PES Programs and commercial viability of forest restoration investments
A simulation study in Germany

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Oral thesis presentation

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Introduction

Forest Restoration Programs – Why?

The Paris Goals require…

- Annual reduction of 10 Gt CO_2 yr^{-1} *(WRI, 2023)*
- Forest can mitigate and remove up to 6 Gt CO_2 yr^{-1} p.a.
- Insufficient existing ***Land-Use**** funding equates to USD 14 bn in 2021 *(Buchner, 2021)*
- Depending on restoration scenario, up to 1 and 173 bn USD p.a. needed *(Austin et al., 2020)*

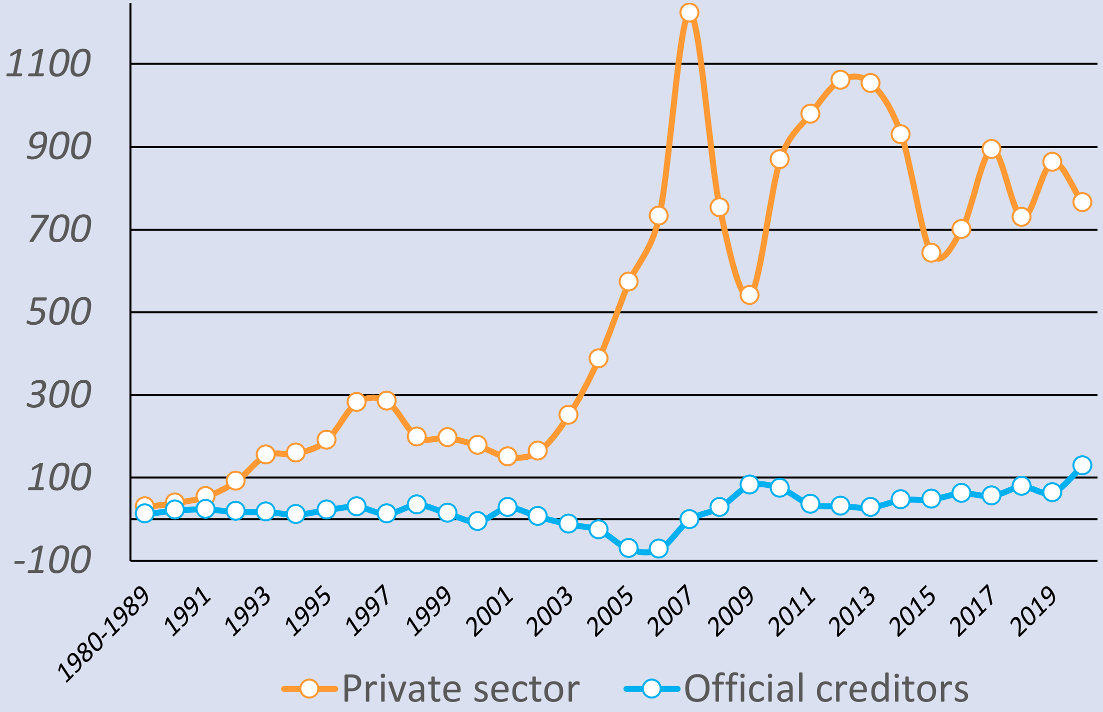
Who could provide so much capital?

**Climate Policy Initiative data, LU includes agriculture, biodiversity, restoration, …*

The Case of Development Finance

Aggregate Net Financial Flows to Low- and Middle-Income Countries

1980 to 2020, in Billion USD



Source: Own representation, based on World Bank International Debt Statistics (2022)
"1980-1989" refers to the average value across the timeframe

Research questions and objectives

Private Sector Mobilization with attractive PES?

„We can't save forests without the private sector"

R. Parizat (World Bank, 2020)

- Simulation study: Can PES programs lead to commercial viability of mixed-species, biodiversity-rich restoration* projects in Germany?

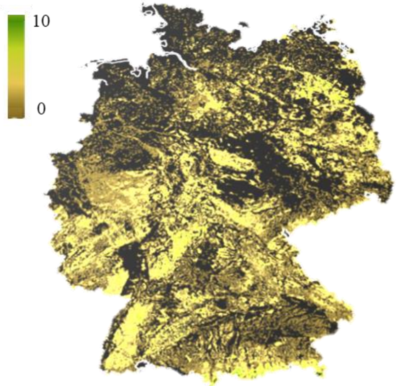
  - Are current carbon prices sufficient to turn restoration profitable?
  - Which carbon-prices are needed to turn projects profitable?
  - Which PES systems increase investment attractivity by how much?

Creating a common language for all stakeholders (policy makers, ecologists & investors)

*Restoration includes reforestation and afforestation (assisted migration)

The German Situation

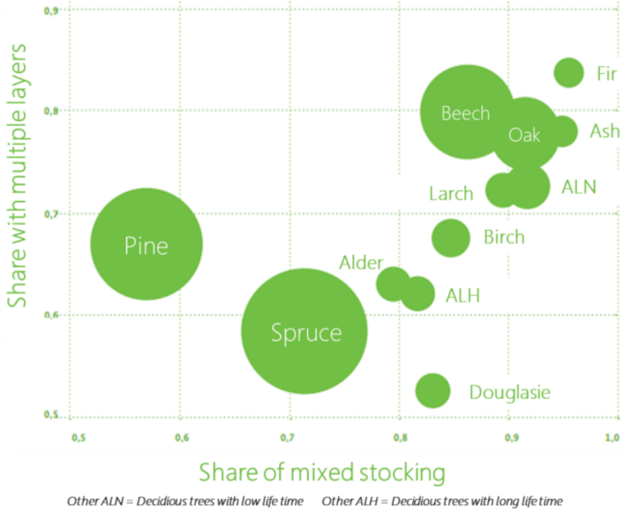
Dying monocultures and the need for new policy



