KIT - ITAS

Model Analysis

Analysis of available models to estimate the potential of biomass for energy use

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Interim Report for Task 1.2. of the project ‚Biomasse OUI - Innovations for sustainable utilization of biomass in the Upper Rhine Region'

16.07.2013

Description and analysis of all researched models for biomass evaluation in the Upper-Rhine region

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1 Analysis scheme

1.1 Approach in the analysis of investigated models:

1) Input-parameter

2) Output-parameter

3) Basic conditions/framework: gives criteria for the transferability (= regionalization)

a. main conditions

b. constraints

4) Algorithm: structure or mathematic algorithms by which the model is described

1.2 Structure in the written summary:

1 Model name:

2 Types of biomass:

3 Region:

4 Input:

5 Output:

6 Conditions:

7 Algorithm:

8 Assessment of the model:

a. Transferability (regionalization)

b. Reproducibility (algorithm completely understandable? Applicability, availability of data)

Table 1: Table format analysis scheme

1. Model name	**NAME, [source]**
2. Type of Biomass	Type
3. Region/resolution	Location or scope/unit area
4. Input	Data
5. Output	Result, data, mapping, objective functions
6. Conditions	Various conditions
7. Algorithm	Functions, tools, etc.
8. Assessment of the model	
a) Transferability	Yes/no
b) Reproducibility	Yes/no

1.3 Bioenergy potentials

The determination of bioenergy potential is divided into theoretical, technical, economic and sustainable potentials.

Definition of potentials[1]:

- THEORETICAL POTENTIAL:
  Physical upper limit of energy which is from a specific source.

- TECHNICAL POTENTIAL:
  Modified on the annual efficiency of the respective conversion path (technology-specific) from the theoretical potential.

ECONOMIC POTENTIAL:

- Economically exploitable part of the technical potential, taking into account the economic conditions.

[1] [1]????

- SUSTAINABLE POTENTIAL:
  Takes all dimensions of sustainability into account, only blurred demarcation possible because definitions and limitations of sustainability can be interpreted differently and will be interpreted differently.

2 Analysis of models that were part of our research

Research for models that assess the availability of agricultural and forest biomass was done. The focus was on models that demonstrate the status quo of biomass potentials and that even allow the evaluation of their potential use.

2.1 The biomass-yield model

1. Model name	**Bym, biomass-yield-model, [2]**
2. Type of Biomass	Assumably agricultural biomass, no specific definition
3. Region/resolution	Republic of Germany on a county-level
4. Input	CORINE 2000, yield data from different data bases, other parameters
5. Output	Spatial modeling with ArcGIS and 3 scenarios
6. Conditions	see algorithm
7. Algorithm	Three dimensional yield function for each type of crop, under consideration of different parameters. No sufficient description of the algorithm (see figure)
8. Assessment of the model	
a) Transferability	Theoretically it can be applied on a regional level, however, the description is insufficient to explicitly evaluate the transferability
b) Reproducibility	Not reproducible with the information that is available

2.2 A GIS-based approach to evaluate biomass potential from energy crops at regional scale

1. Model name	**-, [3]**
2. Type of Biomass	Energy plants
3. Region/resolution	Italien, Emilia-Romagna/?
4. Input	Agricultural data on a regional level
5. Output	Maximization of the energy production of energy crop (wooden and herb-rich biomass)
6. Conditions	Both GIS-Data and yield data
7. Algorithm	1. Produce a data base that includes information concerning needed environmental parameters for each type of crop (soil-type and -fertility, climate, geomorphology, land-suitability, availability of water ...) 2. Determining the amount of soil/area that is potentially available and actually used. Political and social restrictions have to be taken into account. 4. Determining land use. This step bases on the assumption, that there is a best solution for a certain type of crop. If not, then the algorithm has to be optimized. See figure 1.
8. Assessment of the model	Complex algorithm with quite a few coefficients. Basically the model consists of summations.
a) Transferability	Potentially yes.
b) Reproducibility	In parts it is reproducible since formulas are provided

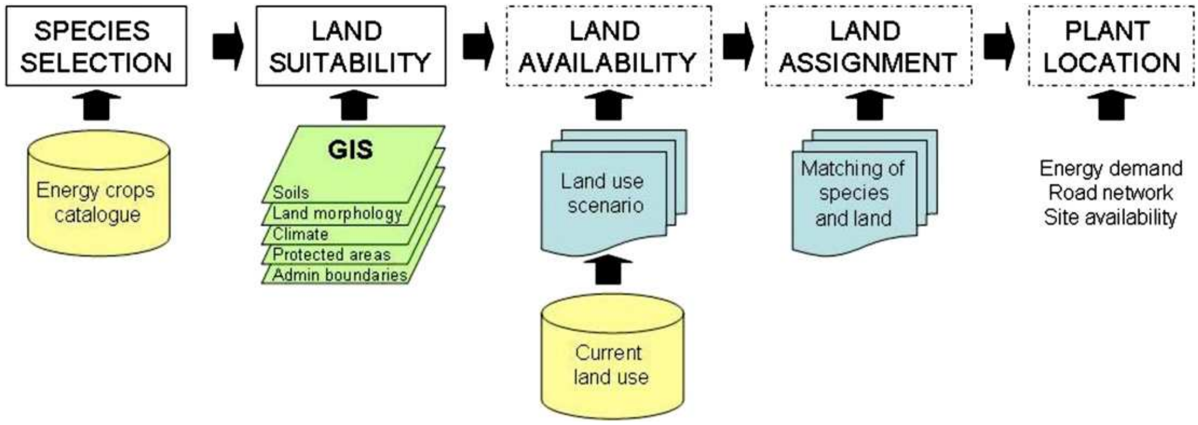


Figure 1: Model scheme

2.3 Land use implications of increased biomass production identified by GIS-based suitability and yield mapping for *Miscanthus* in England

1. Model name	**-, [4]**
2. Type of Biomass	Renewable primary products, permanent crop, *Miscanthus*
3. Region/resolution	England/1 ha
4. Input	GIS-data and statistical, agricultural data regarding yield and crop growing areas
5. Output	The output demonstrates the consequences of potential *Miscanthus* yields so that conclusions regarding competition of land usage or other problems with respect to conservation areas can be drawn.
6. Conditions	Consideration of environmental- and social/economical factors
7. Algorithm	1. ArcGIS-maps of *Miscanthus* yields and resource distribution in England (see „Yield-Mapping") 2. Identifying places that are not suitable for bioenergy production, according to 9 or 11 factors (see „suitability-mapping") 3. Examining the current land use to evaluate if a transformation, that aims at a bioenergetical use, is possible (see figure 2)
8. Assessment of the model	

a) Transferability	
b) Reproducibility	Insufficient description of the algorithm

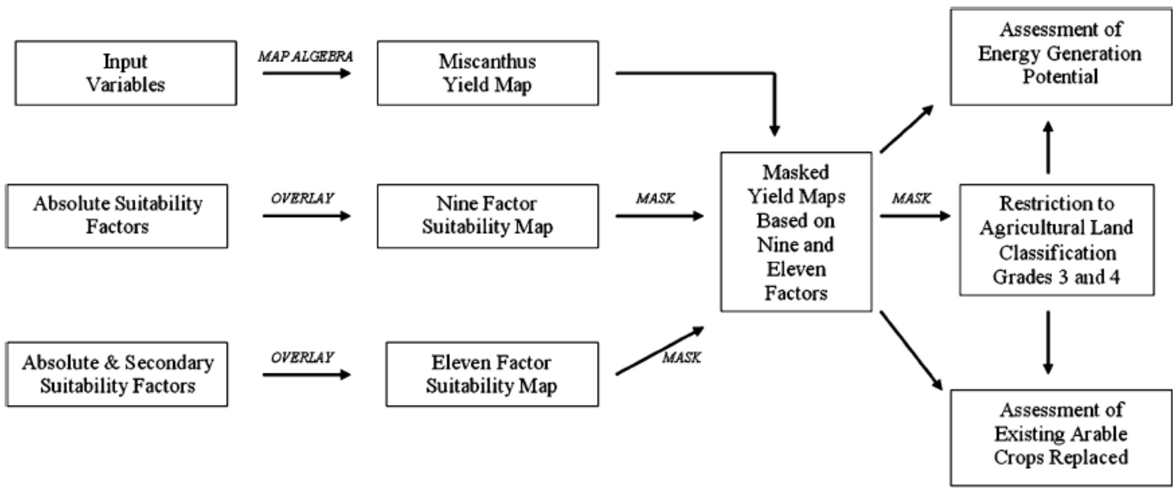


Figure 2: Scheme of model nr. 2.3

2.4 YIELDSTAT – a model for regional yield estimation (Workshop: "Modeling of soil-crop system - Challenges of the 21st Century)

1. Model name	**YIELDSTAT (ZALF, LfLUG, TU-Dresden), [5]**
2. Type of Biomass	Agricultural biomass
3. Region/resolution	Thuringia, Saxony/?
4. Input	Yield data
5. Output	Hybrid scheme based on statistical data that assesses the regional biomass yield for Thuringia. Transferability has been tested for the region of Saxony. The model consists of four different levels, a yield assessment until 2050 is possible and includes several scenarios. These scenarios consider different CO_2 concentrations on the basis of climate change.
6. Conditions	Yield assessment for different regions region
7. Algorithm	1. Level: yield matrix according to [6] site-dependent algorithms. 2. Level: site-specific yield functions 3. Level: trend overlay → statistical trend analyses and trend

	extrapolations 4. level: influence of different CO_2 concentrations, based on the FACE-experiments of vTI-Braunschweig (source: Weigel et al., 2005) (see figure 3) In contrast to the paper published in 2009, the model consists now of 5 levels (see http://www.zalf.de/de/forschung/institute/lsa/forschung/oekomod/yieldstat/Seiten/default.aspx)
8. Assessment of the model	
a) Transferability	Potentially yes
b) Reproducibility	Under consideration of the final report of [7], the model might be reproducible.

