within A/R CDM Project activities).

9.3.4 Sample Plot Tree Measurements

Stem diameter at breast height (1.3 m above ground) is measured in cm, using a digital caliper for efficient data transfer directly into the Heureka system. All reasonable healthy trees with diameter > 4 cm are measured.

Dying or severely damaged trees (wind or snow break, moose browsing) are not measured. In addition, tree height is measured in m and species is registered for one randomly chosen conifer tree/plot. Tree heights are linked with the stem diameter, when recorded. All measured trees are color marked at the diameter measuring point of the stem, with water resistant color, contrasting to the tree bark color.

9.3.5 Quality Assurance and Quality Control Methods (QA/QC)

The monitoring plan has to include QA/QC procedures for:

-) reliable field measurements
-) calculation of fertilizer application rate
-) measurements of harvested and transported tree volumes
-) verifying data entry
-) data archiving

9.3.5.1 Field Measurements

All field activities regarding tree and stand data collection, have to be accompanied by written check lists and step by step procedure descriptions, to ensure that measurement data quality and accuracy are fully repeatable and are independent of measurement occasion and field crews. Field crews must be subjected to sufficient training in all aspects of field data measurements and collection. All such training activities have to be documented by the Project proponent. All Project activity stands have to be subjected to a measurement audit, at which at least 10 % of the sample plots are completely re-measured. This audit should be carried out within one month after the measurements. At this occasion, also other field observations of relevance are made, according to an elaborated check list. The deviation between audit measurements and original measurements (the measurement error) is calculated and compared against a maximum error threshold value of 10% of the true (audit) value at 90% confidence interval. If the error exceeds this threshold value, the reason for that has to be evaluated, according to an elaborated step-by step check list. The evaluation result determines which measures have to be taken. Possible alternatives may be re-measurements of all plots or establishment of new plots.

9.3.5.2 Fertilizer Application Rate

Data for calculation of the fertilizer application rate, variable Apprate, is achieved from the fertilization contractor. The contractor has to provide documentation about amount of fertilizer, delivered to the forest stand, and the remaining amount of fertilizer after the fertilization

operation, so that the total amount of applied fertilizer may be calculated. The contractor also has to present a digital map showing GPS-registered fertilization vehicle routes, from which the fertilized area (equal to the variable Area) may be calculated.

9.3.5.3 Measurements and Simulation of Harvested and Transported Tree Volumes

The harvested tree volumes in each stand at each harvesting operation have to be automatically measured and stored with built-in device in the harvester and classified as timber or pulpwood, and transferred electronically to the Forestry Data Centre, SDC. In addition, data about transportation distance and delivery industry is registered by SDC. SDC will then present a "Measurement account" in which the harvested and transported volume of timber and pulpwood from each stand and harvesting occasion is presented. In addition, a "Transportation account", is presented, showing transportation distances from forest roadside to the end customers for the tree raw material. For these purposes, the Project proponent has to be connected to SDC as customer for the services "Measurement account" and "Transportation account". The use of these SDC services will ensure that all data about harvested volumes and assortments and transportation distances are reliable. These data, delivered by SDC, have to be used for variables Disttimb, Distpulp, Pthtimbvol/ha (t-(t+5)), Pthpulpvol/ha(t-(t+5)), Pfftimbvol/ha (t-(t+5)) and Pffpulpvol/ha (t-(t+5)), for calculation of Project emissions for each 5 year period in equations 4-7 followed by equations 17-19.

For Baseline, for which no actual harvesting operations are carried out during the Project time, the harvesting volumes from thinning and final felling, are simulated, using the Heureka system, available from the Swedish University of Agricultural Sciences. The simulation output harvested volumes/ha are used as input data for the variables Bthtimbvol/ha(t-(t+5)), Bthpulpvol/ha(t-(t+5)), Bfftimbvol/ha(t-(t+5)) and Bffpulpvol/ha(t-(t+5)) for calculation of Baseline emissions for each 5 year period in equations 4-7 followed by equations 14-16. The same transportation distances from forest roadside to industry (Disttimb and Distpulp) are used for the Baseline scenario as for the Project scenario.

9.3.5.4 Data Entry

Measurements should to highest possible extent be carried out with a measurement device with built in data memory for immediate digital recording of measurement values. Written data and information should be transferred into digital form after each work day. A measurement data screening procedure should be elaborated in order to assure that the data are complete before leaving the Project activity area. Missing or erroneous data may be completed by re-measurements. If such correction is not possible, the actual sample plot must be excluded from the calculations.

9.3.5.5 Data Archiving

All the Project procedure descriptions, Project activity descriptions, maps, measurement data, data analyses and calculations and reports have to be securely stored until 2 years after the Project period.

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APPENDIX A: PROJECT ACTIVITY GHG EMISSION SOURCES NOT INCLUDED IN THE PROJECT BOUNDARY

The Project boundary includes carbon pools according to Table 1 and GHG emission sources according to Table 2. However, the Project activities may also influence GHG emissions/removal from other sources within the forest ecosystem, outside the Project boundary. These effects are discussed and quantified in this appendix.

Nitrogen nutrient addition to the forest ground results in reduced autotrophic root respiration and heterotrophic respiration through decomposition of organic matter, resulting in a reduced CO₂ emission by 15-50% (Olsson *et al* 2005). The autotrophic respiration is regulated by the root biomass amount and activity. Increased nitrogen availability results in reduced root biomass and activity, caused by reduced allocation of carbon to the root system (Bloom 1985). The reduction of heterotrophic respiration after nitrogen fertilization is explained by production of less decomposable litter, less litter production from mycorrhiza and fine roots and lowered soil temperature due to more dense tree crowns. From several nitrogen fertilization experiments in Scandinavia, it was calculated that soil carbon increased by 13 kg per kg applied nitrogen in spruce stands and by 7 kg in pine stands (Hyvönen *et al.*, 2008). It was estimated that 60 % of the increased carbon sequestration was a result of slower litter decomposition rate, and the rest of increased litter production.

According to the above, the soil carbon pool increase after fertilization is calculated as:

$$\text{SOILCO}_2 = \text{Apprate} \cdot \text{CN} \cdot 44/12, \text{ kg CO}_2\text{e/hectare} \quad (1)$$

Where

SOILCO₂ = Soil carbon increase after fertilization, kg CO₂e/hectare

Apprate= Fertilizer application rate, kg N/hectare

CN= Soil carbon increase in kg/kg applied N per hectare; CN=13 for spruce and 7 for pine stands

44/12 = conversion factor from C to CO₂

For pine stands, the soil carbon increase (SOILCO₂) after fertilization with 150 kg N/hectare will be 3850 kg CO₂e/hectare.

Methane may both be consumed in the forest ecosystem through oxidation to CO₂ and formed and emitted under oxygen free, mostly wet, conditions in the soil. Such moist conditions will not be common in forests, subjected to nitrogen fertilization, whereas the risk for increased methane emissions after nitrogen fertilization is consider as negligible (Nordin *et al* 2009).

N₂O emissions may occur after fertilization of boreal forests from denitrification under anaerobic (wet) conditions or nitrification of supplied nitrogen. There is a strong positive correlation between soil nitrogen availability and N₂O emissions, with a threshold value of 20 for the C/N ratio in the soil, under which the N₂O emissions increase more rapidly (Klemedtsson *et al.*, 2005). From investigations in Spruce forests, it is estimated that between 0.5 and 1% of the nitrogen deposition is released as N₂O emissions (Macdonald *et al.*, 1997; Papen & Butterbach-Bahl, 1999).

According to this, the estimated increase in N₂O emission after nitrogen fertilization is calculated as:

$$N_2O = 0.01 * \text{Apprate} * 44 / 28 * 298, \text{ kg CO}_2\text{e/hectare} \quad (2)$$

Where:

N₂O = increased N₂O emissions after fertilization, kg CO₂e/hectare

Apprate= Fertilizer application rate, kg N/hectare

44 = molecule weight of N₂O.

