Minimizing direct greenhouse gas emissions in livestock production: the need for a metabolic theory

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Metabolic modelling in grazing livestock

- What are we trying to do?

- Why?
  - Optimize meat and milk production

  - Decrease environmental impacts, i.e., climate (methane, nitrous oxide) and eutrophication (nitrogen)

- Current situation
  - IPCC uses semi-empirical relations, with little consistency

Modelling livestock with Dynamic Energy Budget Theory

Dynamic Energy Budget model

$$\frac{dE}{dt} = \dot{p}_A - \dot{p}_C$$

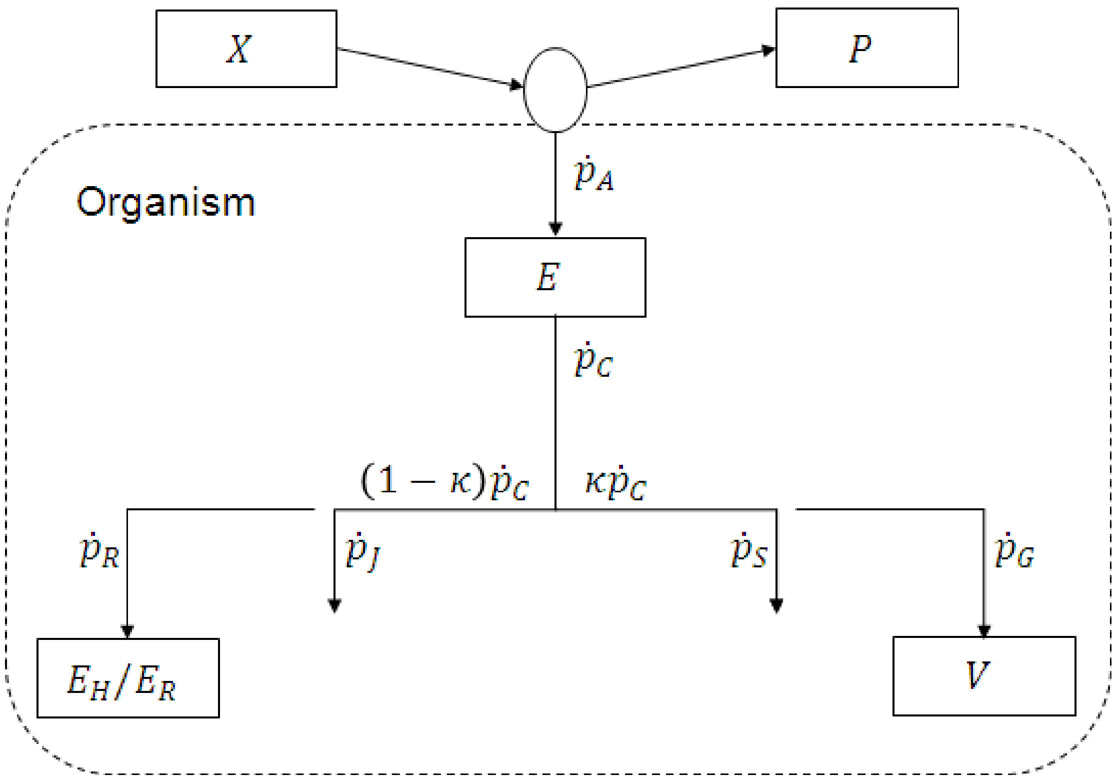
$$\frac{dV}{dt} = \frac{\dot{p}_G}{[E_G]}$$

non-adults

$$\frac{dE_H}{dt} = \dot{p}_R$$

adults

$$\frac{dE_R}{dt} = \kappa_R \dot{p}_R$$



Dynamic Energy Budget model – the parameters

$$\frac{dE}{dt} = \dot{p}_A - \dot{p}_C$$

$$\frac{dV}{dt} = \frac{\dot{p}_G}{[E_G]}$$

$$\frac{dE_H}{dt} = \dot{p}_R$$

$$\frac{dE_R}{dt} = \kappa_R \dot{p}_R$$

$$\dot{p}_A = \{\dot{\boldsymbol{p}}_{\boldsymbol{Am}}\}\, f(X)\, V^{2/3}$$

$$\dot{p}_C = E\,\frac{[\boldsymbol{E_G}]\dot{\boldsymbol{v}}V^{-1/3} + [\dot{\boldsymbol{p}}_{\boldsymbol{S}}]}{\boldsymbol{\kappa}[E] + [\boldsymbol{E_G}]}$$