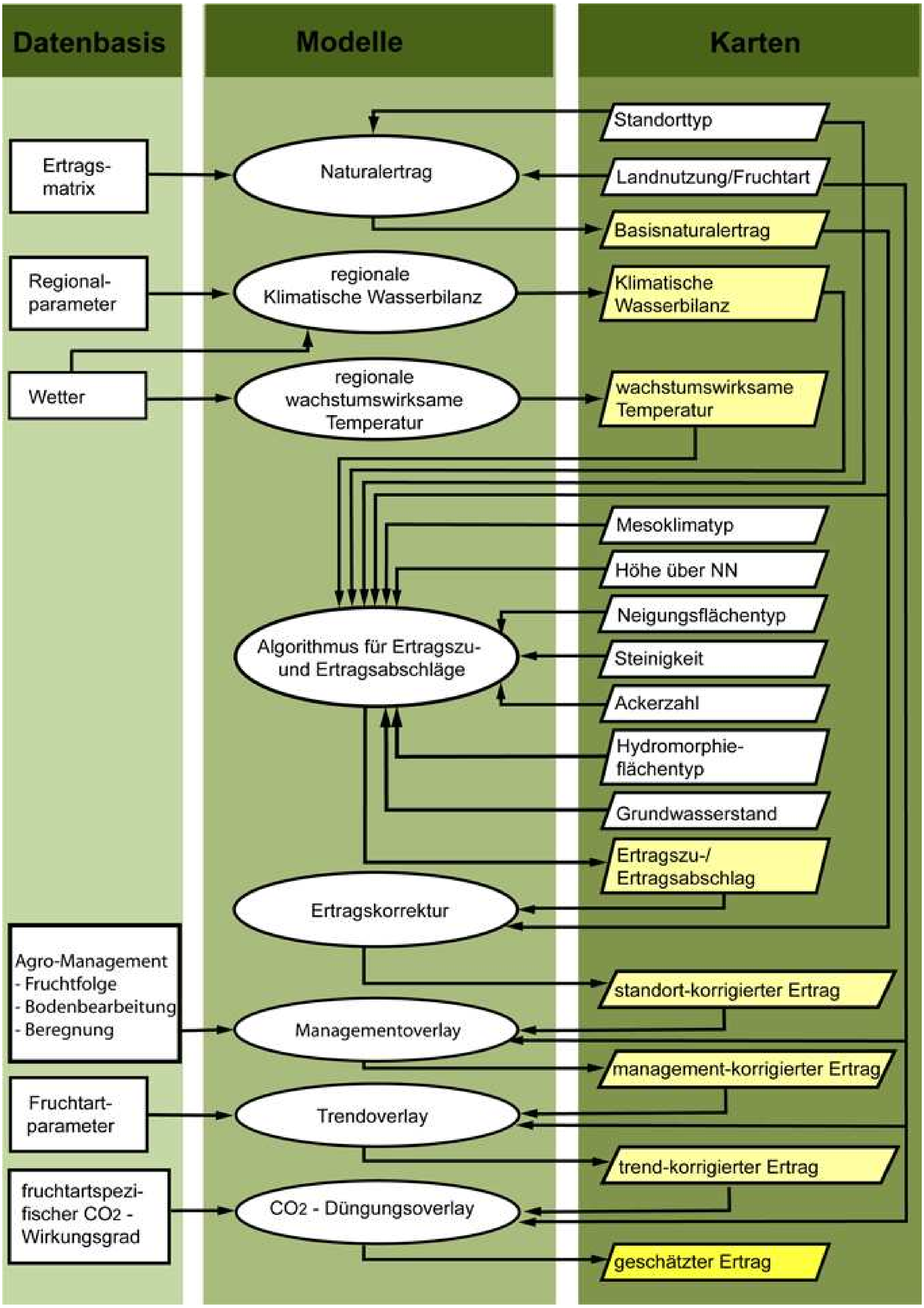


Figure 3: Scheme of Yieldstat, [5]

2.5 Assessment of Biomass Potential for Power Production: A GIS Based Method

1. Model name	**-, [8]**
2. Type of Biomass	Agricultural residual crops
3. Region/resolution	Greek, Creta/?
4. Input	GIS Data and statistical, agricultural data
5. Output	Modeling the energetic use of agricultural residuals by means of GIS-maps (heating values are provided). The model considers conversion pathways, as well as the distribution of biomass in relation to power stations (source-sink). Comparison of power generation costs when renewable energy sources instead of fossil energy sources are used. Use of a „DSS - Decision Support System“
6. Conditions	-
7. Algorithm	1. Theoretical potential – The whole growing area multiplied by the annual yield per hectare. 2. Available potential – The energy content of the biomass is evaluated by the lower heating value (upper heating value is the vaporization enthalpy of water). 3. Technical potential – depends on the choice of technology (which results in different degrees of efficiency, efficiency factors and amounts of energy). 4. Economical potential – costs of capital, investments, maintenance, transportation, purchase and supply. Additionally the model includes a decision support system that helps to choose the best usage of the different potentials (see figure 4)
8. Assessment of the model	-
a) Transferability	Potentially yes
b) Reproducibility	Functions/formulas are represented in an understandable manner.

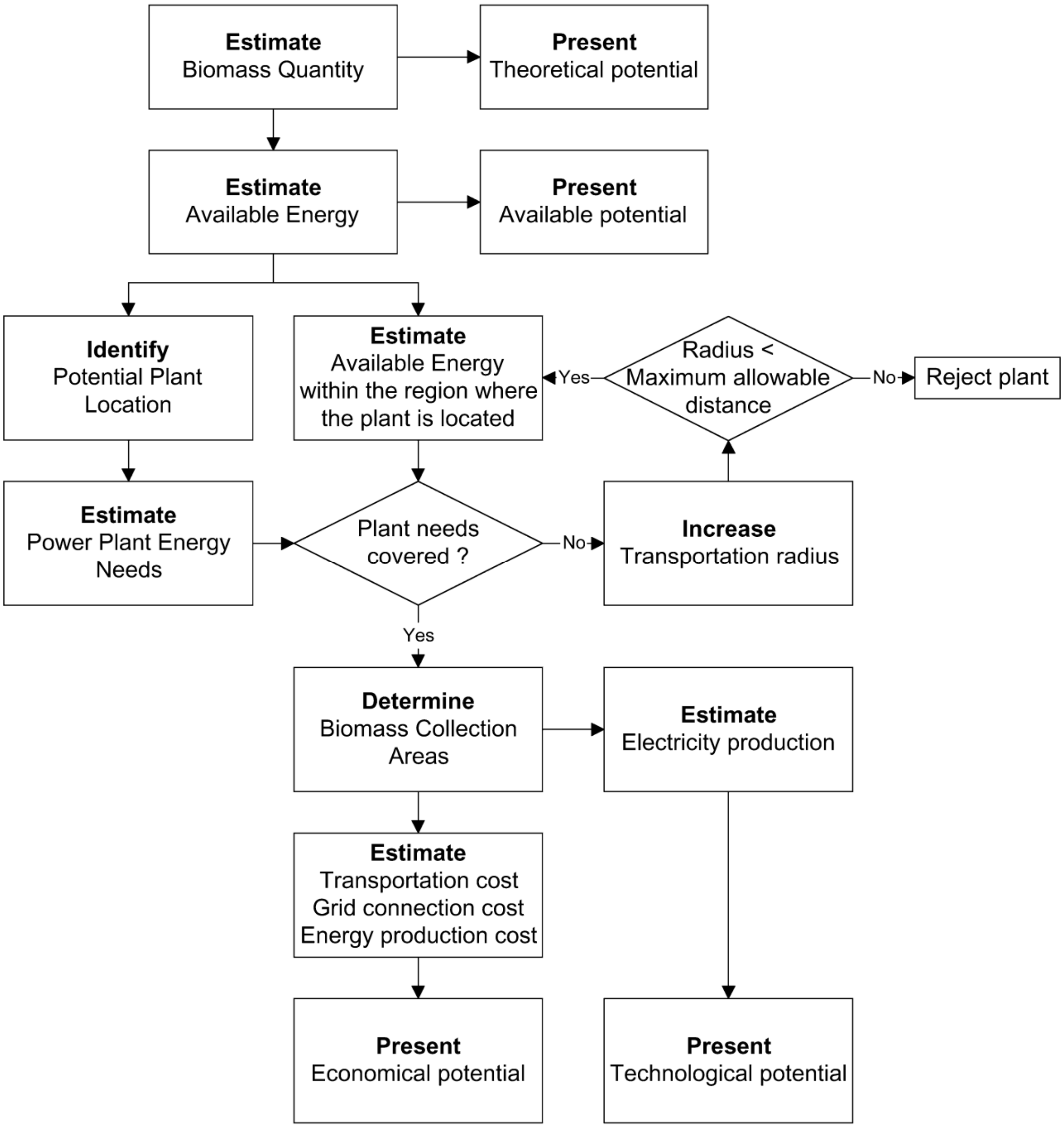


Figure 4: Schema "DSS"

