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"Abatement options for GHG emissions
in a dynamic bio-economic model for dairy farms"

\- DAIRYDYN -

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Content

- Background
- Problem setting and optimization problem
- Overview on model template DAIRYDYN and its modules
- GHG emission indicators and abatement costs
- Possibilities for cooperation

Background

q About 1/3 of agricultural GHGs in Germany directly from dairy

q Diffuse emission sources à GHG measurements quite expensive à emission indicator needed

q Impossible to force real life farms to abate GHGs in order to collect data on abatement strategies and related costs …

q Instead: simulation of cost effective abatement strategies in bio-economic model

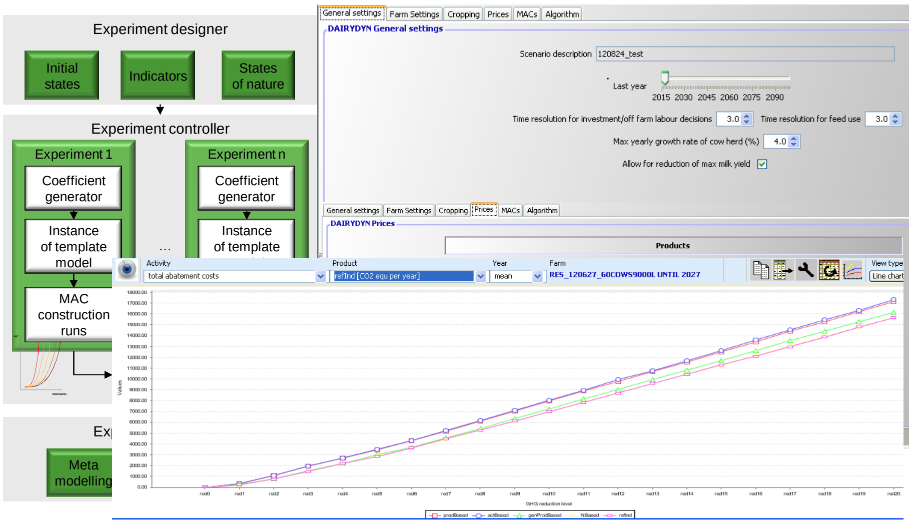
q Key hypothesis: abatement costs depend both on farm attributes and GHG accounting scheme

Problem setting

q We develop
- A generic model template for German dairy farms, i.e. one which can be applied to farms with different attributes
- A matching coefficient generator which populates the template with the necessary parameters
- A set of promising GHG emission indicators which estimate GHGs at farm level from decision variables

q And use that toolbox
- To simulate how farmers adjust their production program when facing GHG emission ceilings under different indicators
- To derive farm specific abatement costs
- And select promising indicators and abatement strategies

Overview on toolbox



Important characteristics to cover

q Dairy farming is characterized by long-term investments and biological /economic linkages between different periods
à dynamic optimization

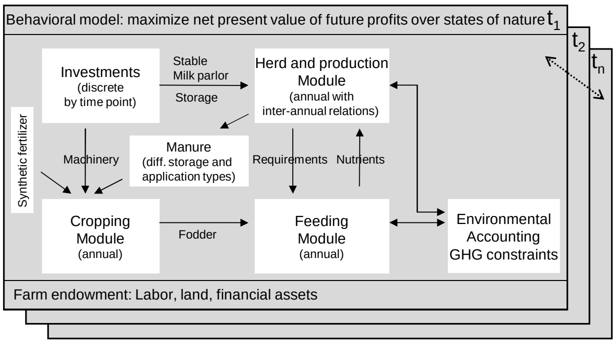
q Investment and labor decisions are not continuous
à mixed integer problem

q GHGs and thus abatement options relate to specific process attributes such as milk yield, feed mix, manure storage and application …
à detailed technology description

q The long time future is not certain
à different state-of-natures (SON) and matching farm strategies

à Rather complex and large template
(>50.000 variables, >120 binaries, depending on planning horizon and temporal resolution of investments/labor decisions)