Forest Integrity Index

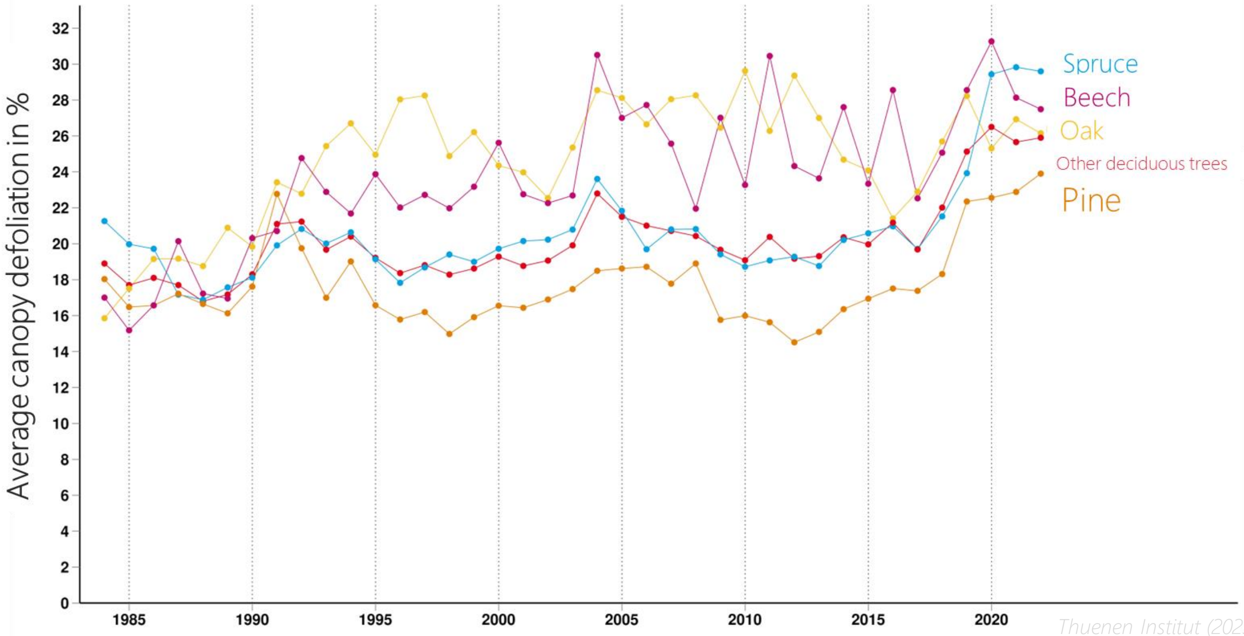
Grantham et al. (2020)

Planted conifer monocultures
dominate existing forests



Forest structure (BMEL, 2021)

"Since 2018, more than 300,000 hectares of Germany's trees (2.5% of total) have died because of bark-beetles and drought, fuelled by a warming climate."
Popkin (2021)



Thuenen Institut (2023)

*"Everyone agrees that **new approaches are needed**, but no one, it seems, can agree on what those should be…*
…Others say, […] Germany must double down on tree planting"
Popkin (2021)

Study Overview

Five major steps

Identification of restoration sites

1

Mapping of Restoration potential in Germany

Selection of sites for analysis

2

Data set generation

Site Clustering

Selection of Exemplary Project sites

Simulation of forest growth paths

3

Pre/Post Stem Biomass & Habitat Quality

Planting and Land cost data collection

Transformation of sites into financial assets

4

Financial Model development (DCF)

Data integration

Scenario analysis

5

Profitability modelling with Biodiversity and Carbon-based remuneration

Step 1 – Identification

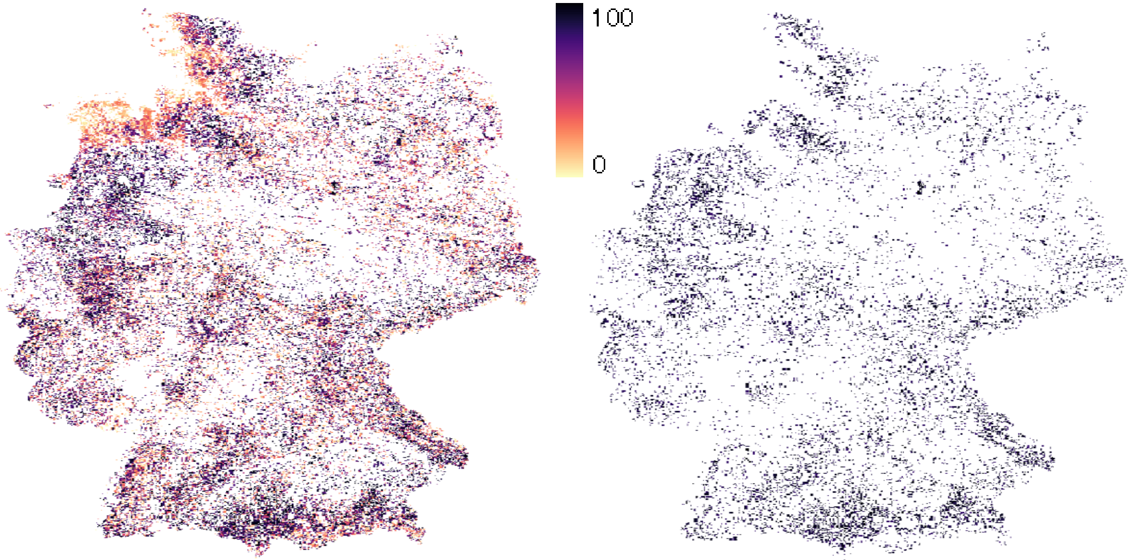
Forest coverage potential in Germany

1.1 Where is additional tree cover possible?

1.2 Where is closed forest restoration possible?

Identification of possible locations in Germany utilizing *Bastin et al. (2019)* data

Exclusion of sites with less than 80% tree cover



Own representation based on Bastin et al. (2019)

N = 62,778 possible locations with a restorative potential of 80% or greater were identified across Germany

Step 2 – Site Selection (1)

Dataset Generation

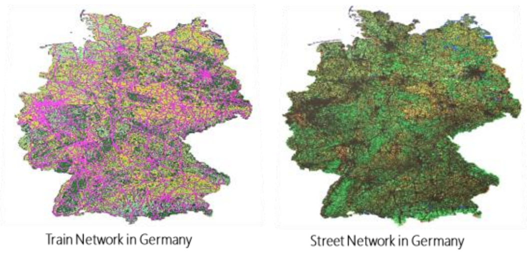
2.1 Generation of dataset for clustering

2.2 Clustering of all identified sites into groups using Principal Component Analysis and Affinity Propagation (Dueck and Frey, 2007)

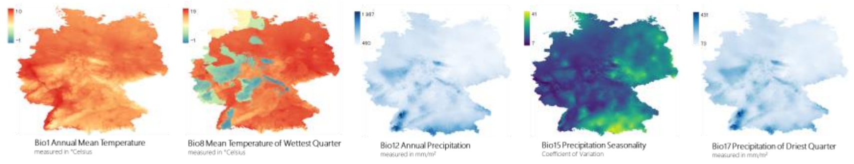
2.3 Selection of group exemplars for further analysis