28 = molecule weight of N₂

298 = conversion factor from kg N₂O to kg CO₂e

The increase of N₂O emissions after fertilization with 150 kg N/hectare will be 702.4 kg CO₂e/hectare, i.e., significantly lower than the above calculated increase of the soil carbon pool after fertilization.

Consequently, the GHG emissions/removal from other sources within the forest ecosystem, outside the Project boundary, do not result in increased net GHG emissions after fertilization.

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APPENDIX B. HEUREKA FORESTRY DECISION SUPPORT SYSTEM

1 General Background

Heureka Forestry Decision Support system (www.slu.se/heureka) is developed and maintained by the Swedish University of Agricultural Sciences (SLU). For an overview of the system, see Wikström et al (2011). Heureka is a software system for forestry planning and analysis and is applicable from a single stand level to whole landscapes, forest ownerships and country regions. The system is widely used by Swedish forest owners and forest companies, as well as for forest research and graduate education at the Faculty of forestry at SLU in Sweden.

Heureka has since the first release in 2009 become the de facto standard tool for long-term forestry analysis in Sweden. For a list of publications where the system is used, see Anon. (2015). The system is the result of a ten year research program and all included models and functions are first subjected to a scientific evaluation through peer-review or similar systems. The tree growth model has been validated and published in a peer-reviewed journal (Fahlvik, Elfving et al., 2014). The growth model in Heureka projects growth in five-year discrete time intervals. The default planning horizon when using Heureka is twenty five-year periods corresponding to 100 years, i.e., approximately one forest rotation.

2 Input Data Required

The minimum input data (variables) required to apply the tree carbon stock prognosis model for a forest stand may be divided into the following three groups:

<u>Group</u>	<u>Input variables</u>
Geographic location:	GPS coordinates
Site characteristics:	Site index (H100) Altitude, m Vegetation type class Soil moisture class
Tree layer:	Mean tree age Number of trees /ha Basal tree area/ha Mean tree height Mean tree diameter Tree species distribution

The system may also import sample plot data and tree lists. The model can handle any naturally occurring tree species in Sweden. The Heureka system supports prognosis on either stratified sampling data, or on one or many stands that belong to a forest holding.

3 Growth and Yield Models

3.1 Tree Development Models

The Heureka growth model system consists of several subcomponents. Each component is responsible for a certain phase of a forest stand's succession from bare land to final felling, or, for uneven-aged management, to an extended series of selection felling. The system uses single-tree objects as the primary description unit. The input data is either actual sample plots with measured trees, or stand-level aggregate values as described above from which the system can generate simulated sample plots and trees. The model acts on a so called prediction unit (PU), which correspond to a sample plot in a stand. A stand may consist of one or more PU:s. For each five-year period, growth is calculated for each PU separately. The results are presented as sums or averages over the included PU:s, taking the inclusion probability for each PU into account.

Before calculating the growth, possible treatments are simulated. The treatments are coordinated over the PU:s units. For example, a thinning is distributed over the PU:s so that the thinning grade for an individual PU is adjusted as a function of the basal area. Dense PU:s will obtain a larger thinning grade percentage than less dense PU:s. The system distinguishes between the two development phases, young stand phase and established stand phase. The fertilization activity is always carried out within the established stand phase.

3.2 The Established Stand Phase

In the established stand phase, when average tree height exceeds 7 m, growth is driven by basal area growth functions and height development functions (see Fahlvik, et al. 2014 for details). The basal area growth model consists of two components, a basal area growth for all trees in stand or plot (called a "stand-level" model), and a single-tree model to allocate the predicted growth to individual trees (Fahlvik, Elfving et al. 2014). This setup, with a stand-level growth model to determine the total growth before proceeding to the single tree growth functions, has shown to give the best growth predictions on a large number of validation plots (Fahlvik, et al. 2014). Tree mortality in established stands are calculated with a model developed by Elfving (2014, see appendix), an adapted version of the peer-reviewed model by Elfving (2010). The calculated probability for a tree to die is applied by reducing its tree expansion factor weight proportionally to the mortality probability.

3.3 Generation of Treatment Schedules

For generating treatment schedules for each stand included in an analysis, Heureka has a so called treatment program generator (TPG). Based on user settings, legislative restrictions (minimum cutting age and mandatory regeneration), and thinning prescription guides, the TPG model uses enumeration to create a number of alternative treatment programs for each stand within the feasible region of allowed actions. Two different treatment schedules for a stand differs in one or several choices of what activities to apply, and when and how to apply them. A user can, for example, set the bounds for what management system to apply (even-aged, uneven-aged or no management), what thinning guide to use, what regeneration species to use, the number of plants when planting, the desired stem density and species distribution after pre-commercial thinning, whether to fertilize or not, and the time for final felling may be varied.

The output from the TPG is used in a built-in optimization model. The optimization problem is formulated by the user which is therefore very flexible to what the user wants to analyze. The optimizer can either be used to optimize the net present value or another objective, subject to those constraints that the user defines (for example related to FSC certification rules and timber flow restrictions). The optimizer can also be used for sensitivity analysis and investigation of trade-offs between different utilities.

4 References

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APPENDIX C: Activity method

This methodology uses the standardized activity method approach for the demonstration of additionality of fertilization in young (about 20-70 years old, depending on site fertility index) conifer dominated forests in Sweden. Project activities that meet the applicability conditions of this methodology (see section 4) and demonstrate regulatory surplus are deemed as additional.

According to the VCS Standard 4.3.9, the methodology has to demonstrate that there is similarity across the sub-areas of the geographic scope in several factors. This demonstration is carried out below.

Socio-economic conditions

The average and median total income among people aged 20 and over does not vary extensively between Swedish counties, according to Statistics Sweden (<http://www.scb.se/en/finding-statistics/statistics-by-subject-area/household-finances/income-and-income-distribution/income-and-tax-statistics/>). Excluding the County of Stockholm, the difference between the highest and the lowest average income in 2015 is 13.6%. This indicates that the socio-economic conditions are similar across the subareas of Sweden.

Timber and pulpwood prices

Timber and pulpwood prices are similar between the four subareas in Sweden. The difference between the highest and the lowest subarea average prices for 2001-2016 in percent of the total average is about 9% and thus similar for all subareas, according to the Swedish Forest Agency (<http://www.skogsstyrelsen.se/Myndigheten/Statistik/Statistikdatabas/>).

Energy prices

The difference between the highest and the lowest average electricity price for the four subareas during years 2012-2016 constitutes 1.46% of the average price for the whole country, according to <https://www.vattenfall.se/elavtal/elpriser/rorligt-elpris/prishistorik/>, i.e. electricity prices are similar across all subareas of Sweden. Fuel prices don't vary between subareas as they are set at a similar level for the whole country by the fuel companies.

Electricity grid emission factor

The electricity grid is in common for the whole country, hence there are no differences in electricity grid emission factors between subareas.

Climatic conditions

Climatic conditions are similar, with the whole applicability area belonging to the Dfc climate zone according to the Koeppen-Geiger classification (<http://www.weatheronline.co.uk/reports/climate/Sweden.htm>).

Raw material availability

All required raw material related to the Methodology activities, are available throughout the whole applicability area of the country.

1 Applicability Conditions

The applicability conditions of this methodology represent the positive list:

-) Conifer dominated (>50% of tree basal area) and production forest in Sweden
-) Site index T16-T26 and G18
-) 1-3 fertilizations, with Project start and the first fertilization carried out no later than the following years before the earliest permitted age for final felling, according to the Forestry Act:

<u>Site index</u>	<u>Years before permitted age for FF</u>
T16	10
T18	10
T20	15
T22	15
T24	20
T26	20
G18	5

-) The Project area must not be exempt from forestry by the Swedish Forest Agency
-) Forest management has to be carried out within the framework of the Swedish Forestry Act.
-) Project start date is the date for the first fertilization
-) Monitoring periods for tree biomass carbon stock calculations have to be 5 years.