2.6 RAUMIS

1. Model name	**RAUMIS (Regionalisiertes Agrar-und Umweltinformationssystem für die Bundesrepublik Deutschland), [9]**
2. Type of Biomass	Theoretically for every type of biomass for which there is data in the agricultural statistics.
3. Region/resolution	Germany/326 model regions in Germany, according to counties
4. Input	Regional-and sector data, agricultural statistics based on a county level and based on the agricultural resource accounting
5. Output	Availability of sectorial products, information regarding material, energy, emissions and land use on different aggregational leves.
6. Conditions	-
7. Algorithm	-
8. Assessment of the model	-
a) Transferability	-
b) Reproducibility	-

2.7 Modeling biomass on a forest sample area

1. Model name	**-, [10]**
2. Type of Biomass	Wood
3. Region/resolution	Germany, Freising
4. Input	Measurements of forest growth increment
5. Output	Light- and population model for forests. Distribution of biomass in dependence on the light field of the population, based on forest growth measurements.
6. Conditions	-

7. Algorithm	See figure 5
8. Assessment of the model	-
a) Transferability	Yes.
b) Reproducibility	It is hard to be reproduced, the description of the algorithm is insufficient. Not suitable for analyzing regional biomass potentials.

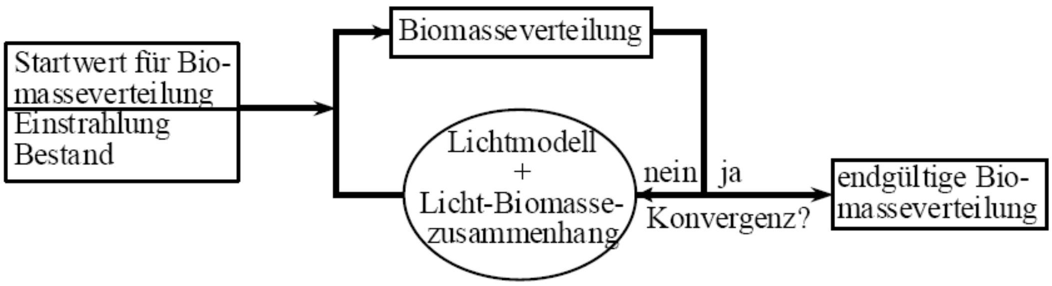


Figure 5: Modeling the distribution of biomass on forest sites, [10]

2.8 Modelling and validation of agricultural and forest biomass potentials for Germany and Austria

1. Model name	**Biosphere Energy Transfer Hydrology = BETHY (German Aerospace Institution, DLR), [11]**
2. Type of Biomass	Agricultural (straw) and forest biomass
3. Region/resolution	Germany, Austria/1km^2
4. Input	Meteorological data, as well as data from remote sensing (for example LIDAR, GLC 2000, Radar etc. (see figure 6))
5. Output	NDVI assessed from different sensor-data, net primary production of biomass (land coverage and total amount of biomass, including underground biomass)
6. Conditions	-
7. Algorithm	Complex algorithm. The model is also called “SVAT-model (soil-vegetation-atmosphere-transfer). Summarizing the model, carbon fixation through assimilation of CO_2 in energy-

	rich, complex molecules of plants is assessed.
8. Assessment of the model	Extensive dissertation regarding the application and validation of the BETHY-Model of the German Aerospace Institution. The model has some weaknesses, as for example the rather low resolution of 1 km.
a) Transferability	Not clear.
b) Reproducibility	Not clear. Do we have accordant data?

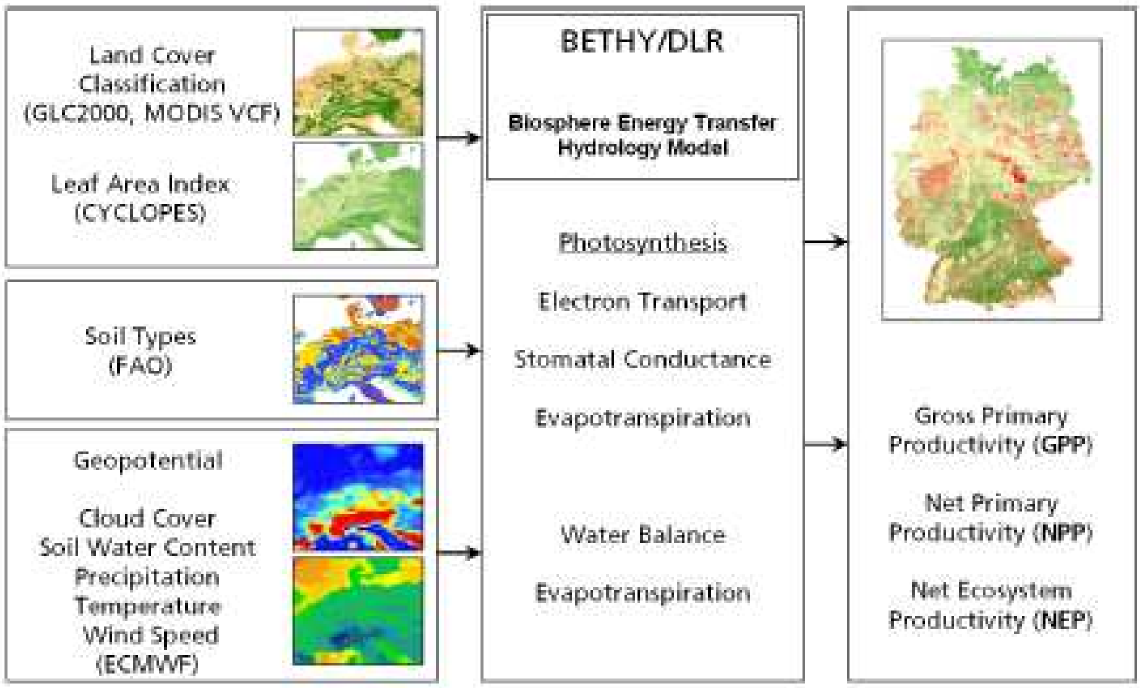


Figure 6: Model scheme of BETHY, DLR, [11]

2.9 Regional potential for the provision of fuel wood - Results of a study in northeast Brandenburg

1. Model name	**-, [12]**
2. Type of Biomass	Energy wood, short rotation
3. Region/resolution	North-East Brandenburg
4. Input	Infrastructural data regarding forestry
5. Output	Suitable sites for biomass facilities
6. Conditions	-
7. Algorithm	The aim of the algorithm is to analyze resources and infrastructure to find sites for biomass facilities. Sites are used to store, to transfer and to distribute energy wood.
8. Assessment of the model	-
a) Transferability	The outcome of the model does not match the aims of our project.
b) Reproducibility	-

2.10 The single tree-based stand simulator SILVA: construction, application and evaluation

1. Model name	**SILVA, TU Munic (Freising), [13]**
2. Type of Biomass	Forest wood
3. Region/resolution	Germany (and ?)/single trees
4. Input	Tree species, data regarding tree sizes and populations
5. Output	Yield development of the whole forest, based on the simulation of the growth increment of single trees
6. Conditions	-
7. Algorithm	Parameters of single tree species and of the terrain, climate- and growth-relevant data. Growth increment of single trees is simulated in dependence on time. The aim is to be able to

	carry out operational and strategic procedure in forest planning based on simulations.
8. Assessment of the model	The model is a tool for predicting the natural growth in the forest, based on single trees.
a) Transferability	Complex model that does not explicitly match the aims of our project.
b) Reproducibility	It is difficult to reproduce, the algorithm is very complex (see also the homepage of TUM/WZW)

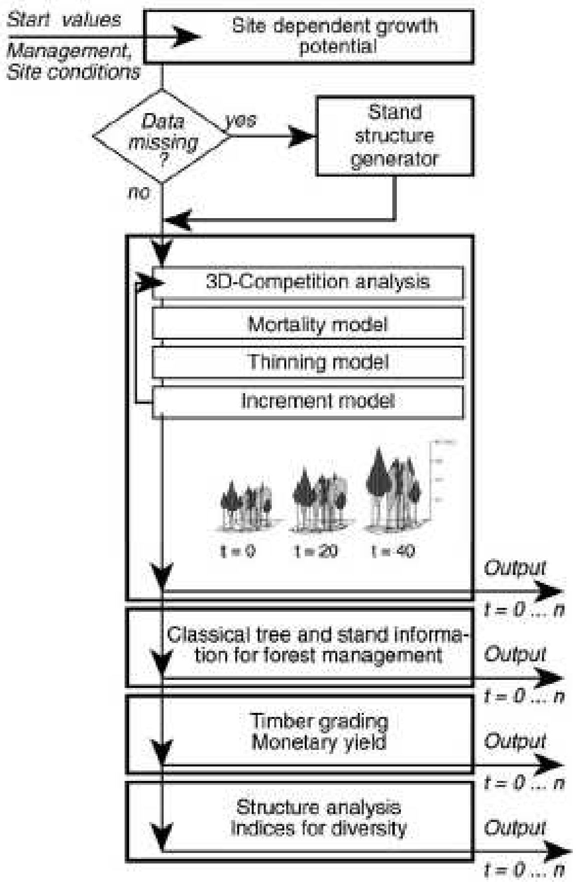


Figure 7: Flowchart for SILVA-Model

2.11 Assessment of pasture production in the Italian Alps using spectrometric and remote sensing information

1. Model name	**-, [14]**

2. Type of Biomass	Grassland
3. Region/resolution	Italien Alps
4. Input	Utilization of different tools, satellite images, empirical field studies, comparison of different vegetation indices: SR, NDVI, SAVI, MSAVI, OSAVI
5. Output	Assessment of pastures of Italian Alps
6. Conditions	-
7. Algorithm	Not comprehensible
8. Assessment of the model	-
a) Transferability	Difficult and not useful
b) Reproducibility	Difficult to reproduce and not useful for the aims of our project.