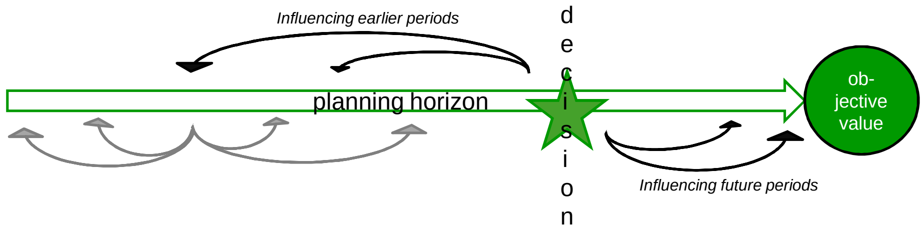
Overview on model template



- Supply-Side-Model for single dairy farms (exogenous prices, i.e. no market feedback)
- What, how much and mix of abatement strategies are decision variables
- Bio-economic interactions between modules, including GHG savings e.g. between different gases

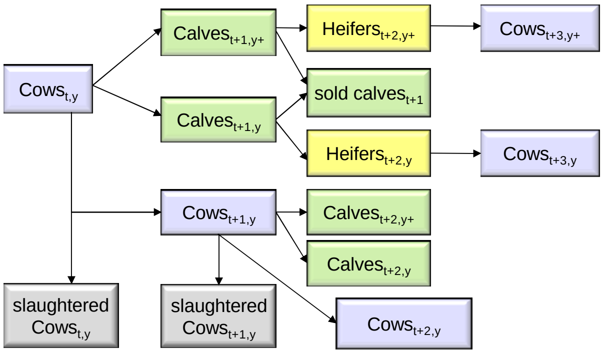
Dynamic character of the model

- Fully dynamic optimization in our context means:
  - Farmers maximizes wealth over planning horizon
  - Implies a rational, fully informed, profit maximizing decision maker
  - Decisions in *t* effect optimal program in later years *t+n* but also earlier ones in *t-n*
  - Recognition of path dependencies



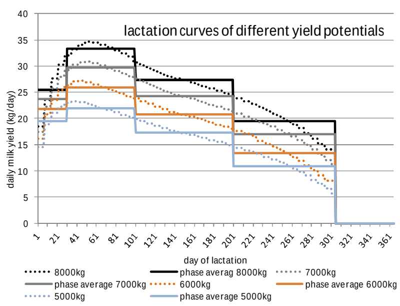
Herd module

- Different herds:
  - Dairy cows, raising calves, heifers
  - All differentiated by maximal milk yield *y* => breeding strategy
  - Explicit inter-annual relations



Feeding module

- Requirements per animal
  - Energy, protein, dry matter max and min, and max/min shares of certain feed
  - For cows differentiated by milk yield and lactation period
- Endogenous feed mix cover requirements
  - by different self-produced fodder
  - by different concentrates
  - differentiated by animal type, year, intra-year planning period and SON, for cows additionally by lactation period and milk yield potential
- Milk yield potential does not need to be fully utilized



Cropping module

- Different types of
  - arable cash crops (cereals, oil seeds…)
  - And fodder (maize silage, grass silage, grazing of different intensities)
- Differentiation between arable and grass lands
- Restrictions for fertilizer application rates and maximum crop shares
- Land can be bought/sold and rented in/out
- Single farm payment is taken into account

Investment & financing module

- Investment types
  - Stables:
    - Different types by size and animal type (cow or young animal)
    - Depreciated over time
  - Manure storage:
    - Differentiated by size and coverage (none, straw, foil)
    - Depreciated over time
  - Machinery:
    - Tractor, plough, sprayer, manure barrel …
    - Depreciated over operating hours
- Financing:
  - Credits, differentiated by payback period and related interest rate
  - Own cash reserves, which alternatively draw interest
- All investment decisions as binary variables
- Per unit investment costs decrease with increasing size

Labor

q On farm:
- Max. labor hours by month and by quarter year
- Some flexibility to work more in certain months
- Labor requirement of herds differ by stable type and milk yield

q Off farm:
- Either full or half time as integer variable
- Or, at a lower wage rate, flexibly on a hourly basis
- Commuting time can be explicitly taken into account

GHG accounting and restriction

q Five IPCC-based indicator schemes:

1. Default per activity emission factors

…

à stepwise increased level of detail à

…

5. Emission calculation basing on feed intake/digestibility and manure removal/application practice

q Emissions factors attached to decision variables, value of factors and variables covered depend on indicator

q Abatement costs are profits foregone under maximal GHG emissions, marginal abatement costs derived by stepwise enforcement of emission ceiling