The project must demonstrate that it meets all of the applicability conditions, and in doing so, it is deemed as complying with the positive list.

Project activities on the positive list are all financially non-viable in Swedish forestry without the intervention created by the carbon market. This is due to the slow forest growth and long rotation cycles (80-120 years), resulting in late pay-back of costs for investments made early during the rotation and with great uncertainties about future revenue levels. Production forests in Sweden are typically managed in a clear-cut harvest regime with replanting or natural regeneration. Differences between sub-areas of Sweden are related to the intensity of the forestry, driven by growth rates etc., but the guiding principles of the management regimes are similar. This methodology is therefore applicable across the whole geographic scope Sweden

2 Baseline Scenario

The common practice forest management regime among big forest companies as well as private forest owners typically focuses on a single dominant tree species in each forest stand. Norway spruce and Scots pine are the most common tree species. Forest stands dominated by hardwood are uncommon, as well as stands of other softwood species. When regenerating forests, most often only a single species is planted on each site or section of a site. A pre-commercial thinning is normally made after the regeneration phase and is typically not generating any commercial products. The goal with stand management operations is in most cases highest possible economical outcome. To improve growth rates and diameter distribution, stands are generally thinned 1-3 times depending on site conditions. The first thinning is in general carried out at a stand age between 30 and 60 years, depending on site fertility index. During thinning operations, the majority of the harvested volume is pulpwood. In some cases stands are fertilized ~10 years before final felling to avoid the declining growth rate in 80-110 year old stands and to increase the final felling net revenue by increasing the

volume of high-value timber. Fertilization of young conifer dominated forests is not carried out at all in practical scale. The final felling is generally made through a clear-cut of a forest stand and generates a large proportion of saw logs. Pulpwood and in some cases tree biomass for energy is also harvested.

In this methodology, common practice forest management without fertilization is considered to be the baseline scenario in young conifer dominated Swedish forests. Forest operations are similar across the country and consistently distributed through forest owners associations, large industrial/non-industrial landowners and purchasing organizations.

3 Positive List

Project activities were selected to the positive list by using the financial viability option (VCS Standard 4.6.9, option B) to demonstrate that they are financially or economically less attractive than their alternatives. The CDM Tool for the demonstration and assessment of additionality sets out the procedures for the investment analysis. The VCS Standard requires that step 1, 2 and 4 of the tool are followed.

-) Step 1: Identification of alternatives to the project activities consistent with current laws and regulations
-) Step 2: Investment analysis
-) Step 4: Common practice analysis

The following sections describe the analyses conducted in each step.

3.1 Step 1: Identification of alternatives to the project activities consistent with current laws and regulations

Step 1 of the additionality tool identifies realistic and credible alternatives to the project activity. The most likely alternative for young and middle-aged (about 20-70 year old, depending on site fertility index) conifer dominated forests to the project activity 1-3 fertilizations is no fertilization. The Swedish forestry Act allows for repeated fertilization in young forests up to a total application rate of 300- 450 kg nitrogen per hectare during a forest rotation, depending on geographic location. This corresponds to maximum two to three fertilization events during a rotation time, with the normally used application rate of 150 kg N/ha. There are no laws or regulations in Sweden that may force forest owners to carry out fertilization. Therefore, the common practice of no fertilization in young forests is considered as the most credible alternative to the project activity. However, an alternative scenario for these stands may also be a single fertilization (SF), carried out 10 years before final felling, although this is annually practiced on only 0.2 % of the forest area.

3.2 Step 2: Investment analysis

3.2.1 Sub-step 2a and 2b: Determine appropriate analysis method

The investment comparison analysis using net present value (NPV) as financial indicator was selected as outlined in step 2 of the additionality tool. This is the standard forestry investment analysis utilized by most forestry professionals in Sweden.

3.2.2 Sub-step 2c: Calculation and comparison of financial indicators

Net present values of forest management costs and harvest revenues were calculated for the project activities and baseline alternatives from project start until the final harvest, for determination of the most financially attractive alternative. The simulations were carried out for three pine dominated stands with site fertility index T16-T26 and one spruce dominated stand with site index G18. Model calculations were carried out using the software PlanWise version 2.5 of the Heureka Forestry Decision Support System (www.slu.se/heureka). See also Appendix B.

3.2.2.1 Simulation of tree and stand data at Project start for Baseline and Project

The stand characteristics for the simulation starting position were manually created for each of the four types of stands. The starting position is aimed at corresponding to the conditions immediately after a pre-commercial thinning to 2500 stems/hectare. The forest stand characteristics at the starting position are described in table 1.

Table 1. Stand characteristics at the starting position for simulation of the stand development until the first thinning.

Forest site fertility index ¹	Mean age (years)	Mean height (m)	Stems/ha	Species stem number distribution		
				Spruce	Pine	Birch
T16	21	2.4	2500	0%	90%	10%
T20	16	2.8	2500	0%	90%	10%
T26	16	4.9	2500	0%	90%	10%
G18	21	2.6	2500	90%	0%	10%

¹ According to the The Swedish National Forest Inventory, Swedish University of Agricultural Sciences

The start position data were then used for Heureka simulation of the tree and stand development until the year when the first thinning was induced by the built-in thinning prescription guide. This year was then set as Project year 10. The Heureka simulation results were then used for a 10 year “backwards” determination of the tree and forest characteristics at Project year 0. These tree and stand data were then used for creation of a new stand register, which was imported to PlanWise¹ as a new dataset (Table 2).

Table 2. Simulated tree and stand data at year 0 of the Project time, used for NPV calculations for Baseline and Project activity.

Forest site fertility index	Mean age (years)	Volume (m ³ sk/ha)	Basal area m ² /ha)	Dgv ² (cm)	Hgv ³ (m)	Stems per ha	Species distribution, %		
							Spruce	Pine	Birch
T16	52	106.7	19.6	13.7	10.8	1547	0	90	10
T20	37	72.1	13.8	10.6	9.9	1899	0	90	10
T26	22	72.2	17.2	10.5	7.7	2436	0	89	11
G18	59	148.3	22.5	12.8	12.7	2158	90	0	10

¹http://heureka.slu.org/wiki/Heureka_Wiki

²Basal area weighed mean stem diameter at 1.3 m height from the ground

³Basal area weighed mean tree height.

3.2.2.2 Calculation of economically optimal tree age at final felling

After that Project year 0 is defined above, also the year for final felling and project end has to be determined. For that purpose, the Heureka treatment program generator (TPG) was used for enumeration to create a number of alternative treatment programs for each stand, within the feasible region of allowed actions. In this case, Heureka was used to calculate the NPV of net revenue of all forest operations during the project period for varying years of final felling, as a tool for determination of the economically most favorable stand age for final felling in Baseline.

3.2.2.3 Assumptions for the calculations

3.2.2.3.1 Management costs

Overhead management and planning costs are assumed to be fixed and independent of the choice of a baseline or project activity. This is also the case for e.g. road maintenance that will be similar in each forest regime. As with wood prices, the model allows costs to increase or decrease over time, by means of a real price inflator/deflator. In this comparison, the deflator is set to 0%. Management cost development over the last 20 years is fairly flat, with decreasing costs in the 1990's and slightly increasing costs in the early 2000's⁸.

3.2.2.3.2 Harvest costs

The model considers varying harvesting costs in different harvest operations. Thinning is more expensive per harvested cubic meter than final felling due to lower tree volume. Similar to forest management costs, harvest costs are also allowed to vary over time. In this case, the deflator is set to 0%, as it is very hard to predict cost development over a project time of up to 60 years. Historically (1970's-1990's), real harvest costs have declined due to the mechanization of forestry. In 1993-2003 harvesting costs fell at a real annual rate of 0.5% per year¹. However, harvest costs have increased at a real annual rate of 0.6% per year over the last 10 years. Current cost development is less

⁸ <http://www.skogsstyrelsen.se/Myndigheten/Statistik/Amnesomraden/Ekonomi/Tabeller--figurer/>.

predictable given strengthened demand for low impact logging operations and potential warmer winters due to climate change, which increase logging cost in wet conditions.