InVEST Habitat Quality as Biodiversity approximation

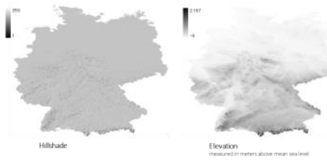
Inputs
InVEST Habitat Quality Model



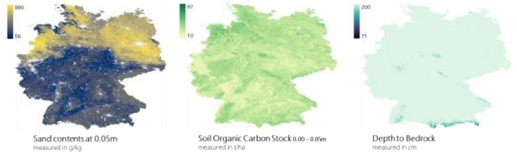
5 Climatic Variables



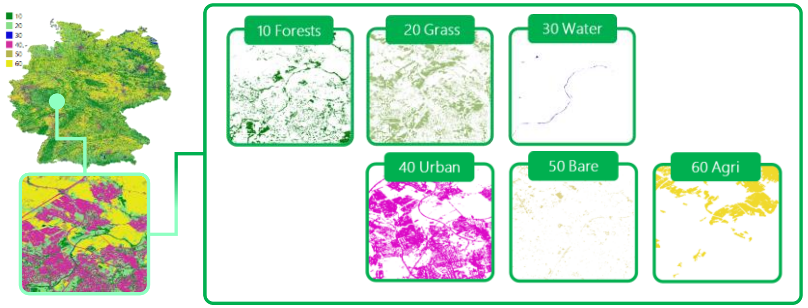
2 Topo-graphic variables



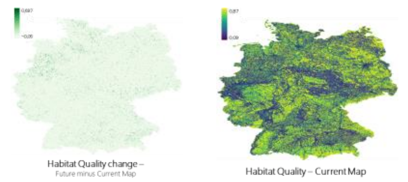
3 Soil variables



6 Land Use classes



1 Habitat quality variable



Outputs
InVEST Habitat Quality Model

Own representation, various sources

Step 2 – Site Selection (2)

Dataset Generation

2.1 Generation of dataset for clustering

2.2 Clustering of all identified sites into groups using Principal Component Analysis (PCA) and Affinity Propagation

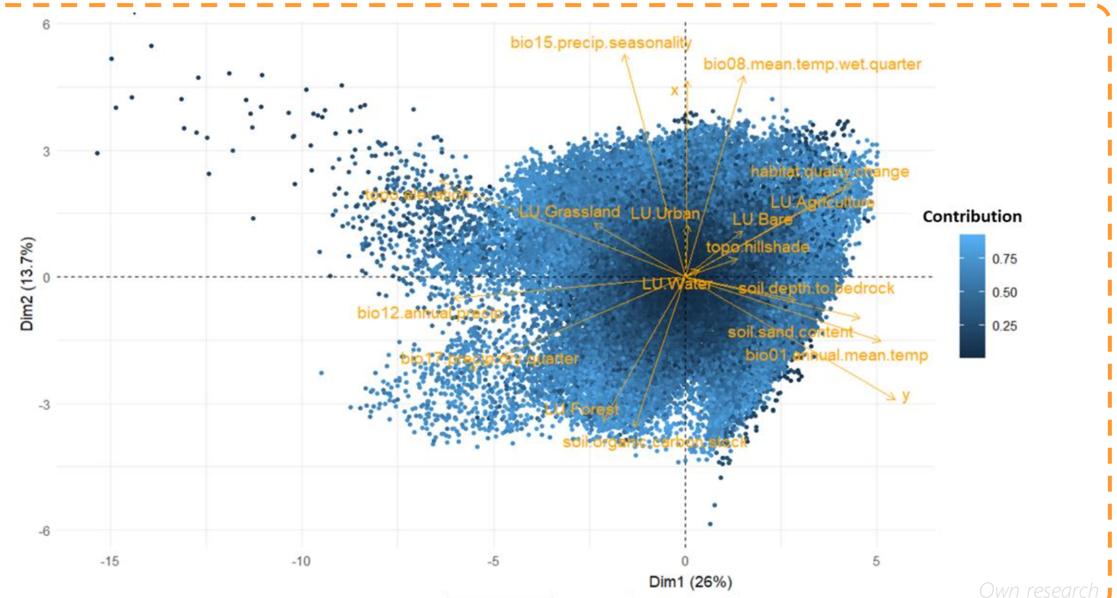
2.3 Selection of group exemplars for further analysis

Clustering and site selection results

In total 92 sites were identified as exemplars

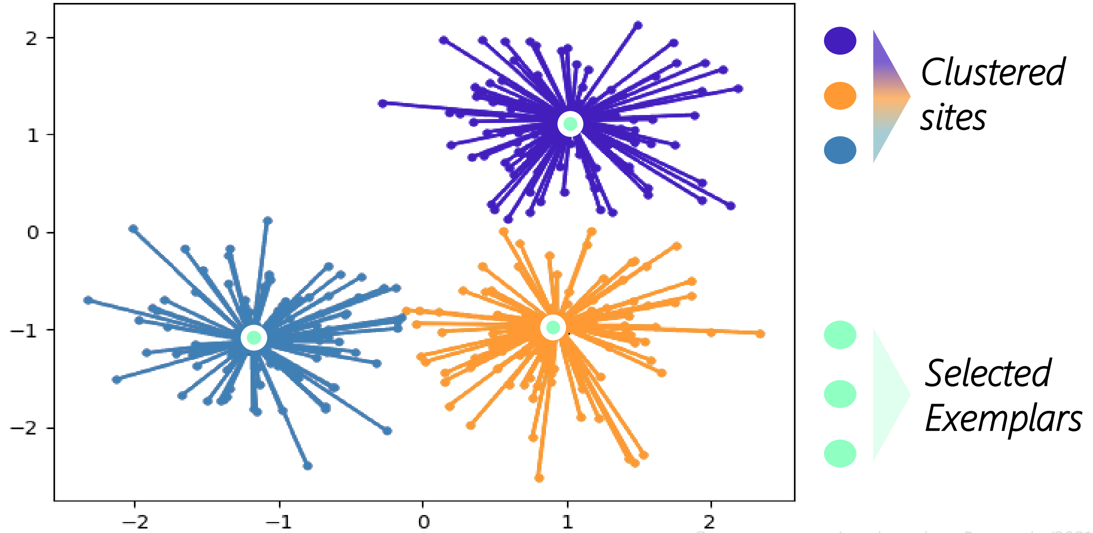
79 sites were selected for the subsequent analysis

Data representation after PCA



Own research

Affinity propagation visualization (Example with only 3 identified clusters)



Own representation, based on Praneeth (2021)

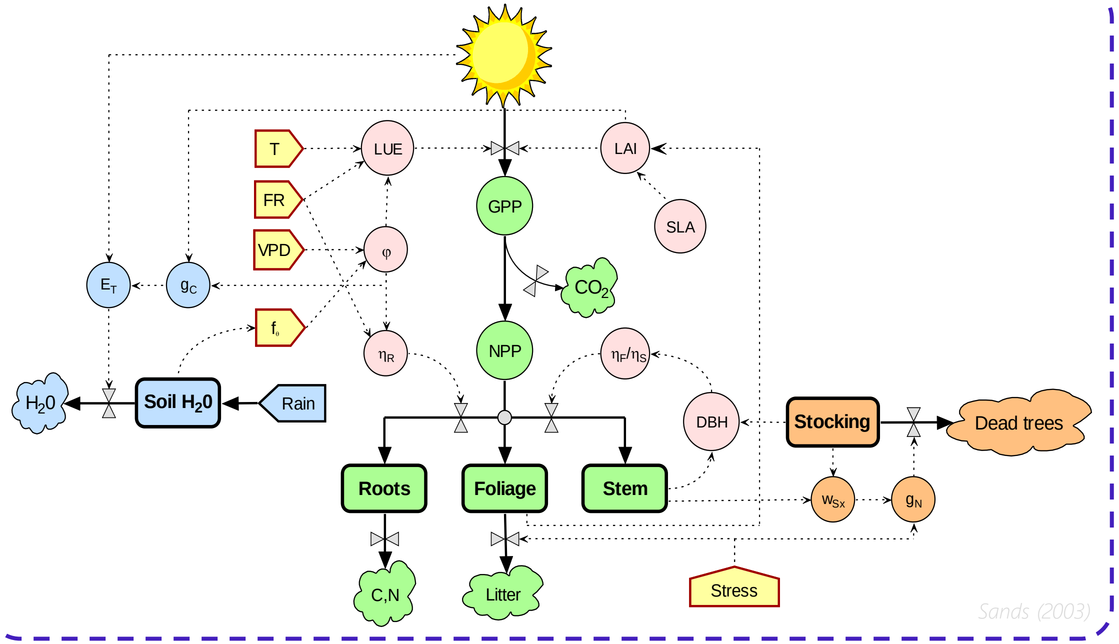
Step 3 – Forest growth simulation (1)