$$\dot{p}_S = [\dot{\boldsymbol{p}}_{\boldsymbol{M}}]V + \{\dot{\boldsymbol{p}}_{\boldsymbol{T}}\}\, V^{2/3}$$

$$\dot{p}_G = \boldsymbol{\kappa}\dot{p}_C - \dot{p}_S$$

$$\dot{p}_J = \dot{\boldsymbol{k}}_{\boldsymbol{J}} E_H$$

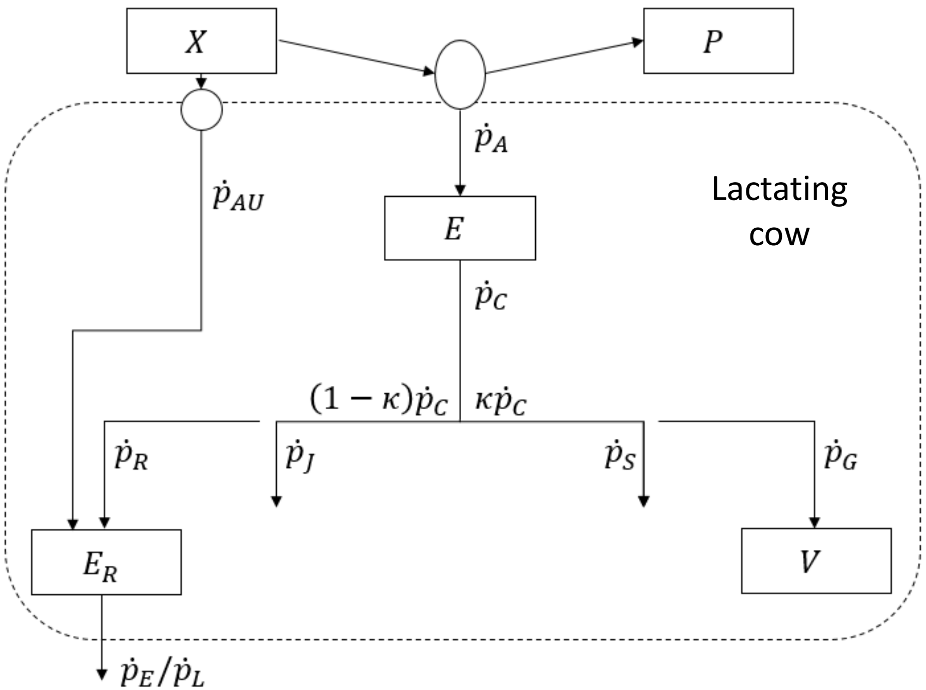
$$\dot{p}_R = (1 - \boldsymbol{\kappa})\dot{p}_C - \dot{p}_J$$