2.12 Biofuel production potentials in Europe: Sustainable use of cultivated land and pastures, Part II: Land use scenarios

1. Model name	**-, [15]**
2. Type of Biomass	Crop- and pasture land
3. Region/resolution	Europe/coarse solution, absolute numbers (of the total area of cultivated crop- and pasture land)
4. Input	Yields, current land use in the EU
5. Output	Land use competition, potential change in land use, potentials of biofuel (first and second generation)
6. Conditions	-
7. Algorithm	Not comprehensible
8. Assessment of the model	-
a) Transferability	Potentially yes.
b) Reproducibility	Difficult to reproduce with the information that is available.

2.13 Assessment of biomass potentials for biofuel feedstock production in Europe: Methodology and results

1. Model name	**ABioE (Area available for growing Biomass feedstock for Energy production) (see above, 2.12), [16]**
2. Type of Biomass	Biofuels
3. Region/resolution	Europe (EU27+Switzerland, Norway, the Ukraine)/1km^2/ 1 ha
4. Input	Geographical data (CORINE ...), agricultural data, data regarding the use of biomass
5. Output	Possible future land use for producing resources for biofuels
6. Conditions	-
7. Algorithm	Complex algorithm, see figure 9 Target function see figure 8
8. Assessment of the model	Potentially yes, further analysis of the 70 pages is needed
a) Transferability	Potentially yes
b) Reproducibility	Yes

$$(1)\quad ABioFuel_{t,c} = AAgric_{2000-02,c} - ABuiltUp_{t,c} - AFoodFeed_{t,c} \qquad \text{[ha]}$$

$ABioFuel_{t,c}$	Available land for bio-fuel feedstock production in future year t of country c	[ha]
$AAgric_{2000-02,c}$	Agricultural land in country c in base period 2000-02	[ha]
$ABuiltUp_{t,c}$	Increases in built-up and associated land areas between base period 2000-02 and future year t in country c	[ha]
$AFoodFeed_{t,c}$	Agricultural land area requirements in country c for domestically produced food and feed (the SSR[15]-fraction of domestic consumption)	[ha]
t	Future year t	
c	Country c	

Figure 8: Target function, [16]

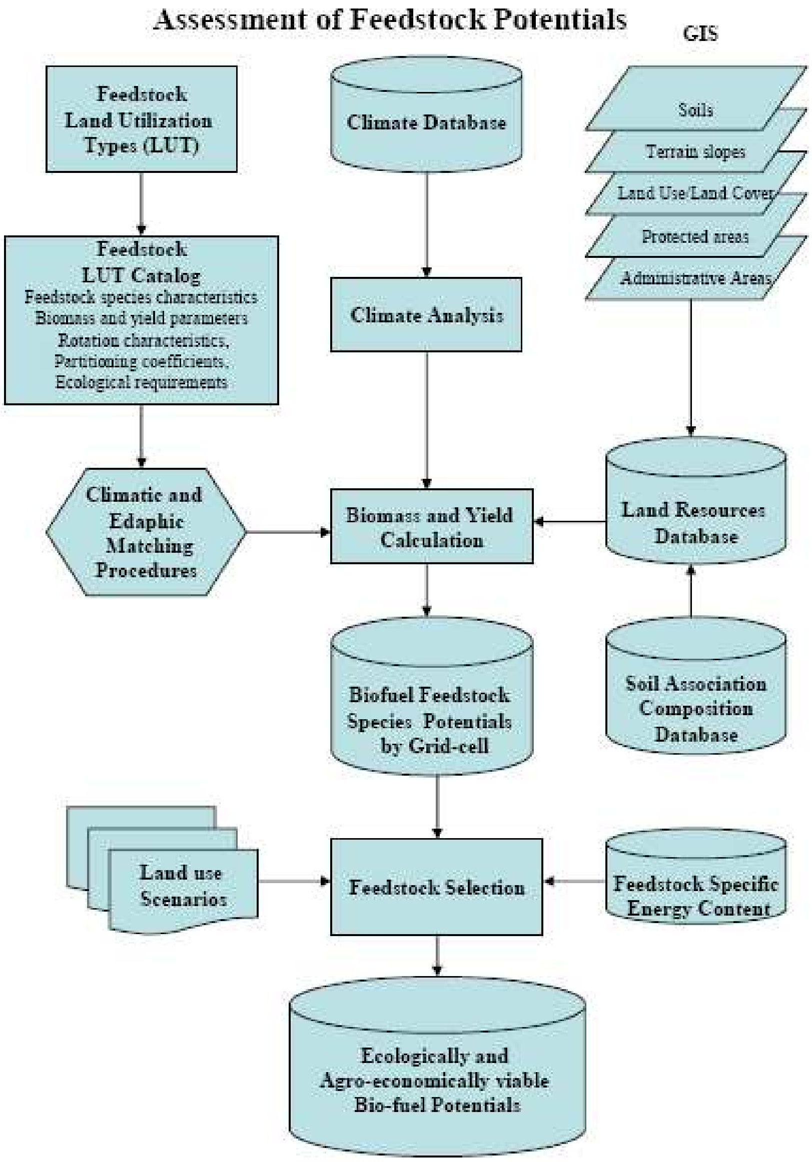


Figure 9: Method for evaluating resources for biofuel-potentials, [16]

2.14 Biofuel production potentials in Europe: Sustainable use of cultivated land and pastures. Part I: Land productivity potentials

1. Model name	**See above, 2.13, [17]**
2. Type of Biomass	Biofuels
3. Region/resolution	See above
4. Input	See above
5. Output	See above
6. Conditions	See above
7. Algorithm	See above

8. Assessment of the model	See above
a) Transferability	See above
b) Reproducibility	See above

2.15 The application of simulated NPP data in improving the assessment of the spatial distribution of biomass in Europe

1. Model name	**-, [18]**
2. Type of Biomass	Straw and forest wood
3. Region/resolution	Europe/resolution of output data: 27,83 km^2
4. Input	Statistical data from FAOSTAT, Eurostat and UNECE/FAO; GIS data from the land cover classification PELCOM, EuroGeographics and from the German Remote Sensing Data Center
5. Output	A map of biomass yields
6. Conditions	-
7. Algorithm	-
8. Assessment of the model	-
a) Transferability	Due to different sizes of the regions, the model is rather unsuitable for our project.
b) Reproducibility	-

2.16 Assessment of bioenergy potential in Sicily: A GIS-based support methodology

1. Model name	**-, [19]**
2. Type of Biomass	Agriculture energy cultivations, forest harvesting, short rotation forestry, food and wood industries
3. Region/resolution	Sicily/100 m

4. Input	CORINE, geological, topological and morphological maps, climate and rain maps
5. Output	Total productivity of regional forest areas, both in terms of marketable wood and in terms of by-products.
6. Conditions	-
7. Algorithm	E.g. biomass from forest areas: The first step is the individuation and analysis of the geographic localization of forest resources through the Territorial Information System; the second is the accounting of sustainable total productivity, by means of a yield coefficient
8. Assessment of the model	-
a) Transferability	-
b) Reproducibility	Not totally clear, but many different types of data are needed.