The following cost/income data were used for the NPV calculations

Hourly cost final felling harvester	1100	SEK/hour
Hourly cost thinning harvester	1000	SEK/ hour
Hourly cost final felling forwarder	800	SEK/ hour
Hourly cost thinning forwarder	700	SEK/ hour
Fertilization	3200	SEK/ha
Average Terrain transport distance	300	m
Pulpwood price	250	SEK/m ³ under bark

The complete price list used for pulpwood and timber is found at:
<http://www.norrskog.se/PageFiles/950/20160329/010-A1.pdf?epslanguage=sv>

3.2.2.3.3 Timber and pulpwood harvest volumes

As with rotation time, the model allows harvest volumes to vary as a result of different management regimes. Similarly the management regimes will affect the distribution of timber vs. pulpwood. To simplify modelling only the dominant tree species is considered. It is assumed that hardwood volumes will be equal in project and baseline activities and thus have limited impact on analysis results.

3.2.2.3.4 Timber and pulpwood prices

The model uses timber and pulpwood prices for the dominant tree species pine and spruce. Assortments are limited to the main assortments on the market – timber and pulpwood. Price information is collected from a pricelist from the Forest Owners Association Norrskog Price List. The Heureka model allows prices to increase or decrease over time, by means of a real price inflator/deflator. In these calculations, the deflator is set to 0%, as it is difficult to predict price variations during a Project time of up to 60 years. Over the last 20 years prices have declined by 0.5-1.5% per year in real terms depending on assortment. However, during the last 5-10 years prices have increased by 0.5-3.0% per year. Current price development is positive, but also less predictable given uncertainty regarding the forest industrial development and potential demand from the biomass energy sector.

¹ Swedish Forest Agency,
<http://www.skogsstyrelsen.se/Myndigheten/Statistik/Amnesomraden/Ekonomi/Tabeller--figurer/>

3.2.2.4 Calculation results

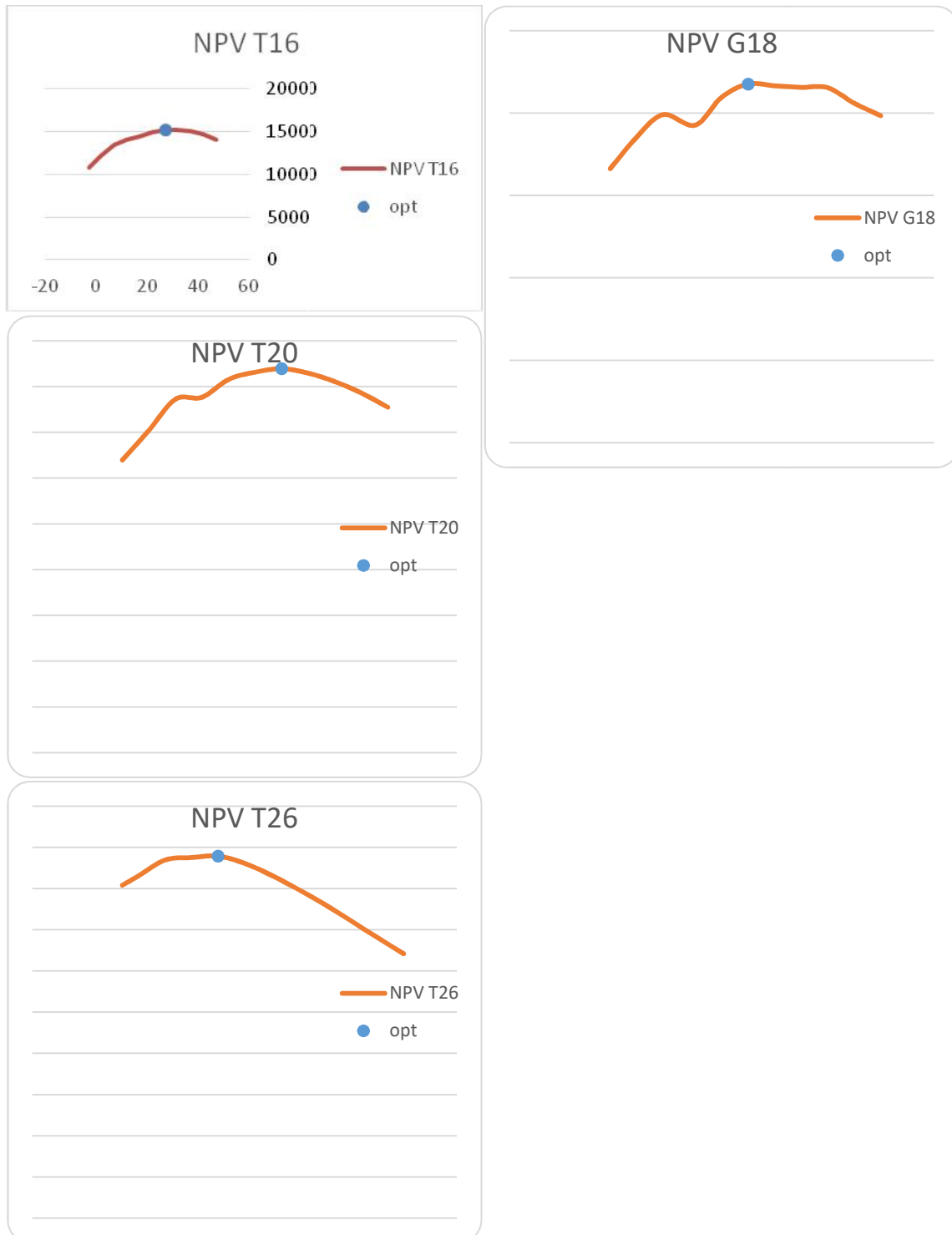


Figure 1. Correlation between final felling (FF) age, expressed as AFF (x-axis) and Baseline NPV (y-axis). Maximum NPV is marked as "opt". AFF= Tree age at FF minus lowest permitted FF age, according to the Swedish Forestry Act. Discount rate 2.33%.

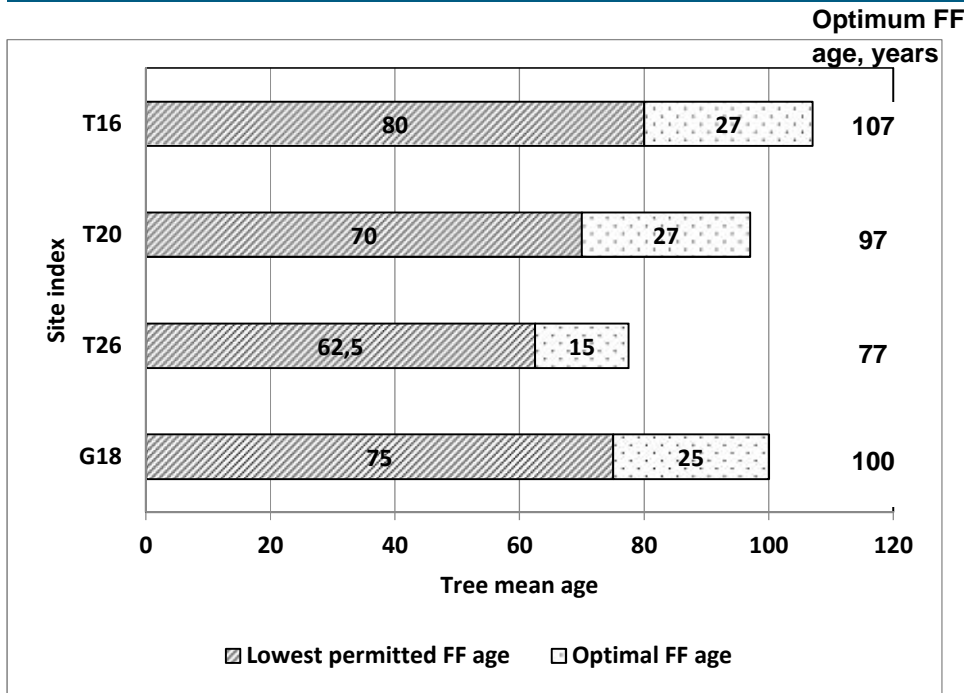


Figure 2. Lowest permitted final felling (FF) tree age according to the Swedish Forestry Act, and number of years after that time at which FF results in the maximum NPV.