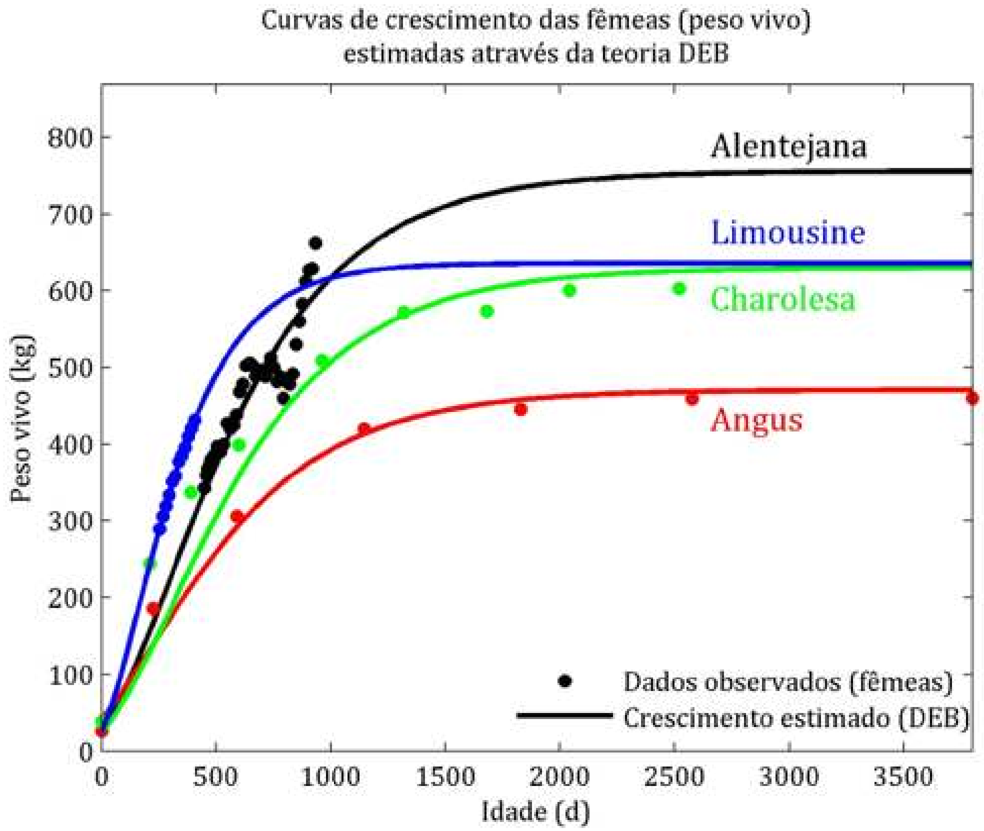
Literature Data

- Age at birth
- Age at puberty
- Age at death
- Length at birth
- Length at puberty
- Length along time
- Ultimate length
- Weight at birth
- Weight at puberty
- Weight along time
- Ultimate weight
- Maximum reproduction rate
- Average milk production rate

	Alentejana	Angus	Charolais	Limousin
a_b (d)	280	282.2	289	289
a_x (d)	210	223	-	246.6
a_p (d)	375	307	375	398
L_w (cm)	162	138	142	148
$W^b{}_w$ (kg)	30	35	42	31
$W^p{}_w$ (T)	-	-	323	-
$W^\infty{}_w$ (T)	700	545	975	700
$\dot{R}_\infty$ (# y^{-1})	0.8	0.72	0.7	0.7
$J^X{}_L$ (L d^{-1})	-	6.65	6.1	4.7