Restoration simulation using 3-PG and InVEST HQ Model

3.1 Assess current & project future natural capital stock using 3-PG model and InVEST framework

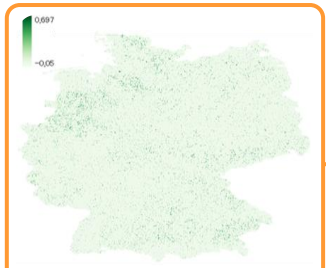
3.2 Data Collection for Financial Model

3-PG Model (Physiological Processes Predicting Growth)



Sands (2003)

Exemplary sites



Habitat Quality change – Future minus Current Map

Site-specific 3-PG inputs

Using InVEST Habitat Quality & 3-PG to simulate restoration

Restoration site A

Pre-restoration (in 2024)

Stem biomass = 0 Mg/ha
Habitat value = 0.05

InVEST integrated valuation of ecosystem services and tradeoffs

Restoration site A

Post-restoration (in 2075)

Stem biomass = 150 Mg/ha
Habitat value = 0.4

Step 3 – Forest growth simulation (2)

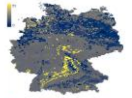
3-PG Inputs and Outputs

3.1 Assess current & project future natural capital stock using 3-PG model and InVEST framework

3.2 Data Collection for Financial Model

3-PG Model Inputs (>120 parameters) for all 79 sites

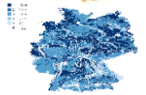
Soil and Site Variables



Topsoil share of clay in %

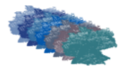
Topsoil share of silt in %

Topsoil share of sand in %



Available soil water capacity

Elevation



7 Soil Quality Indicators

Tree-specific Variables

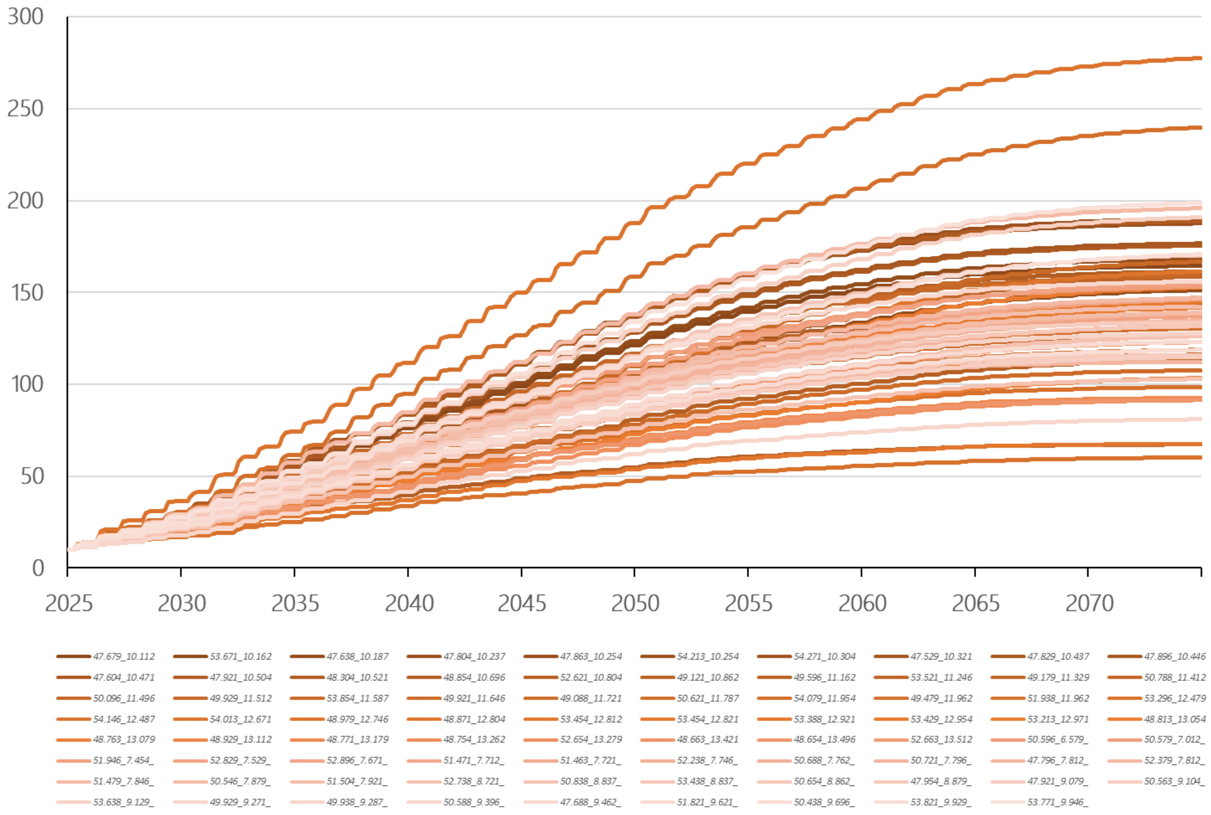
- *220x Acer Pseudoplatanus (Syc. Maple)*
- *220x Fagus Sylvatica (European Beech)*
- *220x Fraxinus Excelsior (European Ash)*
- *220x Quercus Petraea (Sessile Oak)*
- *220x Quercus Robur (English Oak)*

- *Tree Site suitability from Mauri et al (2022)*
- *Tree Growth factors from Forester (2021)*

Climate Variables

- *Temperature (T_Max, T_Min, T_Mean) projection 2025 to 2075*
- *Precipitation*
- *Frost Days*
- *Solar Radiation*
- *Atmospheric CO2 abundance*

3-PG Output of 79 sites
Simulated stem biomass trajectories for each site (in Mg/ha)



Step 3 – Data Collection (3)