The calculated final felling tree age, for which NPV was optimal, was between 77 and 107 years and between 15 and 27 years after the lowest permitted age for final felling according to the Swedish Forestry Act (Figure 1 and 2). NPV for final felling 10 years before or 10 years after the optimal tree age did not deviate more than 5% from NPV of the optimal FF tree age for all site indexes except one (Figure 3).

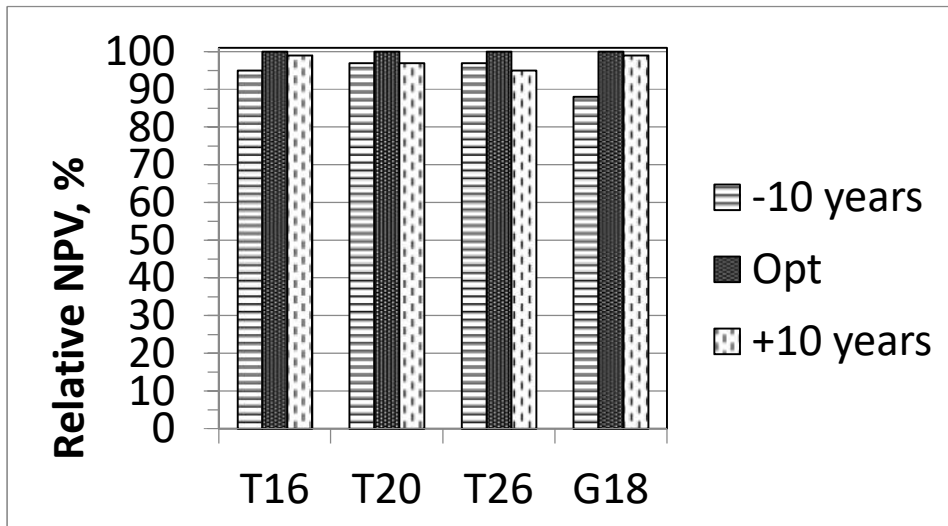


Figure 3. Relative NPV in percent of optimal NPV for final felling 10 years before and 10 years after the optimal age for final felling according to figure 1.

3.2.2.5 Creation of treatment programs for Project activities and alternative Baseline scenario single fertilization (SF)

The treatment programs for the Project activity fertilizations were based on the previously created Baseline treatment program, with harvesting operations occurring at the same ages, and thinning grades being the same, 35% of the tree basal area. The difference is that the fertilization operations were added into the program at certain Project time points. These time points were selected to achieve the highest possible economic net present value for the Project scenarios. Therefore, the first fertilization event (year 0) was added 10 years before the first thinning for all the Project scenarios. The same principle was applied for the subsequent fertilization events. As a result of this,

- the full fertilization growth increasing effect (the effect duration is 10 years) has been achieved at the time of each thinning
- the harvested volume and thinning net revenue is increased, and may thus contribute to an early pay back of the fertilization costs.

Therefore, the applied Project scenarios, presented in tables 3 and 4 are the financially most attractive alternatives for Project activities.

The alternative Baseline scenario single fertilization (SF) was created by adding a fertilization with 150 kg N/ha 10 years before the final felling to the Baseline scenario, and is also presented in tables 3 and 4.

Table 3. Management programs for the NPV calculations. BSL= Baseline FZ=fertilization; FZR=repeated fertilization; SF= alternative Baseline scenario with a single fertilization 10 years before FF TH= thinning; FF= final felling

	T16				T20				T26				G18			
Year	BSL	FZ	FZR	SF	BSL	FZ	FZR	SF	BSL	FZ	FZR	SF	BSL	FZ	FZR	SF
0		FZ	FZ			FZ	FZ			FZ	FZ			FZ		
5																
10	TH	TH	TH	TH	TH	TH	TH	TH	TH	TH	TH, FZ	TH	TH	TH		TH
15																
20			FZ				FZ		TH	TH	TH, FZ					
25																
30									TH	TH	TH	TH				FZ
35	TH	TH	TH	TH	TH	TH	TH	TH								
40													FF	FF		FF
45				FZ								FZ				
50							FZ									
55	FF	FF	FF	FF					FF	FF	FF	FF				
60					FF	FF	FF	FF								

Table 4. Harvested volumes (m³sk/hectare) at thinning and final felling for Baseline (BSL) and for the Project activities one fertilization (FZ) and repeated fertilizations (FZR) and alternative Baseline scenario (SF), during the Project time.

	T16				T20				T26				G18			
Year	BSL	FZ	FZR	SF	BSL	FZ	FZR	SF	BSL	FZ	FZR	SF	BSL	FZ	FZR	SF
0																
5																
10	50.9	55.6	55.6	50.9	45.1	49.6	49.6	45.1	57.3	61.3	61.3	57.3	66.6	71.5	-	66.6
15																
20									72.9	77.0	80.8	72.9				
25																
30									79.1	82.8	89.8	79.1				
35	68.1	72.2	76.9	68.1	73.9	79.1	83.7	73.9								
40													269.0	283.8	-	283.4
45																
50																
55	194.9	204.3	215.0	207.6					323.7	334.5	354.6	335.7				
60					241.4	254.5	265.9	253.9								
SUM	313.9	332.1	347.6	326.6	360.4	383.3	399.3	372.9	533.2	555.5	586.4	545.0	335.6	355.3	-	350.0

3.2.3 Sub-step 2d: Sensitivity analysis

Net present values of the net revenue for all management activities during the Project time until the final felling, were calculated for Baseline and the Project activities one fertilization and repeated fertilizations, as well as for the alternative Baseline scenario single fertilization 10 years before final felling.

The calculations were carried out for different levels of:

-) Discount rate
-) Fertilization cost
-) Harvest net revenue

3.2.3.1 Effect of discount rate on NPV differences

The chosen discount rates are 2.33%, 2.45% and 3%.

The calculated NPV for Baseline and Project activities are presented in Table 5.

Table 5. Calculated NPV in SEK for Baseline (BSL) and Project activities FZ and FZR and alternative baseline scenario (SF) for the project time.

Discount rate		T16	T20	T26	G18
2.33%	BSL	17478	16829	38912	21772
	FZ	16482	15793	38636	21217
	FZR	15975	15209	37819	- ¹
	SF	17508	16883	39208	22137
2.45%	BSL	16556	15777	36908	20811
	FZ	15468	14637	36512	20157
	FZR	14923	14016	35593	- ¹
	SF	16571	15816	37173	21142
3.00%	BSL	12970	11763	29099	16946
	FZ	11521	10220	28227	15892
	FZR	10849	9480	26939	- ¹
	SF	12937	11754	29252	17144

¹No such activity

The NPV differences were negative for all pine site indexes and G18 (Table 6 and 7).

Table 6. Differences in NPV between FZ and BSL and FZR and BSL, respectively, for the NPV values in table 5.

Discount rate		T16	T20	T26	G18
2.33%	FZ	-996	-1036	-276	-555
	FZR	-1504	-1620	-1093	- ¹
2.45%	FZ	-1088	-1141	-397	-653
	FZR	-1633	-1761	-1315	- ¹
3.00%	FZ	-1449	-1544	-873	-1053
	FZR	-2120	-2284	-2160	- ¹

¹No such activity

Table 7. Differences in NPV between FZ and SF and FZR and SF, respectively, for the NPV values in table 5.