DEB model vs. data





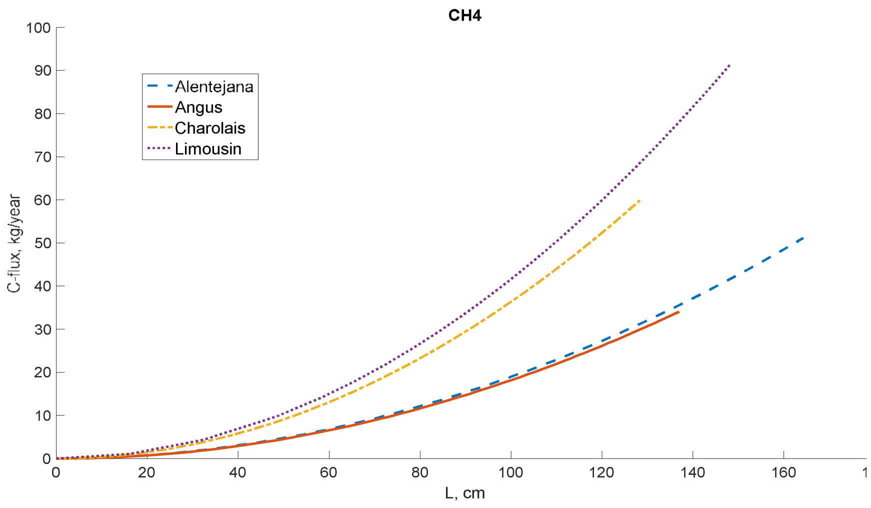
Transformations

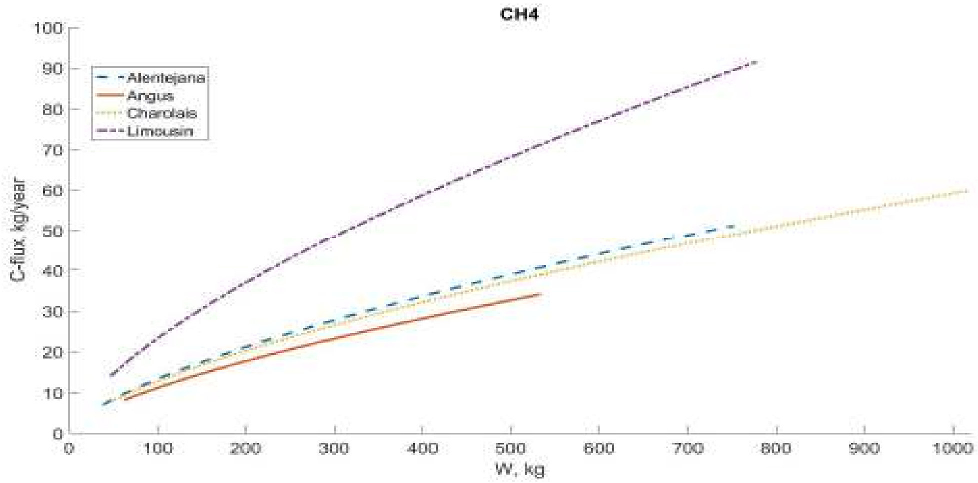
Assimilation	$Y_{XE}^{A}\, X + Y_{OE}^{A}\, O_2 \rightarrow \quad E + Y_{CE}^{A}\, CO_2 + Y_{HE}^{A}\, H_2O + Y_{NE}^{A} CO(NH_2)_2 + Y_{PE}^{A}\, P$
Growth	$E + Y_{OE}^{G}\, O_2 \rightarrow Y_{VE}^{G}\, V + Y_{CE}^{G}\, CO_2 + Y_{HE}^{G}\, H_2O + Y_{NE}^{G}\, CO(NH_2)_2$
Dissipation	$E + Y_{OE}^{D}\, O_2 \rightarrow \quad Y_{CE}^{D}\, CO_2 + Y_{HE}^{D}\, H_2O + Y_{NE}^{D}\, CO(NH_2)_2$