2.17 EU-wide maps of growing stock and above-ground biomass in forests based on remote sensing and field measurements

1. Model name	**-, [20]**
2. Type of Biomass	Wooden biomass (broadleaf wood and conifers)
3. Region/resolution	EU/500 m * 500 m (25 ha)
4. Input	Remote sensing data (CORINE, MODIS), statistical field data
5. Output	Cubic meter per hectare (m^3/ha)
6. Conditions	See paper
7. Algorithm	-
8. Assessment of the model	-
a) Transferability	-
b) Reproducibility	-

2.18 Aboveground Forest Biomass Estimation with Landsat and LiDAR Data and Uncertainty Analysis of the Estimates

1. Model name	**-, [21]**
2. Type of Biomass	Forest
3. Region/resolution	Machandinho d'Oeste, Brazil / 1 km x 1km
4. Input	TM (Landsat Thematic mapper), LiDAR (Light Detection and Ranging)
5. Output	Aboveground forest carbon in t/ha
6. Conditions	-
7. Algorithm	-
8. Assessment of the model	It is a kind of standard procedure for forest biomass estimation with lidar. In our project, we might lack sample plots and our point density is lower than the one mentioned in the paper.
a) Transferability	-
b) Reproducibility	-

2.19 Applying Enhanced k-Nearest Neighbor Approach on SatelliteImages for Forest Biomass Estimation of Vellore District

1. Model name	**-, [22]**
2. Type of Biomass	-
3. Region/resolution	Vellore (=Indien)
4. Input	Images from PRISM-satellite, frost-filter to reduce noise
5. Output	-
6. Conditions	-
7. Algorithm	Nearest-neighbor classification (k-nearest-neighbor). (Algorithm: non-parametric, automatic learning procedure), classification of points with orientation on the closest points.
8. Assessment of the model	The study is not on biomass, but on vegetated areas. Journal is

	one of the hundreds emerging journals from India with questionable quality.
a) Transferability	-
b) Reproducibility	-

2.20 Status and future of laser scanning, synthetic aperture radar and hyperspectral remote sensing data for forest biomass assessment

1. Model name	**-, [23]**
2. Type of Biomass	-
3. Region/resolution	-
4. Input	This paper is a review paper, providing a state-of-the-art review of remote sensing, with a particular focus on biomass estimation, including new findings with fullwave airborne laser scanning. Not all the models have been reviewed, however, we included this paper in our literature research.
5. Output	-
6. Conditions	-
7. Algorithm	-
8. Assessment of the model	-
a) Transferability	-
b) Reproducibility	-

2.21 Nearest neighbor imputation of species-level, plot-scale forest structure attributes from LiDAR data

1. Model name	**-, [24]**
2. Type of Biomass	Forest
3. Region/resolution	North-Central Idaho
4. Input	LiDar data/30 m x 30 m
5. Output	Basal area in m^2/ha
6. Conditions	-
7. Algorithm	-
8. Assessment of the model	The paper is on field sample imputation methods to Lidar metrics. It can be the basis for further treatment and

	calculations towards biomass estimates, but is not basically suited for our project.
a) Transferability	-
b) Reproducibility	-

2.22 Best practices for crop area estimation with Remote Sensing

1. Model name	**-, [25]**
2. Type of Biomass	-
3. Region/resolution	-
4. Input	This document intends to give guidelines on the feasibility of different approaches and general rules on the accuracy assessment that should be respected when reporting results of crop area estimates. The document focuses on methods that can be considered operational or pre-operational. Crop area estimation is addressed, but most criteria can be applied to land cover area estimation f. environmental purposes. What the authors analyze is the step from classified images to area estimation. The authors first mention tools that are at a research level, and then they give a rough classification of situations from the point of view of the user. This paper is included in our literature research because it might include important information on the procedure.
5. Output	-
6. Conditions	-
7. Algorithm	-
8. Assessment of the model	-
a) Transferability	-
b) Reproducibility	-

2.23 Bioenergy in Switzerland: Assessing the domestic sustainable biomass potential

1. Model name	**-, [27]**
2. Type of Biomass	Energy crop, agriculture and forestry residues, waste biomass
3. Region/resolution	Switzerland
4. Input	Data from other literature, not mentioned in the text
5. Output	Technical, sustainable, used and remaining biomass potential of Switzerland. Heating values in GJ/t (dw), potentials in PJ
6. Conditions	-
7. Algorithm	-
8. Assessment of the model	-
a) Transferability	The authors do not explicitly name the data they used, so it is hard to decide whether we could use this model in our project.
b) Reproducibility	-

2.24 Sustainable potential of timber production in Swiss forest

1. Model name	**Massimo, [28]**
2. Type of Biomass	Forest
3. Region/resolution	Switzerland / ha
4. Input	Data from National Forest Inventories. This includes data regarding the tree species, cross-section dimension at breast-height, production area, site quality, altitude, basal area of the tree population, average cross-section dimension at breast height of the 100 thickest trees per hectare, a factor expressing competition, reaction of trees on thinning measures
5. Output	The model forecasts the development of the forest according to its management, the amount of pine- and hardwood are given in million m^3.
6. Conditions	-
7. Algorithm	-
8. Assessment of the model	Very forest management focused with high spatial resolution and fine grained parameters.
a) Transferability	Rather too detailed.
b) Reproducibility	-

2.25 Analysis of forest dynamics under changing environmental conditions - New information for forest planning by coupling models on the example of the forest enterprise Zittau

1. Model name	**Balance**
2. Type of Biomass	Forest biomass
3. Region/resolution	Germany
4. Input	Using the physiological single tree growth model BALANCE, vitality of forest stands is simulated in dependence of the site-

	related factors, climate and stand structure. Data regarding daily averages of measured temperature, precipitation, global radiation, humidity and wind speed is needed. Furthermore, data regarding tree position, initial tree and crown height as well as initial dbh are required.
5. Output	Diameter at breast height increment of trees, tree height, leave coloring.
6. Conditions	-
7. Algorithm	-
8. Assessment of the model	Diameter at breast height increment of trees, tree height, leave coloring.
a) Transferability	-
b) Reproducibility	-

2.26 Effects of environmental changes on the vitality of forest stands

1. Model name	**-, [29]**
2. Type of Biomass	-
3. Region/resolution	-
4. Input	-
5. Output	See 2.25 Analysis of forest dynamics under changing environmental conditions - New information for forest planning by coupling models on the example of the forest enterprise Zittau
6. Conditions	-
7. Algorithm	-
8. Assessment of the model	-
a) Transferability	-
b) Reproducibility	-

2.27 Identifying the regional straw potential for energetic use on the basis of statistical information

1. Model name	**-, [56]**
2. Type of Biomass	Agricultural biomass (straw from barley, wheat, rye, triticale, oats)
3. Region/resolution	Baden-Württemberg (Germany)/calculation for each community
4. Input	Statistical data of yields, distribution and use of areas, livestock breeding
5. Output	Amount of straw that is available (S), amount of straw that is needed for livestock ($D_{pig/\ cattle/\ sheep/\ horse/\ poultry}$), change of the amount of humus (B), potential energy required for each utilization path and each scenario
6. Conditions	None (the current use is demonstrated)
7. Algorithm	(1) Amount of straw that is available in the communities:

$$S = Y * (A - (A * W)) * R$$

S	Amount of straw that is available
Y	Average yields of crop (2003-2007)
A	Average amount of the area that has been cultivated (2003 and 2007)
W	Part of the area that is used for whole crop silage
R	Straw-corn relationship of each type of crop

(2) Amount of straw needed for each type of feedstock:

$$Dswine = \left(\left(\frac{P1}{Pt} * SP1 * BP1\right) + \left(\frac{P2}{Pt} * SP2 * BP2\right) + \left(\frac{P3}{Pt} * SP3 * BP3\right) + \right.$$

D_{pig}	Amount of straw that is needed for pigs
P_{1-6}	Different categories of pigs (piglet-adult pigs)
P_t	Number of all pigs

(3) Change in the amount of humus:

$$B = (S_{crop_1} * C_{crop_1} + S_{crop_2} * C_{crop}$$

B	Humus alteration per hectare in the municipality

	S	Share of crops on cropland in the municipality
	$crop_{1\text{-}n}$	All major crops
	$cover_{w/s}$	Cover crops in winter and summertime
	C	Humus coefficient (pos./neg.)
	R	Amount of crop residues resulting from the cultivated crops
	D	Demand of straw as litter and food for animal husbandry
	M	Organic manure (municipality)
	N	Number of biogas plants (municipality)
	O	Mean output of digestates
	C_{Biogas}	Humus coeff. for digestates
	A	Total agricultural land of the municipality
8. Assessment of the model	-	
a) Transferability	We should be able to transfer it to our region.	
b) Reproducibility	Yes.	