Discount rate		T16	T20	T26	G18
2.33%	FZ	-1026	-1090	-572	-920
	FZR	-1533	-1674	-1389	- ¹
2.45%	FZ	-1103	-1180	-661	-985
	FZR	-1648	-1800	-1580	- ¹
3.00%	FZ	-1416	-1534	-1025	-1252
	FZR	-2087	-2274	-2313	- ¹

¹No such activity

3.2.3.2 Effect of fertilization cost on NPV differences

A 10% lowered cost for fertilizer, resulting in a reduced fertilization cost from SEK 3200/ha to SEK 3040/ha, did not change the main pattern of NPV differences (Tables 8 and 9). A similar 10% cost increase to SEK 3360/ha, results in increased negative differences between the Project activities and Baseline for all site indexes (Tables 10 and 11).

Table 8. Differences in NPV between FZ and BSL and FZR and BSL, respectively, with 10% decreased fertilization cost to SEK 3040/ha, compared to table 6.

Discount rate		T16	T20	T26	G18
2.33%	FZ	-836	-876	-116	-394
	FZR	-1243	-1359	-705	-
2.45%	FZ	-928	-981	-237	-653
	FZR	-1374	-1502	-931	-
3.00%	FZ	-1289	-1384	-713	-893
	FZR	-1872	-2035	-1792	-

Table 9. Differences in NPV between FZ and SF and FZR and SF, respectively, with 10% decreased fertilization cost to SEK 3040/ha, compared to table 6.

Discount rate		T16	T20	T26	G18
2.33%	FZ	-922	-981	-468	-840
	FZR	-1329	-1464	-1057	-
2.45%	FZ	-997	-1067	-625	-902
	FZR	-1443	-1589	-1319	-
3.00%	FZ	-1298	-1410	-908	-1158
	FZR	-1881	-2062	-1988	-

Table 10. Differences in NPV between FZ and BSL and FZR and BSL, respectively, with 10% increased fertilization cost to SEK 3360/ha, compared to table 6.

Discount rate		T16	T20	T26	G18
2.33%	FZ	-1156	-1196	-436	-715
	FZR	-1765	-1881	-1481	-
2.45%	FZ	-1248	-1301	-557	-813
	FZR	-1891	-2020	-1699	-
3.00%	FZ	-1609	1704	-1033	-1213
	FZR	-2369	2532	-2528	-

Table 11. Differences in NPV between FZ and SF and FZR and SF, respectively, with 10% increased fertilization cost to SEK 3360/ha, compared to table 6.

Discount rate		T16	T20	T26	G18
2.33%	FZ	-1129	-1199	-675	-1000
	FZR	-1737	-1884	-1720	-
2.45%	FZ	-1209	-1300	-767	-1067
	FZR	-1853	-2019	-1910	-
3.00%	FZ	-1533	-1657	-1143	-1346
	FZR	-2293	-2486	-2683	-

3.2.3.3 Effect of harvest net revenue on NPV differences

A 10% increased or 10% reduced harvest net revenue did not change the pattern of negative net present value differences (Tables 12-15).

Table 12. Differences in NPV between FZ and BSL and FZR and BSL, respectively, with 10% increased harvest net revenues compared to table 6.

Discount rate		T16	T20	T26	G18
2.33%	FZ	-776	-888	16	-290
	FZR	-1132	-1328	-426	-
2.45%	FZ	-877	-1002	-116	-399
	FZR	-1279	-1487	-678	-
3.00%	FZ	-1299	-1441	-640	-839
	FZR	-1987	-2079	-1641	-

Table 13. Differences in NPV between FZ and SF and FZR and SF, respectively, with 10% increased harvest net revenues compared to table 6.

Discount rate		T16	T20	T26	G18
2.33%	FZ	-922	-1048	-422	-853
	FZR	-1278	-1489	-865	-
2.45%	FZ	-1001	-1141	-515	-917
	FZR	-1403	-1626	-1077	-
3.00%	FZ	-1322	-1504	-893	-1189
	FZR	-1883	-2141	-1893	-

Table 14. Differences in NPV between FZ and BSL and FZR and BSL, respectively, with 10% reduced harvest net revenues compared to table 6.

Discount rate		T16	T20	T26	G18
2.33%	FZ	-1217	-1184	-569	-819
	FZR	-1875	-1912	-1760	-
2.45%	FZ	-1279	-1279	-677	-908
	FZR	-1987	-2035	-1952	-
3.00%	FZ	-1624	-1646	-1105	-1268
	FZR	-2405	-2489	-2679	-

Table 15. Differences in NPV between FZ and SF and FZR and SF, respectively, with 10% reduced harvest net revenues compared to table 6.

Discount rate		T16	T20	T26	G18
2.33%	FZ	-1130	-1133	-721	-988
	FZR	-1788	-1860	-1912	-
2.45%	FZ	-1205	-1219	-807	-1051
	FZR	-1892	-1975	-2082	-
3.00%	FZ	-1509	-1564	-1158	-1315
	FZR	-2291	-2407	-2732	-

3.2.3.4 Average NPV differences between Project activities and Baseline

The average NPV differences for the different alternatives, presented in tables 6-15, with varying discount rates, harvest net revenues and fertilization costs, are negative for FZ and FZR for and all site index (Figure 4). The average negative NPV differences between FZ and FZR compared to Baseline are statistically significant at the 99% significance level for the Project activity one fertilization (FZ) for all site indexes. For repeated fertilization (FZR), the same significance level is also valid for all the pine (T) indexes.

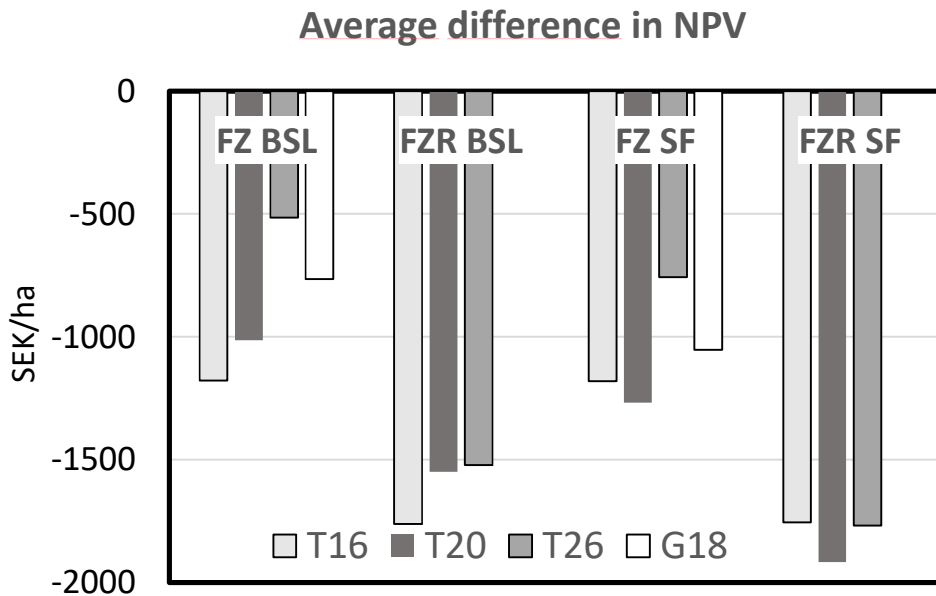


Figure 4. Average for the NPV differences between the Project activities FZ and FZR and Baseline (BSL) and alternative Baseline scenario SF, presented in tables 6-15. N=15 for each site index and FZ and FZR NPV difference.