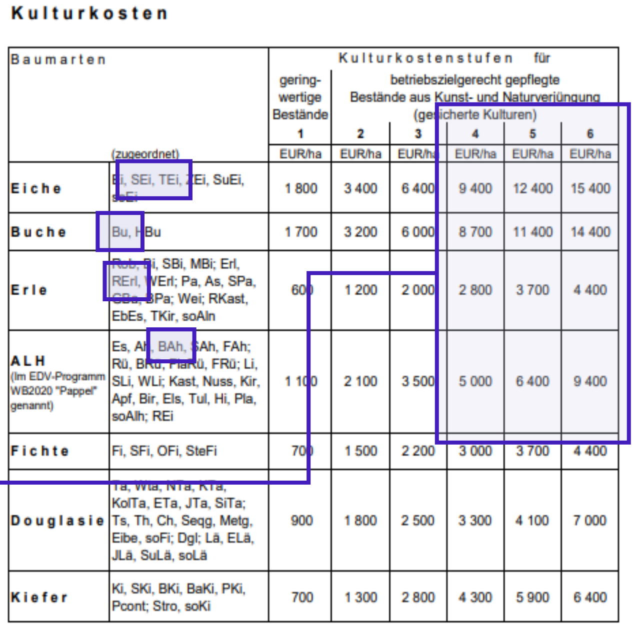
Planting and Land acquisition costs

3.1 Assess current & project future **natural capital stock** using 3-PG model and InVEST framework

3.2 Data Collection for financial model

Planting Costs, retrieved from Federal Forest administrations

Planting costs per tree type in EUR per planted ha

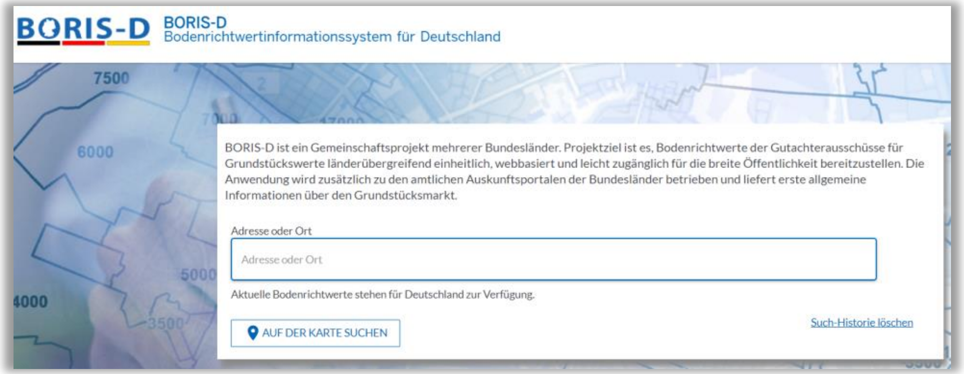


Kulturkosten

Baumarten	(zugeordnet)	Kulturkostenstufen für: geringwertige Bestände 1	betriebszielgerecht gepflegte Bestände aus Kunst- und Naturverjüngung (gesicherte Kulturen) 2	3	4	5	6
		EUR/ha	EUR/ha	EUR/ha	EUR/ha	EUR/ha	EUR/ha
Eiche	Ei, SEi, TEi, ZEi, SuEi, soEi	1 800	3 400	6 400	9 400	12 400	15 400
Buche	Bu, HBu	1 700	3 200	6 000	8 700	11 400	14 400
Erle	Rob, Bi, SBi, MBi; Erl, RErl, WErl; Pa, As, SPa, GPa, BPa; Wei; RKast, EbEs, TKir, soAln	600	1 200	2 000	2 800	3 700	4 400
ALH (Im EDV-Programm WB2020 "Pappel" genannt)	Es, Ah, BAh, SAh, FAh; Rü, BRü, FlaRü, FRü; Li, SLi, WLi; Kast, Nuss, Kir, Apf, Bir, Els, Tul, Hi, Pla, soAlh; REi	1 100	2 100	3 500	5 000	6 400	9 400
Fichte	Fi, SFi, OFi, SteFi	700	1 500	2 200	3 000	3 700	4 400
Douglasie	Ta, WTa, NTa, KTa, KolTa, ETa, JTa, SiTa; Ts, Th, Ch, Seqg, Metg, Eibe, soFi; Dgl; Lä, ELä, JLä, SuLä, soLä	900	1 800	2 500	3 300	4 100	7 000
Kiefer	Ki, SKi, BKi, BaKi, PKi, Pcont; Stro, soKi	700	1 300	2 800	4 300	5 900	6 400

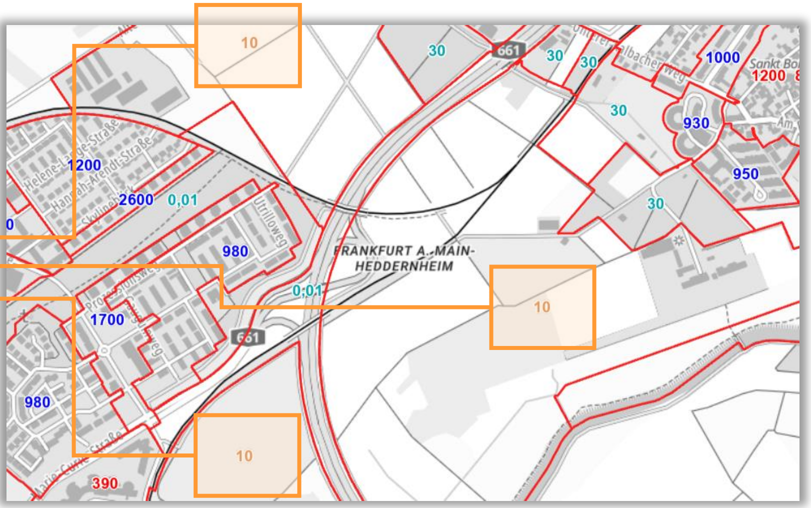
Niedersächsiche Landesforsten (2020)

Land Acquisition cost collection using German Land price database BORIS-D for each location individually



BORIS (2022)

