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

- DAIRYDYN -

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Content

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

- About 1/3 of agricultural GHGs in Germany directly from dairy
- Diffuse emission sources: GHG measurements quite expensive: emission indicator needed
- Impossible to force real life farms to abate GHGs in order to collect data on abatement strategies and related costs …
- Instead: simulation of cost effective abatement strategies in bio-economic model
- Key hypothesis: abatement costs depend both on farm attributes and GHG accounting scheme

Problem setting

- 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
- 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
Dairy farming is characterized by long-term investments and biological/economic linkages between different periods, leading to dynamic optimization.

- Investment and labor decisions are not continuous, making them mixed integer problems.

- GHGs and thus abatement options relate to specific process attributes such as milk yield, feed mix, manure storage and application, requiring a detailed technology description.

- The long time future is not certain, highlighting the need for different state-of-natures (SON) and matching farm strategies.

- 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 $y \Rightarrow$ 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

**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

**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

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### GHG accounting and restriction

**Five IPCC-based indicator schemes:**
1. Default per activity emission factors
   - à stepwise increased level of detail à
2. Emission calculation basing on feed intake/digestibility and manure removal/application practice

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

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

<table>
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<th>Level of detail</th>
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<th>Act Based</th>
<th>Prod Based</th>
<th>Gen Prod Based</th>
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*Also recognizing digestibility of different feed components*

Accounts 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

\[ \text{Indicator determines accounted mitigation strategies and adherent GHG-ACs} \]

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
  - ...
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
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!
Enteric fermentation

*Actbased = activity based indicator, refInd = reference indicator

Milk and calves equal to actBased

Cows from NBased, differentiated by milk yield

Cows from Gross energy demand according to IPPC requirement functions, for cows differentiated by milk yield

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

GHG reduction level

actBased norm.  refined  actBased

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splitting of overall emissions caused by livestock

- cattle 81%
- pigs 15%
- calves 2%
- goats 1%
- sheep 1%
- poultry 0%

splitting of overall emission from cattle

- milk cows 52%
- heifers 24%
- suckler cows 5%
- breeding bulls 1%
- bulls 17%

Britz & Lengers: DAIRYDYN
Systematic of the mixed integer linear programming model

\[ \text{Sum of all state-of-nature levels} \]

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[Diagram of a matrix with rows labeled S1, S2, ..., Sn and columns labeled t1, t2, ..., tn. Each cell contains symbols and percentages.]

- \( r \): endowments at start of year (such as land, stable places, machinery park, liquidity)
- \( a \): \( a \% \), factor demand/delivery coefficient of decision variables
- \( € \): cost/revenues related to decision variables

\[ \text{Max! (net present value)} \]

Single activity levels

Endowment or Resource \( \rightarrow \) Investment \( \rightarrow \) Method (Feeding)

Fix for all state of nature \( \rightarrow \) Adjusted to state of nature

\[ \sum = \text{100\%} \]