3.2.3.5 Appropriateness of chosen parameter levels

3.2.3.5.1 Discount rate

The chosen discount rates were 2.33%, 2.45% and 3%. The Swedish National Mapping, Cadaster and Registration Authority, recommends two different discount rates for forest investment analysis and forest property value estimation. A linearly moving discount rate from 2.3% in the beginning of the forest rotation, to 2.5% in the end of the rotation is the most recommended. It is also possible to use a fixed discount rate of 2.33% for properties with even forest age distribution. In the proposed methodology, each project is carried out in one forest stand. The project time runs from about the middle of the rotation age until the end of the rotation period. This means that a discount rate of about 2.4% at the project start and 2.5% at the project end, would be the most appropriate. However, harvesting in each project forest stand, and thus the main costs and income, occur at the same tree age for baseline and project activity in these NPV calculations. Therefore, the use of an average discount rate of 2.45% for the whole project period should not cause misleading results regarding the financial viability of the project activity. This discount rate is also in accordance with the most commonly used 2.5% discount rate for Swedish forest investment analyses among forest companies and forest economists in Sweden.⁹ The present very low interest rate levels in international economy, makes an increased rate more probable than a further decrease. Therefore, a higher discount rate of 3 % together with the lower discount rates of 2.33% and 2.45% are considered to be appropriate for this purpose.

3.2.3.5.2 Fertilization cost

The fertilization cost per hectare was set to SEK 3200 /hectare, according to information from forest companies, and is composed of a cost for the fertilizer (50%) and a cost for fertilizer application (50%). It is estimated that cost changes will mainly refer to the fertilizer, and the cost variation in the sensitivity analysis was therefore set to $\pm 10\%$ of the fertilizer cost, i.e., \pm SEK 160 from the base cost alternative.

3.2.3.5.3 Harvesting net revenue

The sensitivity analyses for harvest net revenue were carried out for a $\pm 10\%$ change from the base alternative in table 6. Harvest net revenue is the difference between the income from and the costs for harvesting. Harvest income is determined by the price for the harvested timber and pulpwood. These prices vary over time due to the economy and the state of the market, and are impossible to predict for a whole Project time of up to 50 years. The price statistics for timber and pulpwood show a great variation over time. For pulpwood, the average price during 1995-2015 is SEK 260 (Figure 5).

⁹ <http://www.skogsstyrelsen.se/Global/PUBLIKATIONER/Skogsskotselserien/Flippbok/18-SkogsskotselsIns%20ekonomi/index.html>

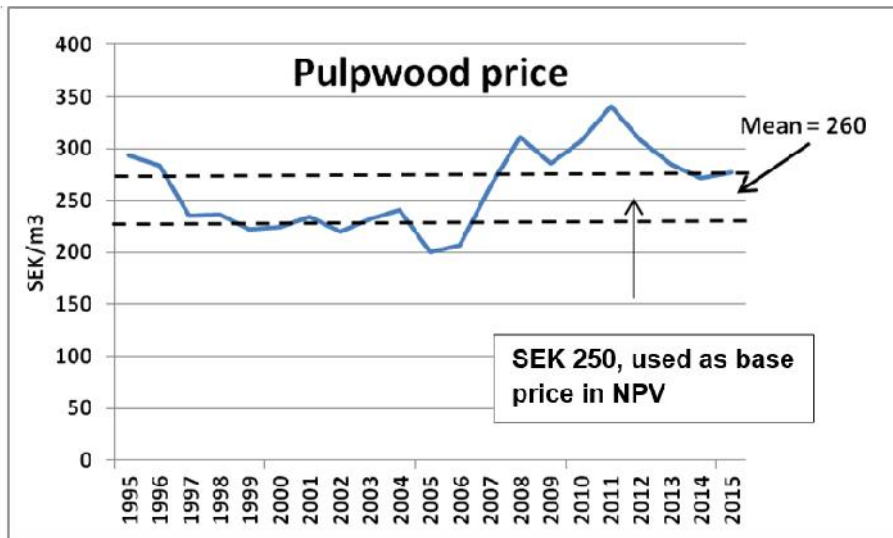


Figure 5. Pulpwood prices in Sweden during 1995-2015 according to the Swedish Forest Agency (<http://www.skogsstyrelsen.se/Myndigheten/Statistik/Amnesomraden/Ekonomi/Tabeller-figurer/>).

The used price in the NPV calculations is SEK 250/m³, and the price interval for the sensitivity analyses is maximum SEK 225-275 (if harvest costs are unchanged), which is marked with dotted lines in figure 5. The chosen price range shows a good representativeness for the long time average price variation. It is not possible to specify a similar single average price per m³ for timber, since there are several quality factors difficult to access within Heureka, which determines the price. Therefore, the same ± 10% variation is applied for the timber prices at assumed unchanged harvest costs.

The long term variation in harvest costs shows a slightly increasing trend, but has leveled out during recent years (Figure 6).

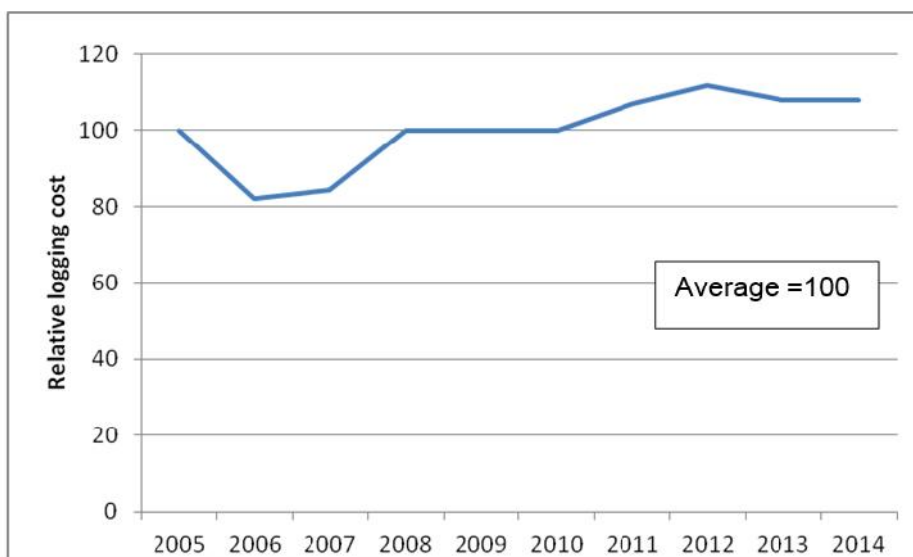


Figure 6. Relative harvesting costs during 2005-2014 according to the Swedish Forest Agency (<http://www.skogsstyrelsen.se/Myndigheten/Statistik/Amnesomraden/Ekonomi/Tabeller--figurer/>).

3.2.3.5.4 In conclusion

The presentation of the background and reason for the choice of parameter values for the sensitivity analyses of NPV differences between Project and Baseline, show that these selected values are at an appropriate level for the purpose of the analyses.

3.3 Step 4 : Common practice analysis

Common practice in young and middle-aged (about 20-70 years old, depending on site fertility index) forest in Sweden is no fertilization. The total annual forest fertilization area is only about 0.2 % of the forest area in Sweden¹⁰ and the fertilization is predominately performed in older forest stands 10 years before final felling. Therefore, fertilization in young and middle-aged forest cannot be considered as common practice in Sweden.

3.4 Conclusion about financial viability

An investment analysis through calculation of differences in net present values between Project activities and Baseline (no fertilization) as well as an alternative Baseline scenario with a single fertilization 10 years before final felling, has been carried out for varying discount rates, net revenues and fertilization costs. The Project activity net present values were based on management scenarios, chosen to achieve highest possible net present values. The results show that the Project activities do not show financial viability for site fertility indexes T16-T26 and G18 in comparison with the suggested Baseline no fertilization as well as the alternative Baseline scenario with a single fertilization 10 years before final felling. It is thus demonstrated that the Project activities are financially or economically less attractive than the most plausible management alternatives.

¹⁰ <http://www.skogsstyrelsen.se/Myndigheten/Statistik/Amnesomraden/Skogsvard-och-miljohansyn/Tabeller--figurer/>

APPENDIX D: THE ACCURACY OF TREE GROWTH PREDICTIONS

From Elfving 2009, Growth modelling in the Heureka system, pages 98-99.