Transformations

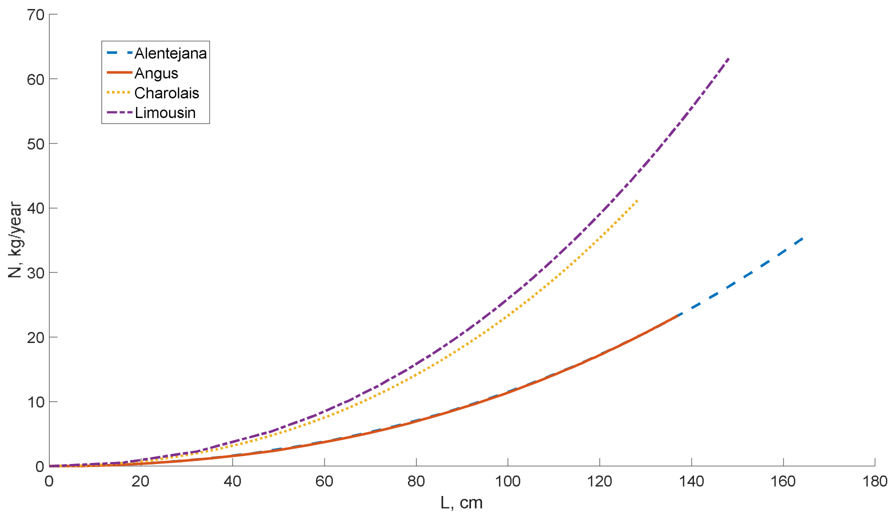
Assimilation		$Y_{XE}^{A}\ X + Y_{OE}^{A}\ O_2 \rightarrow E + Y_{CE}^{A}\ CO_2 + Y_{HE}^{A}\ H_2O + Y_{NE}^{A} CO(NH_2)_2 + Y_{PE}^{A}\ P$
Growth		$E + Y_{OE}^{G}\ O_2 \rightarrow Y_{VE}^{G}\ V + Y_{CE}^{G}\ CO_2 + Y_{HE}^{G}\ H_2O + Y_{NE}^{G}\ CO(NH_2)_2$
Dissipation		$E + Y_{OE}^{D}\ O_2 \rightarrow Y_{CE}^{D}\ CO_2 + Y_{HE}^{D}\ H_2O + Y_{NE}^{D}\ CO(NH_2)_2$
Assimilation	$(1-\xi_C)$	$Y_{XE}^{A}\ X + Y_{OE}^{AC}\ O_2 \rightarrow E + Y_{CE}^{AC}\ CO_2 + Y_{HE}^{AC}\ H_2O + Y_{NE}^{AC}\ CO(NH_2)_2 + Y_{PE}^{A}\ P$
	ξ_C	$Y_{XE}^{A}\ X + Y_{OE}^{AM}\ O_2 \rightarrow E + Y_{CE}^{AM}\ CH_4 + Y_{HE}^{AM}\ H_2O + Y_{NE}^{AM}\ CO(NH_2)_2 + Y_{PE}^{A}\ P$