2.28 Energy wood potentials outside of the forest

1. Model name	**-, [57]**
2. Type of Biomass	Forest biomass
3. Region/resolution	Forests in Switzerland
4. Input	Data from land use statistics, interviews with experts
5. Output	Theoretical, technical and usable potentials in t per year
6. Conditions	-
7. Algorithm	-
8. Assessment of the model	-
a) Transferability	We rather do not want to have extra work to do interviewing experts. Not so suitable.
b) Reproducibility	-

2.29 Bioenergy crop models: descriptions, data requirements, and future challenges

1. Model name	**-, [30]**
2. Type of Biomass	-
3. Region/resolution	-
4. Input	This paper is a review paper, providing a state-of-the-art review of remote sensing, with a particular focus on biomass estimation, including new findings with fullwave airborne laser scanning. Not all the models have been reviewed, however, we included this paper in our literature research.
5. Output	-
6. Conditions	-
7. Algorithm	-
8. Assessment of the model	-
a) Transferability	-
b) Reproducibility	-

2.30 Spatially Explicit Large Area Biomass Estimation: Three Approaches Using Forest Inventory and Remotely Sensed Imagery in a GIS

1. Model name	**-, [31]**
2. Type of Biomass	Forest biomass
3. Region/resolution	714,000 ha of forest in Canada
4. Input	Forest inventory data, moderate resolution remotely sensed imagery (Landsat)
5. Output	Above-ground biomass in mega tons
6. Conditions	-
7. Algorithm	-
8. Assessment of the model	-

a) Transferability	-
b) Reproducibility	High demand on input data and calculations of very fine resolution

2.31 Collaborative research project integrating optimization approaches for the supply of sustainable fuel wood

1. Model name	**-, [32]**
2. Type of Biomass	Forest biomass
3. Region/resolution	Rottenburg/small and private forests
4. Input	Laserscanning
5. Output	Analyses and information on the wooden energy potential, questions regarding the state of the forest, exploitation, ownership, restrictions, determining the use-, economical and technical potential.
6. Conditions	-
7. Algorithm	The possible use of wood is demonstrated by using GIS data.
8. Assessment of the model	-
a) Transferability	Yes
b) Reproducibility	-

2.32 Status of biomass resource, version 3

1. Model name	**Crop rotata, [58]**
2. Type of Biomass	Forest and crop biomass
3. Region/resolution	Europe
4. Input	Data from EUROSTAT, FAO, FADN, TBFRA, ESDB, Corine LC, Terrastrat
5. Output	Technically available biomass potential in tons of dry matter
6. Conditions	-
7. Algorithm	-
8. Assessment of the model	-

a) Transferability	-
b) Reproducibility	-

2.33 Collection of energy wood potential and its availability in forest and open land with new remote sensing methods

1. Model name	**-, [33]**
2. Type of Biomass	Forest biomass
3. Region/resolution	Small areas, e.g. the area of North-Karlsruhe
4. Input	Airborne laser scanner data, color infrared orthophotos combined with forest inventory data
5. Output	Detailed maps showing the distribution of forest biomass
6. Conditions	-
7. Algorithm	-
8. Assessment of the model	-
a) Transferability	Andreas Fritz is planning to use some aspects of this model, he knows the person who wrote the paper
b) Reproducibility	-

2.34 3D segmentation of non-forest trees for biomass assessment using LiDAR data

1. Model name	**-, [34]**
2. Type of Biomass	Forest biomass (single tree, tree stands and hedges)
3. Region/resolution	Sites in six federal States of Germany, mostly Baden-Württemberg
4. Input	First and last pulse LiDAR-data
5. Output	-
6. Conditions	LiDAR data is used to model the relationship between the vegetation volume derided from LiDAR measurements and the

	above-ground biomass (ABG) for well-defined grove types. The paper is reporting about results from a novel 3D segmentation adopted for non-forest trees and the follow-on vegetation volume calculation. Furthermore, the focus is on the estimation of AGB from the diameter at breast height and the tree height. Finally, conversion factors are derived which relate the AGB to the LiDAR derived volume calculations.
7. Algorithm	-
8. Assessment of the model	-
a) Transferability	The model uses N-Cut algorithm which requires point densities which we do not have.
b) Reproducibility	No

2.35 Estimating forest LAI profiles and structural parameters using a ground-based laser called Echidna

1. Model name	**-, [35]**
2. Type of Biomass	Forest biomass
3. Region/resolution	The Sierra Nevada national forest, California, and the Harvard forest, Petersham/50 m x 50 m
4. Input	Data from multiple scans of the ground-based full-waveform lidar
5. Output	Forest structural parameters like diameter at breast height, tree height, crown diameter, crown height and foliage area volume density are estimated.
6. Conditions	-
7. Algorithm	-
8. Assessment of the model	-
a) Transferability	-
b) Reproducibility	We do not have a full wave TLS. coverage is not suitable to us

2.36 Quantification of live aboveground forest biomass dynamics with Landsat time-series and field inventory data: A comparison of empirical modeling approaches

1. Model name	-, [37]
2. Type of Biomass	Forest biomass
3. Region/resolution	Study locations in Arizona and Minnesota/30 m
4. Input	Forest inventory data and analysis field data
5. Output	Maps of biomass dynamics including maps depicting the location and timing of forest disturbance and regrowth to assess the biomass consequences of these processes over large areas and long time frames
6. Conditions	-
7. Algorithm	-
8. Assessment of the model	--
a) Transferability	Data demand is rather high and tailored on north America.
b) Reproducibility	-

2.37 Potential of woody biomass determination with the usa of UAV aerial imagesDetermining the potential of biomass of wood using UAV-images

1. Model name	-, [38]
2. Type of Biomass	Forest biomass
3. Region/resolution	Study sites in Thuringia and Brandenburg/10m x 10m/20m x 20m
4. Input	Aerial images with information regarding foliated and unfoliated vegetation, as well as vegetation covered with snow
5. Output	Tons of biomass available in a certain area
6. Conditions	-
7. Algorithm	-
8. Assessment of the model	-
a) Transferability	-

b) Reproducibility	-

2.38 Aggregating pixel-level basal area predictions derived from LiDAR data to industrial forest stands in North-Central Idaho

1. Model name	**-, [39]**
2. Type of Biomass	Conifer landscapes
3. Region/resolution	North-Central Idaho/30m
4. Input	LiDar data and samples of field plots
5. Output	Basal area per acre
6. Conditions	-
7. Algorithm	-
8. Assessment of the model	-
a) Transferability	-
b) Reproducibility	-

2.39 Forest biomass mapping from lidar and radar synergies

1. Model name	**-, [40]**
2. Type of Biomass	Forest biomas
3. Region/resolution	Howland, Maine
4. Input	Aircraft borne lidar and SAR data
5. Output	Above-ground biomass map (in Mg/ha)
6. Conditions	-
7. Algorithm	-
8. Assessment of the model	-
a) Transferability	-
b) Reproducibility	-

2.40 L- and P-band backscatter intensity for biomass retrieval in hemiboreal forest

1. Model name	**-, [41]**
2. Type of Biomass	Hemiboreal forest biomass
3. Region/resolution	Southern Sweden/the SAR images used in the analysis were multi-look images with about 2.5 looks.
4. Input	Polarimetric SAR backscatter measurements at low frequencies.
5. Output	Biomass estimates in t/ha
6. Conditions	-
7. Algorithm	-
8. Assessment of the model	-
a) Transferability	-
b) Reproducibility	-

2.41 Lidar remote sensing of forest biomass: A scale-invariant estimation approach using airborne lasers

1. Model name	**-, [42]**
2. Type of Biomass	Forest biomass
3. Region/resolution	Eastern Texas, USA/
4. Input	LiDar data
5. Output	Biomass estimates in Mg/ha
6. Conditions	The objective of this paper is to develop methods for scale-invariant estimation of forest biomass using lidar data. The proposed methods are a linear functional model and an equivalent nonlinear model that use lidar-derived canopy height distributions and canopy height quantile functions as predictors. Results suggest that the models can accurately predict biomass and yield.
7. Algorithm	-

8. Assessment of the model	-
a) Transferability	Interesting approach since scale invariant predictors is actually what we need.
b) Reproducibility	-

2.42 Mapping the height and above-ground biomass of a mixed forest using lidar and stereo Ikonos images

1. Model name	**-, [43]**
2. Type of Biomass	Forest biomass
3. Region/resolution	Forest area located in Quebec, Canada
4. Input	LiDar data, IKONOS images, aerial photographs and field data
5. Output	Biomass estimates in Mg/ha
6. Conditions	The objective of the paper was to assess the accuracy of the forest height and biomass estimates derived from an Ikonos stereo pair and a lidar digital terrain model (DTM). After the Ikonos scenes were registered to the DTM with submeric accuracy, tree heights were measured individually by subtracting the photo-grammetric elevation of the treetop from the lidar ground level of the tree base. Matched images of the stereo pair were used to create a digital surface model. Matched images of the stereo pair were then used to create a digital surface model. The latter was transformed to a canopy height model by subtracting the lidar DTM. Plotwise height percentiles were extracted from the Ikonos-lidar CHM and used to predict the average dominant height and above-ground biomass.
7. Algorithm	-
8. Assessment of the model	-
a) Transferability	-
b) Reproducibility	-

2.43 Mapping and spatial uncertainty analysis of forest vegetation carbon by combining national forest inventory data and satellite images

1. Model name	-, [44]
2. Type of Biomass	Forest biomass
3. Region/resolution	Wu-Yuan County, Jiangxi, China
4. Input	National forest inventory data and satellite images
5. Output	The results showed that the methods reproduced not only the spatial distribution of forest carbon, but also the spatial pattern of variances of its estimates and was able to quantify the contributions of uncertainties from the field plot data and satellite images to the uncertainties of forest carbon estimates.
6. Conditions	-
7. Algorithm	-
8. Assessment of the model	-
a) Transferability	The focus lies on the variability within forest areas, so it is not that suitable for our project.
b) Reproducibility	-

2.44 Forest structure and aboveground biomass in the southwestern United States from MODIS and MISR

1. Model name	-, [45]
2. Type of Biomass	Aboveground woody biomass
3. Region/resolution	Southwestern United States
4. Input	Red band bidirectional factor data from NASA, moderate resolution imaging spectroradiometer (MODIS)
5. Output	Aboveground woody biomass in Mg/ha
6. Conditions	Red band bidirectional reflectance factor data from the NASA MODerate resolution Imaging Spectroradiometer (MODIS) acquired over the southwestern United States were

	interpreted through a simple geometric-optical (GO) canopy reflectance model to provide maps of fractional crown cover, mean canopy height, and aboveground woody biomass.
7. Algorithm	-
8. Assessment of the model	-
a) Transferability	No – the model relies on MODIS images we don´t have
b) Reproducibility	-