GHG abatement options

- Flexible (monthly up to yearly):
  - Feed mix including additives (oils to increase digestibility)
  - Fertilizer application rates (organic and synthetic)
  - Frequency of manure removal
  - Pasture management
  - Milk yield per cow
  - Herd sizes
- Investment based:
  - Manure storage type (with and without coverage)
  - Manure application technique (broad spread, drag hose, injector)

Indicator dependent choice of abatement strategy

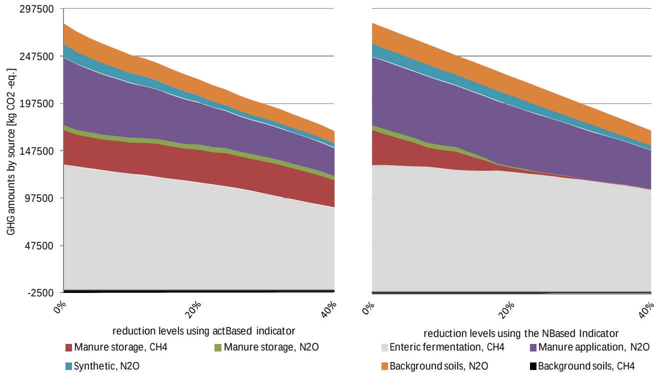
Level of detail -->

	actBased	prodBased	genProdBased	Nbased	refInd
investment based					
manure management techniques				x	x
application techniques				x	x
felxible					
fodder optimization				x	x*
breeding activities			x	x	x
intensity management			x	x	x
N-reduced feeding				x	x
fertilizer practice				x	x
soil cultivation	x	x	x	x	x
herd size managment, crop growing decisions	x	x	x	x	x
feed additives/ fat content					x
pasture management/ increase grazing		x	x	x	x

(* also recognizing digestibility of different feed components)

à Accounted for mitigation options of the different indicators impact abatement strategy and thus MACs

Indicator dependent abatement strategies



- Simplest indicator allows GHG reductions by adjustments of crop areas and herds only
- Detailed indicator enable GHG reduction e.g. by changes in manure management

à *Indicator determines accounted mitigation strategies and adherent GHG-ACs*

Coefficient generator

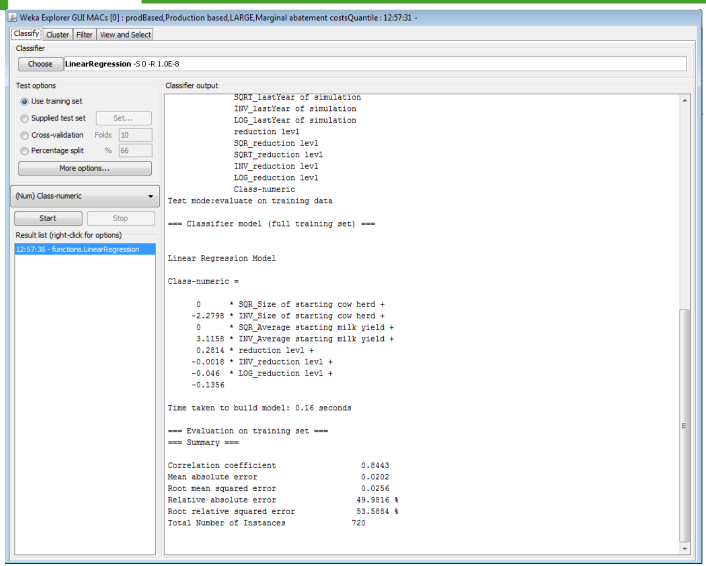
- Allows to parameterize the model template from a few key farm characteristics (herd size and average milk yield, labor endowment, last investments in stables, stocking rate):
  - Mix of look-up tables from farm planning (labor needs, investment costs etc.) and continuous functions (e.g. requirement functions for animals)
  - Automatically chooses matching stable size and defines future investment possibilities in stables
  - ….