Land acquisition costs in EUR per m²

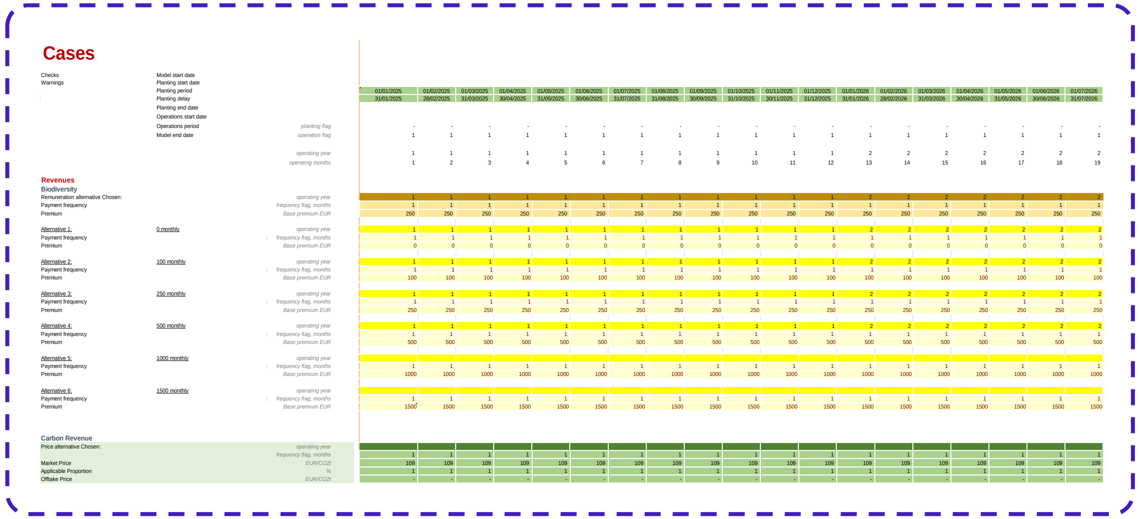


Step 4 – Consolidation

Incorporation of both geophysical, biological and financial data

4.1 Development of financial model
Discounted Cashflow Model and WACC

4.2 Integration of project-site and cost data into financial models



Model Variables (all 79 sites)		
Revenues		
Biodiversity premium	*variable (in EUR/month)*	*Fully flexible*
Carbon sales	*variable (in EUR/month)*	
Capital Expenditures (CAPEX)		
Planting costs	*Cost level 1 (low)*	*Choose level*
	Cost level 2 (medium)	
	Cost level 3 (high)	
Land acquisition cost	*Existing Ownership (0)*	*Choose level*
	Grazing land (low)	
	Farm land (high)	
Operating Expenditures (OPEX)		
Insurance	*3.00 (EUR/month)*	
Salary	*2.22 (EUR/month)*	
Interest Spread	*1.50% spread (low)*	*Choose level*
	2.50% spread (high)	
Financing costs		
WACC	*4.80% (calculated)*	
tax rate (T_c)	*30.00%*	
risk-free rate (r_f)	*2.10%*	
market premium (r_m)	*5.94%*	
unlevered beta (β)	*0.84*	

Step 5 – Scenario analysis (1)

PES Evaluation

5.1 **Test PES concepts** and **adjust rewards** to simulate effects on key financial ratios (NPV, IRR,…)

$$\boldsymbol{NPV} = C_0 + \sum_{t=1}^{T} \frac{C_t}{(1+r)^t}$$

$$NPV = Net\ present\ value$$

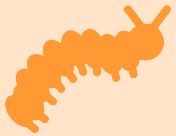
$$C_t = Cashflows\ in\ period\ t$$

$$r = discount\ rate\ (e.g., WACC)$$

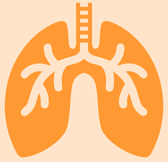
$$0 = C_0 + \sum_{t=1}^{T} \frac{C_t}{(1+\boldsymbol{IRR})^t}$$

$$IRR = Internal\ rate\ of\ return$$

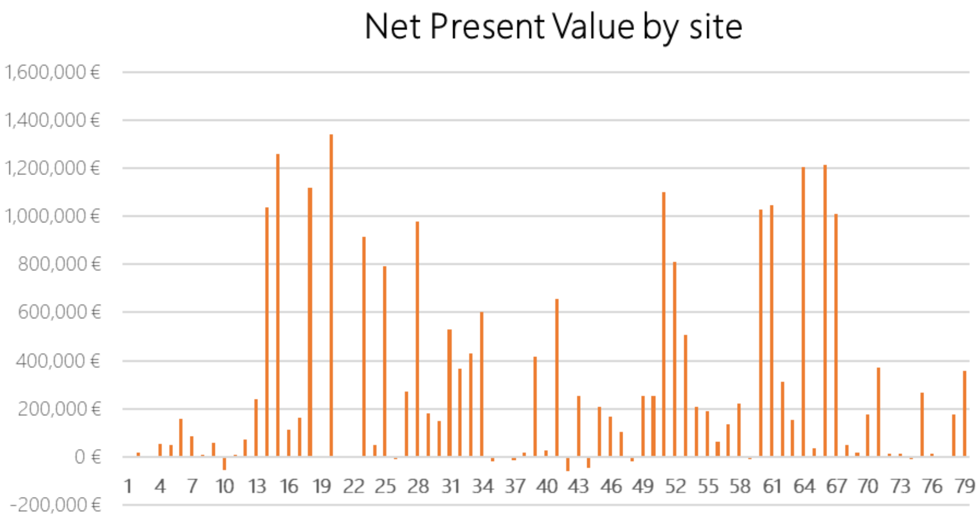
Exemplary PES Revenues



Biodiversity premium, each month of no thinning earns [X] USD/EUR*



CO_2 sequestration, every ton can be sold on carbon market for [X] USD/EUR.



**Max. Biodiversity premium, to be multiplied with site-specific habitat quality change factor*

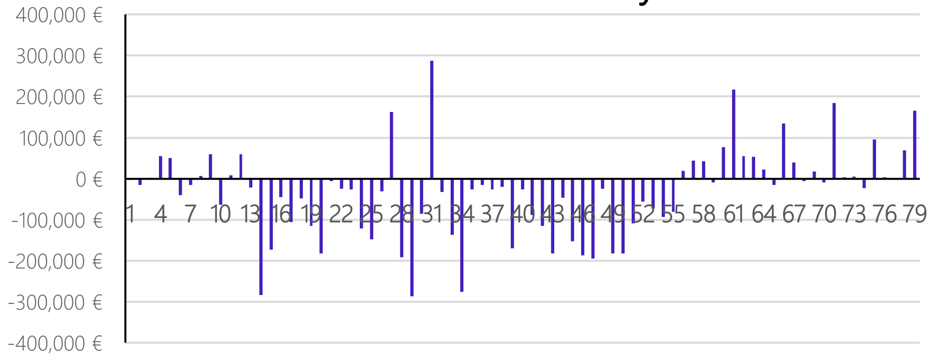
Step 5 – Scenario analysis (2)

Results – Research Questions 1 - 2

Question 1: Current Prices and Profitability?

Case Details			
Biodiversity	0 monthly		
Carbon	World Bank USD 120		
Planting costs	Cost level 1 (4)		
Land acq cost	Existing Ownership		
Interest_Spread	1.50% spread		
Variables	Average	Stdev	**Median**
Site_size	30.65	13.65	**36**
Habitat	9.67%	0.10	**0**
NPV	(33431)	108552	**(22589)**
IRR	-0.67%	2.31%	**-0.49%**
MinDSCR	-16.14%	0.38	**-0.4**
AvgDSCR	3.20	1.06	**3.2**
MedianDSCR	0.42	0.53	**0.3**
Accreditive NPV	34.18%		

Net Present Value by site



Question 2: Which price is needed to reach profitability for the majority of sites? (>50%)

Case Details	
Biodiversity	0 monthly
Carbon	*To be calculated*
Planting costs	*Changing*
Land acq cost	*Changing*
Interest_Spread	1.50% spread
Accreditive NPV	51.90%

changing but always above 50%

Q2: Only carbon - Goal set >50% Profitability

	Price in EUR	*Planting costs* 1	2	3
Land acquisition costs	1	125	*160*	*210*
	2	*444*	*475*	*550*
	3	*670*	*700*	*755*