2.45 Three-Dimensional Modeling of an Urban Park and Trees by Combined Airborne and Portable On-Ground Scanning LIDAR Remote Sensing

1. Model name	**-, [46]**
2. Type of Biomass	Biomass from an urban park
3. Region/resolution	National Garden of Tokyo
4. Input	LiDar data
5. Output	Quantitative estimation of canopy volume, trunk volume and of canopy cross-sectional area
6. Conditions	LIDAR data is used to visualize an urban park and to quantify biophysical variables of trees in the park. A digital canopy height model and a digital terrain model generated from airborne scanning LIDAR data provide precise images of the ground surface and individual tree canopies. Airborne and on-ground Lidar images are combined to overcome blind regions and to create a complete three-dimensional model of standing trees.
7. Algorithm	-
8. Assessment of the model	-
a) Transferability	-
b) Reproducibility	-

2.46 Land Availability for Biofuel Production

1. Model name	**-, [47]**
2. Type of Biomass	Biomass for biofuels
3. Region/resolution	Global, all continents
4. Input	Statistical data (global)
5. Output	Land use for producing resources for biofuel production
6. Conditions	-
7. Algorithm	-
8. Assessment of the model	-
a) Transferability	No
b) Reproducibility	No

2.47 Biomass resources and costs: Assessment in different EU countries

1. Model name	**BIORAISE, [48]**
2. Type of Biomass	Wood and biomass from agriculture
3. Region/resolution	Selected locations in the Mediterranean EU countries: Spain, Portugal, France, Italy and Greece
4. Input	CORINE Land Cover data, forestry data from the National Forest Inventories and agricultural data from the EUROSTAT Regional Statistics utility.
5. Output	Potential resources in odt/yr, biomass extraction costs
6. Conditions	Bioraise is a computer GIS based tool designed for the calculation of agricultural and forest biomass resources, collection and transportation costs. The tool is operated by a web viewer interface which displays the geographic environment of the included countries as well as their background basic elements. The interface tool allows to calculate the biomass resources existing within a determinate surface around a previously selected site. The tool also allows estimating the biomass transport cost from any pixel within

	the selected circle to the selected central site.
7. Algorithm	-
8. Assessment of the model	-
a) Transferability	-
b) Reproducibility	-

2.48 SOCRATES – an object-oriented model system for regional assessment of the impact of land use and climate change on soil and plant sizes

1. Model name	**SOCRATES (scenarios), a part is from ZEUS (program/model), [49]**
2. Type of Biomass	Agricultural biomass
3. Region/resolution	Basin of the river Uecker in Brandeburg, Germany/25 ha
4. Input	GIS-maps; regional metrological data; data regarding crop- and cultivation Modeling of soil types (1,5 m in depth), determining soil characteristics
5. Output	Assessing consequences of land use- and climate change on soil and plants, nitrogen exports
6. Conditions	-
7. Algorithm	Object-oriented model development in C++ Indicators: abiotic and biotic, qualitative and quantitative, soil- and plant indicators: nitrogen export, evapotranspiration, seepage, biomass and yield 3 Objects: Plant, soil nitrogen, soil water 1. Object plant: plant parameters, static numbers at the moment of harvest, calculation of yields (site, weather, culture management), description of the resulting dynamic development of biomass of plants until harvest (calculations are based on differential

	equations / Evolon-approach), taking into account dependences of temperature, water and nitrogen. 2. Object soil nitrogen: mineralization that is dependent on soil moisture and soil temperature. temporal resolution: one day 3. Object soil water: seepage, capillary ascent, actual evapotranspiration temporal resolution: one day
8. Assessment of the model	GIS and scenario-simulationtool
a) Transferability	Yes, potentially
b) Reproducibility	impossible with available information

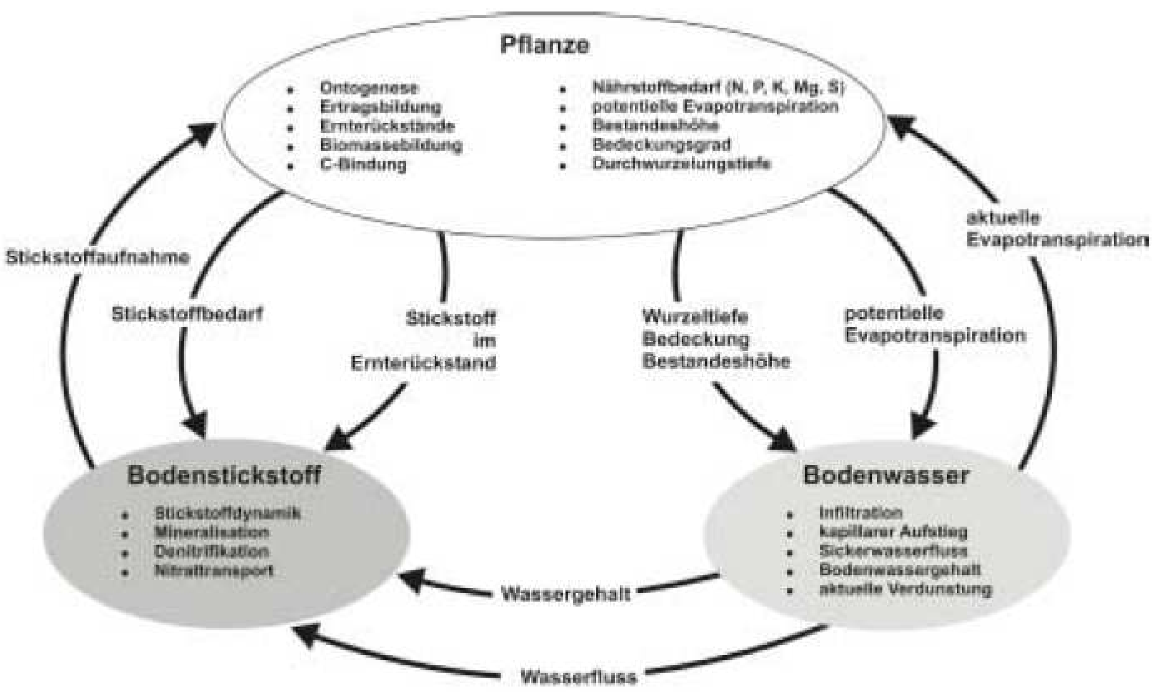


Figure 10: Model structure SOCRATES

2.49 Potential analysis for detection of woody biomass in Lower Saxony by remote sensing methods

1. Model name	-, [50]
2. Type of Biomass	Biomass from landscape work
3. Region/resolution	Lower Saxony/20 cm
4. Input	Digital ortho-photos used in ArcGIS, data from land surveys and from geo base information of Lower Saxony
5. Output	Assessments of available and of potential areas based on random sampling
6. Conditions	-
7. Algorithm	See paper
8. Assessment of the model	Rather not that suitable for our project
a) Transferability	Yes
b) Reproducibility	Reproducibility depends on data

2.50 Development and testing of a method for the estimation of regional dendromass balances on the example of North Rhine-Westphalia

1. Model name	-, [51]
2. Type of Biomass	Wood
3. Region/resolution	North Rhine-Westphalia
4. Input	Statistical data for wood production- and usage
5. Output	Capturing the energetic and material use of wood (dendromass). Balancing, comparison, use and potential. Calculating scenarios for the energetic use of wood (dendromass) in small and large plants.
6. Conditions	-
7. Algorithm	See paper
8. Assessment of the model	Not that suitable for our project
a) Transferability	Is possible but depends on the data that is available
b) Reproducibility	Potentially yes

2.51 Competition for biomass

1. Model name	**LaNuOpt, (Dissertation, Prof. Heißenhuber, TUM), [52]**
2. Type of Biomass	Agricultural biomass
3. Region/resolution	Bavaria/1 ha
4. Input	Data from KTBL and LfL, from GENESIS-databases of the Bavarian Statistical Office and Data Processing
5. Output	Modeling approach for evaluating the sustainability of biomass cultivation with respect to socio-economic aspects (e.g. ground rent). Visualization in GIS (see figure 11) **The aim of the model is to find answers for the following questions:** Which consequences do political measures have on agriculture? How does competitiveness of different production methods change in dependence on changing market conditions? Which prices have to be paid for an agricultural product so that food demand can be satisfied? Which effects result for employment and greenhouse gases? Possible behavior of farmers should be predicted in case of changing general conditions, especially when it comes to competition between food production and producing bioenergy (focus is on an economic background). Ground rent is calculated, which is a full cost accounting. • The smallest decision making unit is 1 ha of agricultural area • Agricultural data from KTBL and LfL, as well as information regarding the agricultural structure • Results can be chosen within a time frame from 2008 and 2028 Location factors: • Dependent location factors → company-specific factors