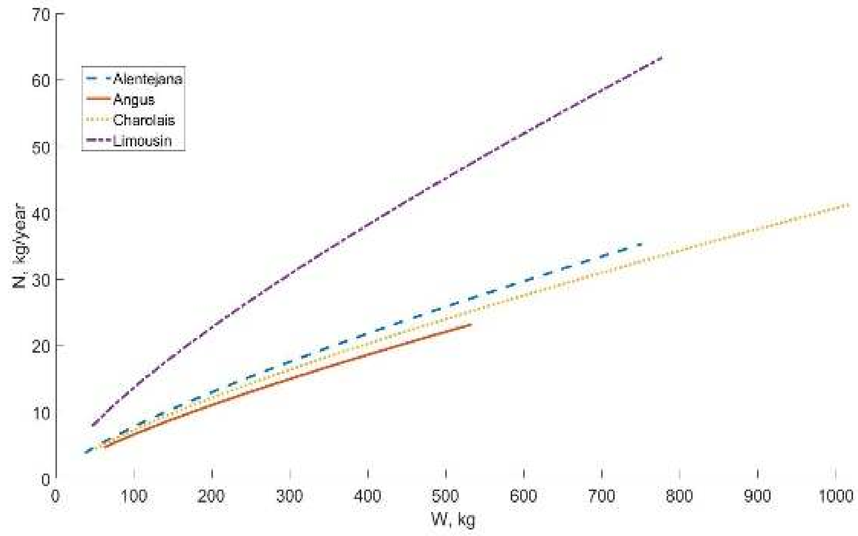
Methane


CH4
Alentejana
Angus
Charolais
Limousin
C-flux, kg/year
L, cm

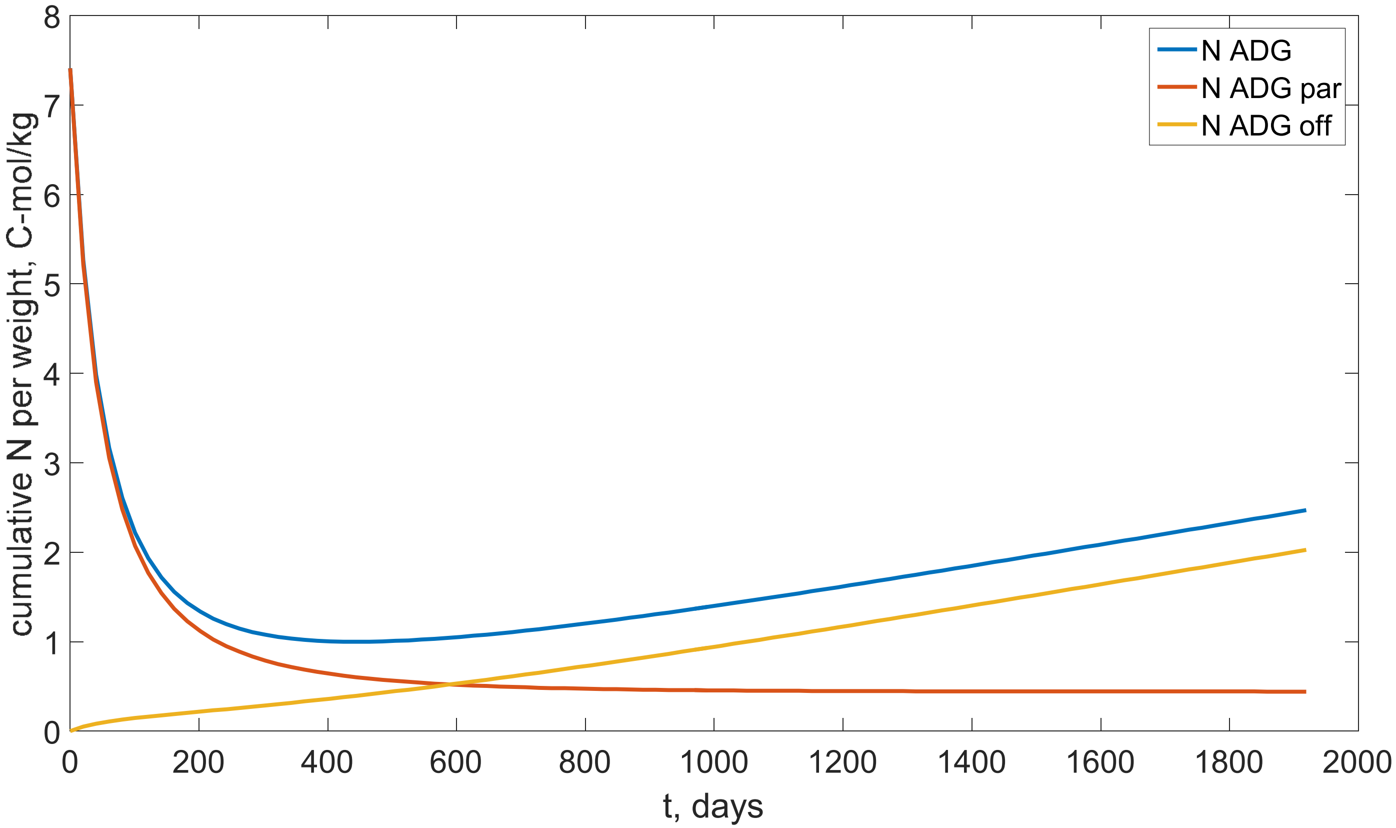

CH4
Alentejana
Angus
Charolais
Limousin
C-flux, kg/year
W, kg

N-waste


Alentejana
Angus
Charolais
Limousin
N, kg/year
L, cm
0
10
20
30
40
50
60
70
0
20
40
60
80
100
120
140
160
180