Step 5 – Scenario analysis (3)

Results – Research Question 3

Question 3: WB High Price and Biodiv. Premia focussed on max returns

Case Details	
Biodiversity	*Variable, goal seeking*
Carbon	World Bank USD 120
Planting costs	*Variable*
Land acq cost	*Variable*
Interest_Spread	1.50% spread
Insurance p.m.	3.00
Salary p.m.	2.22
WACC	4.80%
tax rate (T_c)	30.00%
risk-free rate (r_f)	2.10%
market premium (r_m - r_f)	5.94%
Unlevered beta	0.84

100 BioP

	Price in EUR	Planting costs 1	Planting costs 2
Land acquisition costs	1	65.82% profitable, 6.18% Max returns	30.38% profitable, 3.59% Max returns
Land acquisition costs	2	2.5% profitable, 0.58% Max returns	0% profitable, -0.07% Max returns

250 BioP

	Price in EUR	Planting costs 1	Planting costs 2
Land acquisition costs	1	84.54% profitable, 10.39% Max returns	58.23% profitable, 6.93% Max returns
Land acquisition costs	2	12.66% profitable, 3.76% Max returns	8.86% profitable, 2.76% Max returns

- *Monthly Biodiversity premium* of 250 EUR turns forest restoration into highly lucrative investment opportunity for existing landowners (farmers)*
- *Land Acquisition costs were identified as key factor across all simulations*

**Max.Biodiversity premium to be multiplied with site-specific habitat quality change factor*

Summary

- A total of N = 62,277 with greater than 80% restoration potential were identified in Germany
- Using PCA and Affinity Propagation clustering as trade-off, 79 exemplary sites were selected
- 3-PG simulation predicted forest (stem) biomass in line with existing research
- Standardized tree- and individual site-specific cost data were collected across all sites
- An integrated DCF model was developed, enabling simulation of changing carbon- and biodiversity remuneration policy across all 79 sites
- Scenario analysis suggest insufficiency of current carbon price levels for restoration investments in Germany and indicates land prices as crucial factor

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Backup slides

Step 2 – Clustering Example

Project site clustering (Example)

Group 1

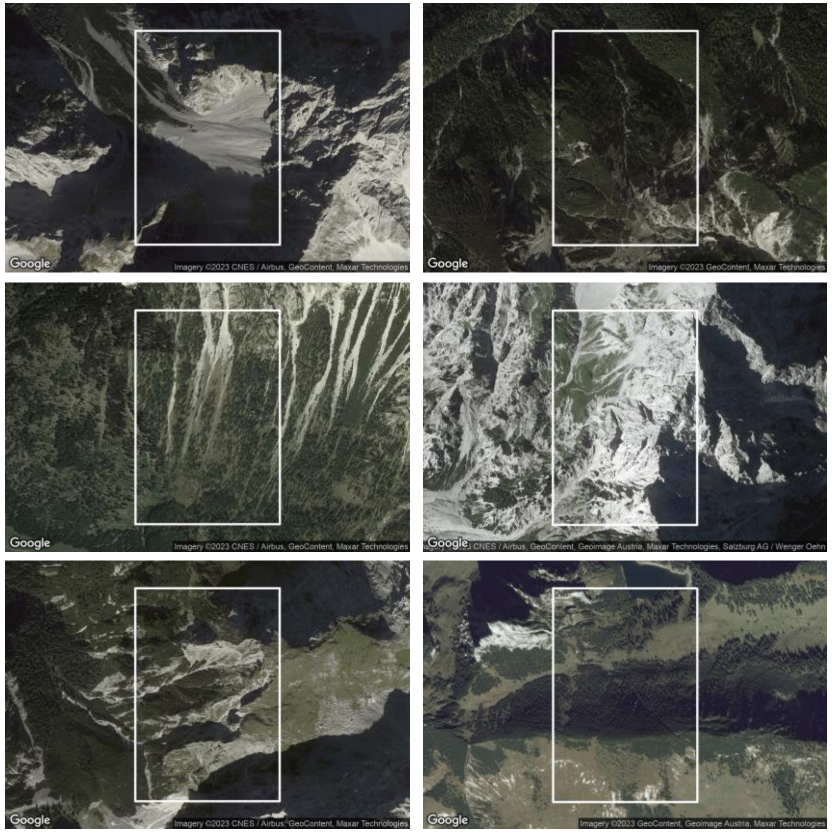
Group 2

	Identified site 1	*Identified site 2*	*Identified site 3*	*Identified site 4*
temperature	25 C°	18 C°	26 C°	16 C°
precipitation	750 mm p.a.	950 mm p.a.	750 mm p.a.	850 mm p.a.
soil content	sandy	no sand	sandy	no sand
elevation	0 meters	240 meters	0 meters	180 meters
Habitat quality change	0.15	0.02	0.21	0.00

2.2 Clustering of all identified sites into groups using *Principal Component Analysis (PCA)* and *Affinity Propagation*
(Dueck and Frey, 2007)

Step 2 – Site Selection

Removing inapt sites - From 92 to 79 sites



Low future (or current) suitability values *according to Mauri et al. (2022)*

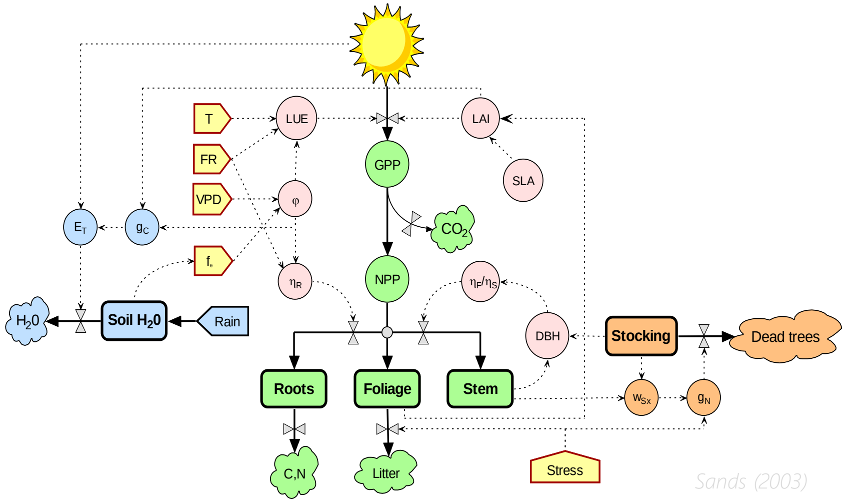
Solar panels installed

Already reforested

Step 3 – 3-PG model (1)

From Solar Radiation to Stem Biomass Growth trajectories

3-PG Model (Physiological Processes Predicting Growth)



Sands (2003)

The 3-PG Model, invented by Landsberg and Waring (1997), is a **popular, highly flexible process model.**

By representing nature via mathematical formulas, the model can **effectively simulate climate change effects and forest restoration on new sites.**