	- 3 production factors – soil, labor, funds • Independent location factors → location-specific circumstances - 3 Definitions of locations with different location factors, see figure 12
6. Conditions	-
7. Algorithm	Complex algorithm (however, its description is insufficient), the paper is rather an approach to a model instead of a model itself.
8. Assessment of the model	Interesting model-approach, specially its focus on socio-economic aspects. Comprehensive land use model that focuses on economical evaluations. However, it is very complex and cannot be reproduced without further information (especially the location factors and the algorithm).
a) Transferability	Potentially yes, if we have the right data
b) Reproducibility	The information that is available is insufficient

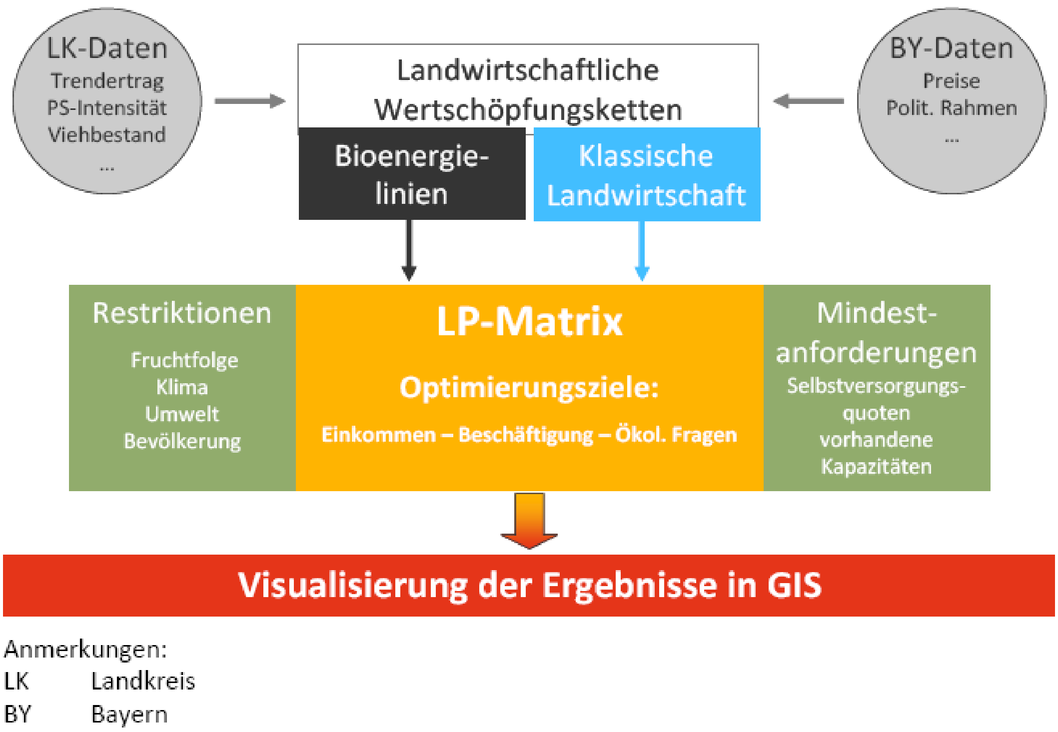
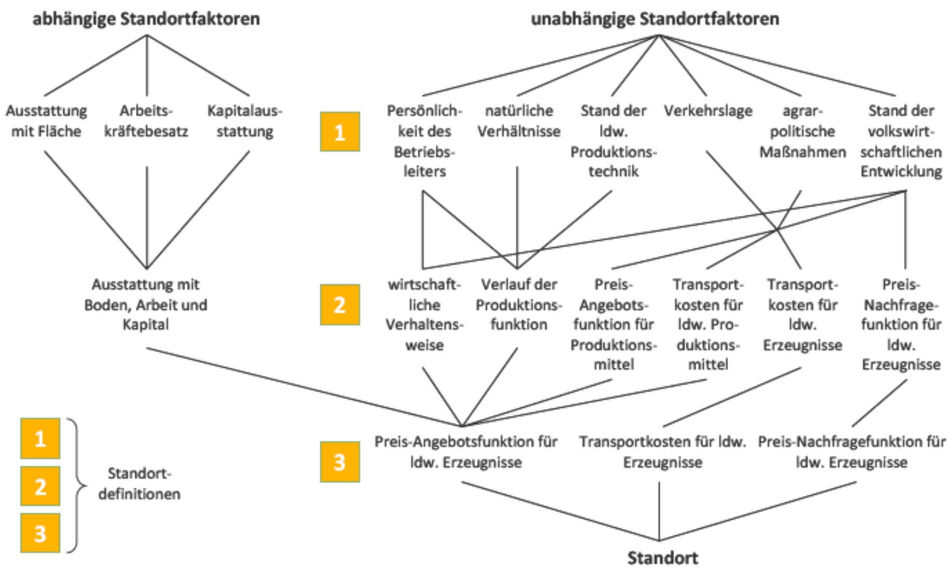


Figure 11: Set-up of the model LaNuOpt, [52]



Quelle: WEINSCHENCK und HENRICHSMEYER 1966, S. 205

Figure 12: Link between the location factors, [52]

2.52 Bioenergy in the global energy system, possibilities and limitations

1. Model name	**Scenarios (Consequences for agriculture and the environment), Institution: ANNA in Müllheim (Baden) [53]**
2. Type of Biomass	Agricultural biomasse
3. Region/resolution	German Upper-Rhine-Region
4. Input	Statistical data
5. Output	Scenarios/ecological assessment for future forestry, maize- and crop cultivation with respect to climate change
6. Conditions	-
7. Algorithm	Evaluating the possibility of producing bioenergy resources instead of intense agricultural farming. The aim is the nitrate-removal from ground water.
8. Assessment of the model	Scenarios
a) Transferability	-
b) Reproducibility	Yes

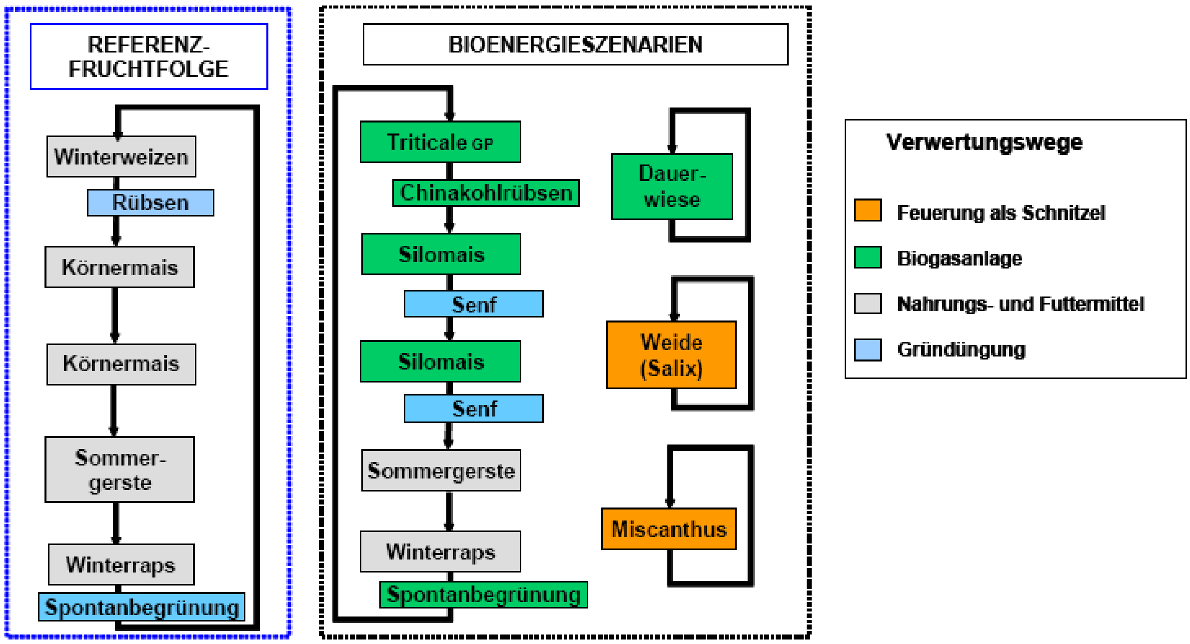


Figure 13: Scenarios of bioenergy, [53]

2.53 Bioenergie im globalen Energiesystem, Möglichkeiten und Grenzen

1. Model name	**- (TU Hamburg-Harburg, Prof Kaltschmitt qnd DBFZ, Daniela Thrän) [54]**
2. Type of Biomass	All kinds of biomass
3. Region/resolution	Calculation of all the biomass on earth in joule/global, EJ/a[2]
4. Input	Statistical data, modeling the amount of biomass
5. Output	Summation of biomasses
6. Conditions	-
7. Algorithm	(?)
8. Assessment of the model	Coarse solution
a) Transferability	No (?)
b) Reproducibility	No(?)

[2] (1 Exajoule=10^{18} Joule)

2.54 Master thesis Daniel Ketzer – Model-based assessment of biomass with scenarios for the Odenwaldkreis

1. Model name	**DEBIO, [55]**
2. Type of Biomass	Agricultural biomass
3. Region/resolution	Odenwaldkreis
4. Input	-
5. Output	-
6. Conditions	-
7. Algorithm	See thesis
8. Assessment of the model	-
a) Transferability	Yes
b) Reproducibility	Yes

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