Meta-modelling (1)

- Simulating ten reduction steps for all five indicators with a thirty year planning horizons takes about 2 hours
- Not possible to conduct simulations for a very large number of different farms
- Instead: development of a meta-model to identify key factors and their interaction in determining abatement costs under different indicators while reducing computing needs:
  1. Define representative sample of model farms
  2. Simulation of MAC-curves for sample
  3. Estimate regression function of MACs depending on farm attributes for each indicator

- Long term aim: upscaling to sector

Meta-modelling (2)



Cooperation possible?

- Improvement of emission factors, e.g.
  - Losses of different N-compartments in crop production
  - Requirement functions and GHG emissions (e.g. effect of feed additives) in animal production
  - Improvement of process description in crop and animal production (manure emission factors, fertilizer application rates, typical yields, budgets …)
- Implementation of price volatility for in- and outputs to detect uncertainty aspects of different GHG mitigation options

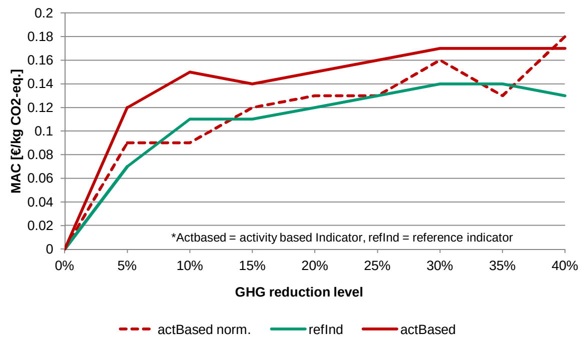
Thank you very much for your intention!

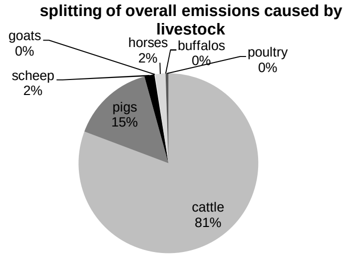
SOURCE →

INDICATOR ↓

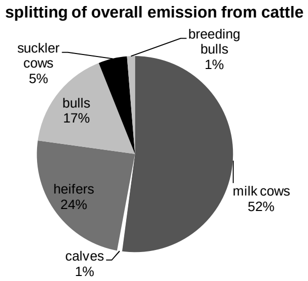
INDICATOR	enteric fermentation	manure management	fertilization	background emissions
actBased	CH_4 IPCC Tier 1 default values (cows 117, heifers and calves 57) *[kg CH_4/animal & year]*	CH_4 IPCC Tier 1 default values (cows 21, heifers and calves 6) *[kg CH_4/animal & year]* N_2O calculated from IPCC Tier 1 (cows 1.4, heifers0.52, calves 0.13) *[kg N_2O /animal & year]*	ProdBased indicator multiplied by average yield over planning horizon *[kgN_2O/ha]*	CH_4 and N_2O from grassland and other agricultural soils (CH_4: crops -1.5,gasslands -2.5; N_2O: 1.41) *[kg CH_4 or N_2O/ha & year]*
ProdBased	Milk: actBased divided by 6000kg *[kgCH_4/kg milk]* Heifers and calves equal to actBased *[kg CH_4/animal & year]*	For cows: actBased divided by 6000 kg [kg N_2O and CH_4/kg milk] Heifers and calves equal to actBased [kg N_2O CH_4/animal & year]	Equal to genProdBased	Equal to actBased
genProdBased	Heifers and calves with GE demand from Kirchgessner (2004), calculated per animal *[kg CH_4/animal & year]* Cows from NBased, differentiated by milk yield *[kg CH_4/kg animal & year]*	Manure emitted by heifers and calves, using assumed shares of storage types *[kgN_2O and CH_4/animal and year]* Manure emitted per kg milk, using assumed shares of storage types *[kg N_2O and CH_4/kg milk]*	N_2O calculated from N content of harvested product time 1.25, based on assumed application shares synthetics and organic broad spread *[kgN_2O/kg crop output]*	Equal to actBased
NBased	CH_4 derived from gross energy demand according to IPPC requirement functions, for cows differentiated by milk yield. Assuming default feed digestibility *[kg CH_4/GE demand]*	Equal to refInd	Equal to refInd	Equal to actBased
refInd	CH_4 derived from real gross energy and feed intake according to IPPC requirement functions and recognition of feed digestibility and addition of fat and oils, for cows differentiated by milk yield. *[kg CH_4/kg intake of feed]*	CH_4 and N_2O emitted per kg manure N and month differentiated by storage type *[kg N_2O and CH_4/kg N & month]*	N_2O calculated for actual N application, differentiated by synthetic and organic fertilizer, the latter depending on application technique *[kgN_2O/kg N]*	Equal to actBased