Beer's Law

$$Q_{\text{int}} = (1 - e^{-kL})Q_0$$

$\mathbf{Q_o}$ = *Incoming Solar Radiation*
$\mathbf{L}$ = *Leaf Area Index*
$\mathbf{k}$ = *Extinction coefficient*
$\mathbf{E}$ = *Euler*
$\mathbf{Q_{int}}$ = *Intercepted Solar Radiation*

Sands (2003)

Light use efficiency

$$\alpha_C = f_T f_F f_N \min\{f_D, f_\theta\} f_{age} \alpha_{Cx}$$

Factor	Modifier
Vapor pressure deficit	$f_D(D)$
Soil water	$f_\theta(\theta)$
Temperature	$f_T(T_{av})$
Frost	$f_F(d_f)$
Site nutrition	$f_N(FR)$
Stand age	$f_{age}(t)$

$$f_D(D) = e^{-k_D D}$$

$$f_\theta(\theta_S) = \frac{1}{1 + [(1 - \theta_S/\theta_{SX})/C_\theta]^{n_\theta}}$$

$$f_T(T_a) = \left(\frac{T_a - T_{min}}{T_{opt} - T_{min}}\right)\left(\frac{T_{max} - T_a}{T_{max} - T_{opt}}\right)^{(T_{max}-T_{opt})/(T_{opt}-T_{min})}$$

$$f_F(d_f) = 1 - (d_f/30)$$

$$f_N(FR) = 1 - (1 - f_{N0})(1 - FR)^{n_{fN}}$$

$$f_{age}(t) = \frac{1}{1 + [(t/t_x)/r_{age}]^{n_{age}}}$$

α_{Cx} is maximum canopy quantum efficiency

Sands (2003)

Step 3 – 3-PG model (2)

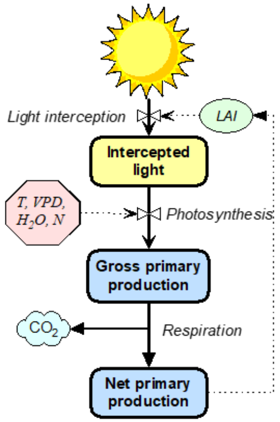
From Solar Radiation to Stem Biomass Growth trajectories

Primary production
Gross/Net

$$P_g = \alpha_C (1 - e^{-kL}) Q_0$$

$$P_n = Y P_g = \varepsilon Y (1 - e^{-kL}) Q_0$$

$$Y = 0.47 \text{ (constant)}$$



Sands (2003)

Biomass partitioning

$$\Delta W_F = \eta_F P_n - \gamma_F W_F$$

$$\Delta W_R = \eta_R P_n - \gamma_R W_R$$

$$\Delta W_S = \eta_S P_n$$

(γ_F)	Litter-fall
η_F	Partition rate foliage
W_F	Foliage biomass pool
(γ_R)	Root turnover
η_R	Partition rate root
W_R	Root biomass pool
η_S	Stem biomass pool
W_S	Partition rate stem

Sands (2003)

Step 4 – Underlying financial theory

Weighted Average Cost of Capital (WACC)

return on debt (e.g, bank loan effective rate)

$$r_D = r_f + credit\ spread$$

$$\text{WACC} = r_E * \frac{E}{E+D} + r_D(1 - T_C)\frac{D}{E+D}$$

The Weighted Average Cost of Capital (WACC) is a financial metric that calculates the average cost of capital for a company. Considering the proportionate weights of equity and debt in the company's capital structure, the WACC is a combination of the cost of equity, represented by the expected return demanded by investors, and the cost of debt, depicted by the cost of borrowing funds. By assigning weights to each financing source based on their market values, the WACC provides a single discount rate used to assess the present value of future cash flows, reflecting both opportunity costs and the tax shield of debt (T_c)

$$r_E = required\ rate\ of\ return\ on\ equity\ (CAPM)$$

$$E = market\ value\ of\ company\ equity$$

$$D = market\ value\ of\ company\ debt$$

$$T_C = applicable\ tax\ rate$$

Capital Asset Pricing Model (CAPM)

$$r_E = r_f + \beta * (r_m - r_f)$$

1) Corporation tax is levied at a rate of 15.825%, comprising a uniform rate and a "solidarity surcharge". (*"Körperschaftssteuer"*)

2) Trade tax comprises a base rate of 3.5%, multiplied with an additional local municipality factor, ranging from 250% to 1000%. (*"Gewerbesteuer"*)

3) Total tax rates typically range from 28 to 35%, simplified as 30% within this study

Step 4 – Underlying financial theory

Capital Asset Pricing Model (CAPM)

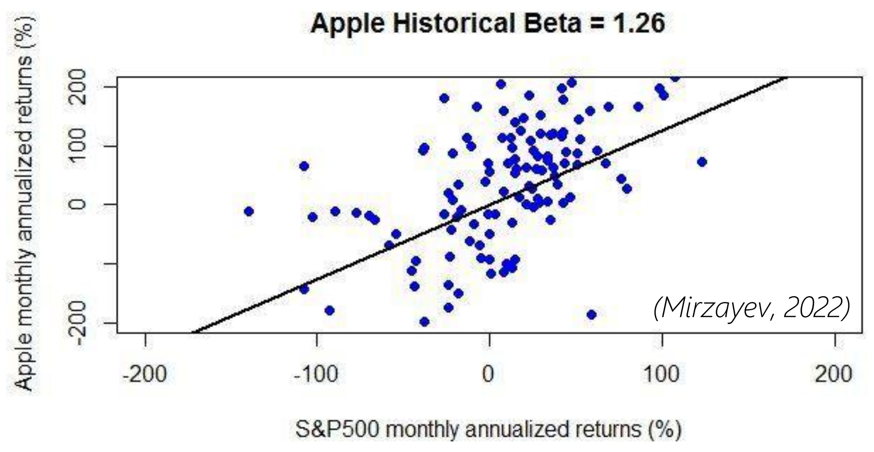
Risk-free rate

The risk-free rate refers to the theoretical **rate of return on an investment with zero risk**. It serves as a **baseline for evaluating the expected returns of riskier investments** and is associated with the yield on government bonds, considered to have negligible default risk.

The beta factor is a measure of a stock's sensitivity to systematic market risk. In the context of CAPM, **beta quantifies the relationship between the returns of an individual stock and the returns of the overall market.** A beta of 1 indicates that the stock tends to move in line with the market. A beta greater than 1 suggests the stock is more volatile than the market, while a beta less than 1 indicates lower volatility.

$$r_E = r_f + \beta * \underbrace{(r_m - r_f)}$$

The equity risk premium represents the **additional return investors expect to earn from investing in risky securities** (here: stocks) compared to the risk-free rate, **compensating for the higher risk accepted.**



Unlevered Beta

Unlevered beta is frequently used in valuation models to estimate the risk associated with a specific investment or project, providing a **pure measure of the risks associated with the asset, excluding financial structure impact.**