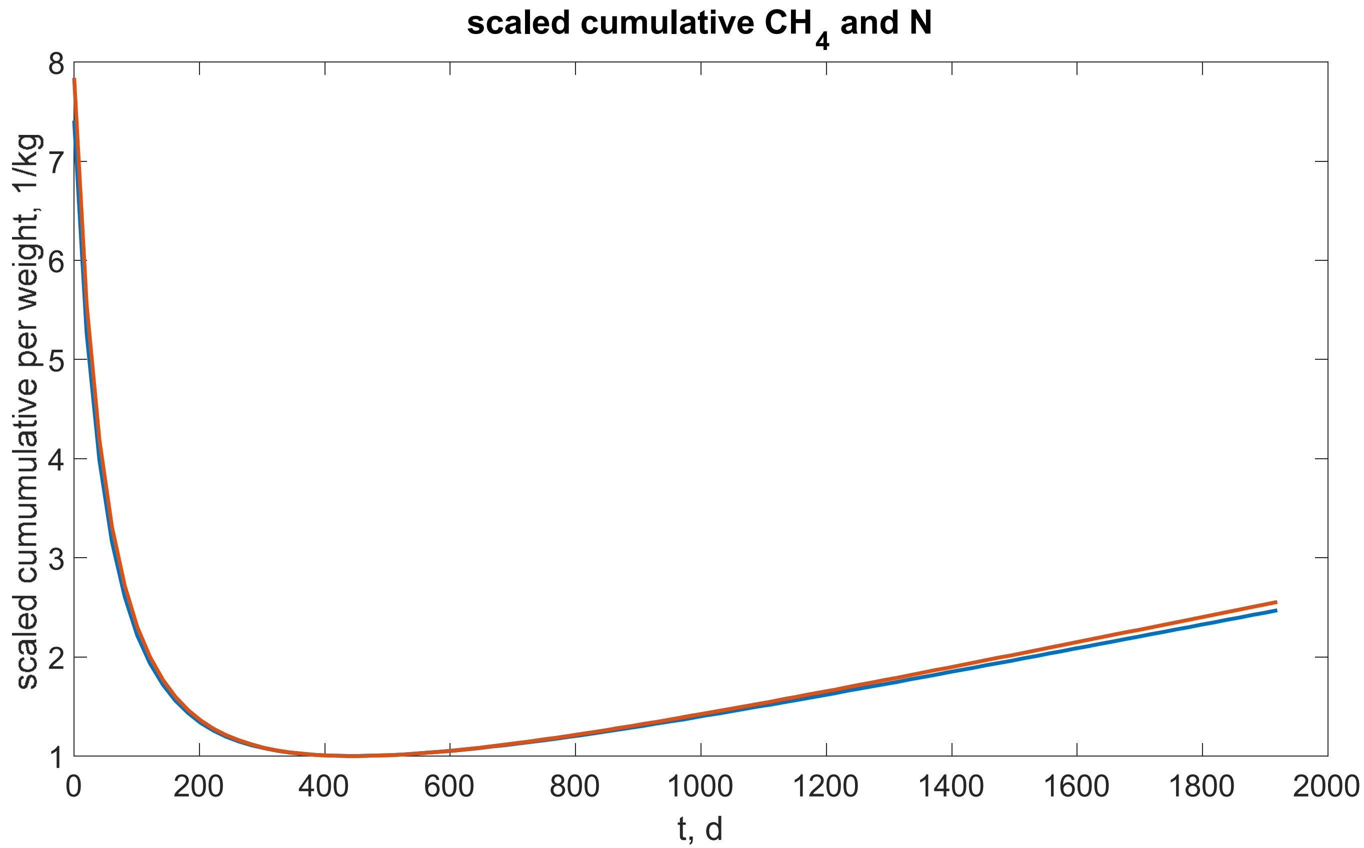

Alentejana
Angus
Charolais
Limousin
N, kg/year
W, kg
0
10
20
30
40
50
60
70
0
100
200
300
400
500
600
700
800
900
1000

N-Waste: Cumulative Flows



Limousine

Methane and N-Waste: Scaled Cumulative Flows



Limousine

Outlook

- Improve methane modelling
- Parametrize the model for individuals, leading to individual based decisions and selection
- Integrate the model in farm-level and watershed-level models, to model greenhouse gas emissions and nitrogen flows
- Plan grazing management, combining with remote sensing of pastures
- Plan amounts and type of suplementation for each life stage (juvenile, adult, gestating, lactating)
- Develop models for "representative cows" to use in planning at the European scale.