MACs and normalized MACs of farm with 70 cows and 8000 l yield level per cow

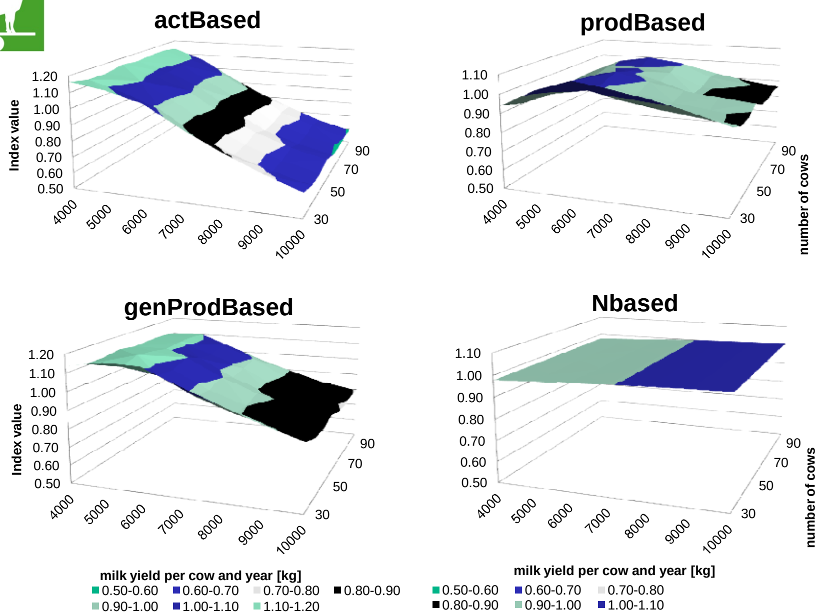




splitting of overall emissions caused by livestock
goats 0%
horses 2%
buffalos 0%
poultry 0%
scheep 2%
pigs 15%
cattle 81%

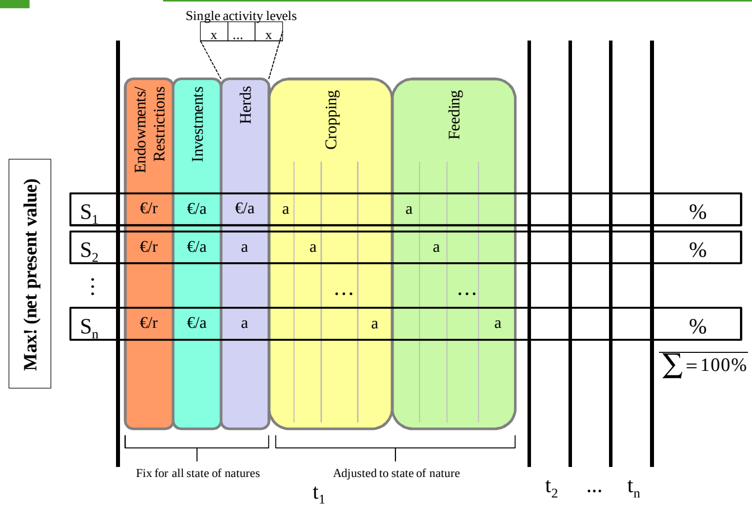


splitting of overall emission from cattle
suckler cows 5%
breeding bulls 1%
bulls 17%
heifers 24%
milk cows 52%
calves 1%



actBased
prodBased
genProdBased
Nbased
Index value
number of cows
milk yield per cow and year [kg]
0.50-0.60
0.60-0.70
0.70-0.80
0.80-0.90
0.90-1.00
1.00-1.10
1.10-1.20

Systematic of the mixed integer linear programming model



r = endowments at start of year (such as land, stable places, machinery park, liquidity ..)
a = i/o, factor demand /delivery coefficient of decision variables
€ = cost/revenues related to decision variables
S_n = States of nature