PM for Heureka 2008-May-15 by Björn Elfving

Growth simulators linked to a site index system principally gives the average volume development at a given course of height development. For pure and even-aged stands with given initial density the variation coefficient for volume production to a given height is about 0.15 (Assman 1963). A growth prediction includes both this variation and the residual variation in the height growth prediction.

In order to estimate the total prediction error the following study was performed. Data consisted of long-term thinning trials (the GG trials) that were established in the period 1966-1983 and had been followed for an average period of 30 years. There were 23 blocks in Norway spruce and 47 blocks in Scots pine. Each block contained 4-12 treatments. For this study only the treatments un-thinned control and one heavy thinning from below were selected. The volume growth during the observation period (iV) was regressed on initial stem number per hectare (N1), top height (H1) and height increment during the observation period (iH), either the observed value (iHobs) or the value predicted with site curves (iHpred). There was a difference between the species also that could be modelled by a dummy variable for spruce. The regressions were as follows:

$$\ln(iV) = -0.5954 + 1.1476 \cdot \ln(iHobs) + 0.4264 \cdot \ln(N1) - 0.000158 \cdot N1 + 0.0623 \cdot H1 + 0.2249 \cdot SPRUCE;$$

$$n = 136 ; R^2_{adj} = 0.934 ; s(res) = 0.144 ;$$

$$\ln(iV) = -1.2310 + 1.2432 \cdot \ln(iHber) + 0.5300 \cdot \ln(N1) - 0.000227 \cdot N1 + 0.0488 \cdot H1 + 0.2079 \cdot SPRUCE;$$

$$n = 136 ; R^2_{adj} = 0.881 ; s(res) = 0.192 ;$$

The residuals of those functions had normal distributions and indicated a smooth fit over included variables and no significant correlation with some other tested variables (site index, latitude). An effort was made to also include an expression for local yield class but it was not significant. As expression for local yield class the residuals from the function $\ln G1 = f(\ln H1, \ln N1)$ were used, where G1 is initial basal area. The prediction error for the function with iHobs was $\exp(0,144) = 0,15$ as expected. The total prediction error (from the function with iHpred) was estimated at $\exp(0,192) = 0,21$. Eriksson (1976) also estimated the prediction error for volume growth at 0.21, based on data from spruce stands in the Great Yield Investigation. Söderberg (1986) compared predicted and observed basal area growth on 18 yield plots that had been followed during 44 years.

Observed growth was adjusted to normal weather conditions with year-ring indices. The prediction error for adjusted basal area growth was estimated at 0.12. The same prediction error for volume growth was estimated for 26 pine plantations in northern Sweden that had been followed in 20 years. Pretzsch (2002) estimated the prediction error of the model SILVA with data from German long-term yield plots. The error was 0.19 for oak, 0.20 for spruce, 0.29 for beech and 0.39 for pine.

My conclusion of this examination is that the variation coefficient of predicted growth in growth predictions (the prediction error) generally can be expected to be about 0.2.

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APPENDIX E: BIOMASS ESTIMATING FUNCTIONS FOR TREE STEM AND CROWN IN ESTABLISHED STANDS ACCORDING TO PETERSSON (1999).

Table 1. Response (dependent) variables for biomass weight estimation functions for established stands

Biomass fraction	Scots pine	Norway spruce	Birch sp
Stem inclusive bark	Y_{Pstem}	Y_{Sstem}	Y_{Bstem}
Living branches and needles/leaves	$Y_{Plivebranch}$	$Y_{Slivebranch}$	$Y_{Blivebranch}$
Dead branches	$Y_{Pdeadbranch}$	$Y_{Sdeadbranch}$	$Y_{Bdeadbranch}$

Table 2. Input variables for biomass weight estimation functions for established stands.

Input data abbreviations	Description	Unit
Db	Stem diameter at 1,3 m height from the ground	mm
Gr5	Last five years stem diameter growth at 1,3 m height from the ground	0.1 mm
Age	Tree age at 1,3 m height from the ground	year
SI	Site index	m
soil	Peat or mineral soil	
alt	Altitude above sea level	m
nco	North geographic coordinate, according to the Swedish net RT90	100 m
eco	East geographic coordinate, according to the Swedish net RT90	100 m

Table 3. Function variables, parameters and coefficient of determination (R^2) for tree stem and crown for established stands.

Y_{Pstem}		X_1	X_2	X_3	X_4	X_5	X_6	X_7	R^2
		Ln (db+25)	db	Ln(gr5)	gr5	Ln(age)	Sl	nco	
	0	1	2	3	4	5	6	7	
	7.674621	3.155671	0.002197	0.084427	0.002665	0.253227	0.031435	0.000008342	0.99
$Y_{Plivebr}$		X_1	X_2	X_3					
		Ln(db)	Ln(gr5)	Ln(age)					
	0	1	2	3					
	2.533220	1.989129	0.387203	0.105315					0,93
$Y_{Pdeadbr}$		X_1	X_2	X_3	X_4	X_5			
		Ln(db)	Ln(gr5)	Ln(age)	alt	eco			
	0	1	2	3	4	5			
	1.596001	2.441173	0.437497	0.711616	0.001358	0.000129			0,67
Y_{Sstem}		X_1	X_2	X_3	X_4	X_5	X_6	X_7	
		Ln (db+25)	db	Ln(gr5)	gr5	Ln(age)	Sl	nco	
	0	1	2	3	4	5	6	7	
	6.839310	3.578450	0.003042	0.093033	0.002763	0.111347	0.012148	0.000020194	0,99
$Y_{Slivebr}$		X_1	X_2	X_3					
		Ln(db)	Ln(gr5)	Ln(age)					
	0	1	2	3					
	0.718621	1.740810	0.348379	0.180503					0,96

Y _{Sdeadbr}		X ₁	X ₂	X ₃					
		Ln(db)	Ln(gr5)	Ln(age)					
	0	1	2	3					
	1.763738	2.616200	0.745459	0.359509					0,76
Y _{Bstem}		X ₁	X ₂	X ₃ ¹	X ₄ ²				
		Ln(db+7)	Ln(age)	Sl _P	Sl _S				
	0	1	2	3	4				
	3.091932	2.479648	0.243747	0.022955	0.22185				0,98
Y _{Blivebr}		X ₁	X ₂						
		Ln(db)	Ln(gr5)						
	0	1	2						
	2.782537	2.276815	0.228528						0,91
Y _{Bdeadbr}		X ₁							
		Ln(db)							
	0	1							
	2.059091	1.657683							0,46

APPENDIX F: VEGETATION AND SOIL MOISTURE CLASSES

Vegetation and soil moisture classes according to the Swedish National Forest Inventory (<http://www.slu.se/en/collaborative-centres-and-projects/swedish-national-forest-inventory/>)

Vegetation classes

- 1=Rich-herb without shrubs
- 2=Rich-herb with shrubs/bilberry
- 3=Rich-herb with shrubs/lingonberry
- 4=Low-herb without shrubs
- 5=Low-herb with shrubs/bilberry
- 6=Low-herb with shrubs/lingonberry
- 7=No field layer
- 8=Broadleaved grass
- 9=Thinleaved grass
- 10=Sedge, high, *Carex ssp.*,
- 11=Sedge, low, *Carex ssp.*,
- 12=Horsetail, *Equisetum ssp.*
- 13=European blueberry
- 14=Lingonberry
- 15=Crowberry
- 16=Poor shrub
- 17=Lichen, frequent occurrence
- 18=Lichen, dominating

Soil moisture classes

- 1=Dry (subsoil water depth >2 m)
- 2=Mesic (subsoil water depth = 1-2 m)
- 3=Mesic-moist (subsoil water depth <1 m)
- 4=Moist (subsoil water depth <1 m, and pools visible in hollows)
- 5=Wet (subsoil water pools visible)