A new Dutch Net Energy formula for feed and feedstuffs for growing and fattening pigs

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CVB-Documentation Report nr. 56
May 2015

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Preface

In 1993 a new formula to calculate the net energy (NEv) value of feed ingredients for growing and fattening pigs was introduced. In this formula the (digestible) carbohydrate fraction was separated in Starch, Sugars and (digestible) NSP. In the former CVB formula, developed by the Rostock group and Nehring e.a. and presented at the 4th Energy Symposium of the E.A.A.P. in Poland (September 1967), the digestible carbohydrate fraction was split up in a digestible crude fibre fraction and a digestible NFE fraction.
The realization of the formula introduced in 1993 was partly based on the dataset of J. Noblet as published in 1989 (41 diets), general considerations on the energy utilization of enzymatically digestible carbohydrates (starch) and fermentable carbohydrates (NSP) and pragmatic considerations.

CVB was very satisfied with the generous offer of Dr. J. Noblet of INRA (France) to make available not only the complete database of 61 diets that were evaluated in climate respiration chambers on growing pigs but also to put at our disposal a large number of samples of the feeds tested (52 samples) to perform additional chemical analyses. In the feed samples the starch content was analysed, using the enzymatic method with Amyloglucosidase. In addition the composition of the sugar fraction was analysed using HPLC, to divide this fraction in enzymatic digestible and fermentable sugars.
On behalf of CVB I wish to express our great appreciation to Dr. J. Noblet for making available this dataset which was of inestimable significance to develop a new NEv formula by CVB to calculate the NEv value of feed ingredients for growing and finishing pigs.

The new NEv formula described in this CVB Documentation Report was developed in fact already in 2006 and has been presented in a satellite workshop of the 10th Symposium on Digestive Physiology in Pigs held in May 2006 in Vejle (Denmark).
The present Report has been approved in 2011 by the CVB Working Group ‘Voeding en Voederwaardering Varkens en Pluimvee’ (Feeding and feed evaluation Pigs and Poultry).
As J. Noblet has introduced a new formula (NEm = 0.750 MJ/kg $^{BW0.}$60) to calculate the energy required form maintenance, resulting in higher energy levels form maintenance as calculated with the classical formula (NEm = 0.289 MJ NE/kg $BW^{0.75}$) it was decided to evaluate the scientific basis for this formula. This desk study is described in CVB Documentation Report nr. 57 (H. Everts, 2015). This Report was approved also in 2011 by the CVB Working Group.
In May 2015 it was decided to add a Table with the NEv value of a number of organic acids, ethanol and glycerol. Further, for estimation of the net energy value of feed ingredients containing certain organic acids, ethanol or glycerol – in addition to the new NEv formula derived from the database with dry concentrates – a formula has been added containing the relevant organic acids, ethanol and glycerol to calculate the NEv value of feed ingredients containing these compounds.

The reason that this formula has not been introduced earlier than in 2015 it the fact that it was decided to introduce simultaneously the new net energy (NEv) formula and an updated Table on the faecal digestibility of feed ingredients for growing and fattening pigs.
To update this Table new digestibility trials had to be executed. In these new trials the feeding level was 2.8 * maintenance, which is much closer to the feeding level in practice than the feeding level of 2.3 * maintenance used in the trials on which the present Table is based. Until recently insufficient new trials were available to update this Table. After completion of a third project of digestibility trials enough observations were obtained to update the Table on faecal digestibility of feed ingredients for growing and finishing pigs.

On behalf of the CVB I want to thank the members of the Project Group that has guided and executed the development and evaluation of the new NEv formula.

Wageningen, May 2015

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Abbreviations

AA	Acetic Acid
BA	Butyric Acid
BW	Body Weight
CF	Crude fibre
CFat	Crude Fat, determined without prior acid hydrolysis with HCl
$CFat_h$	Crude Fat, determined after prior acid hydrolysis with HCl
CP	Crude Protein
DE	Digestible Energy
DM	Dry Matter
DMSO	Dimethylsulfoxide
Eth	Ethanol
EW	‘Energiewaarde’ (in Dutch; energy value)
fCH	fermentable carbohydrates
fNSP	fermentable NSP (=Non-Starch Polysaccharides) fraction
GE	Gross Energy
GOS	Glucose Oligosaccharides
HP	Heat Production
HPact	Heat Production due to physical activity
HPtot	Total Heat Production
kJ	kilo Joule
LA	Lactic Acid
ME	Metabolisable Energy
MEm	Metabolisable Energy required for maintenance
MJ	Mega Joule
NE	Net Energy
NEm	Net Energy for maintenance
NEp	Net Energy for production
NFE	Nitrogen-Free Extractives
NSP	Non-Starch Polysaccharides
OM	Organic Matter
PA	Propionic Acid
RE	Retained Energy
$Starch_{EW}$	Starch analysed according to the method of Ewers (polarimetric Method)
$Starch_{AM}$	Starch analysed according to the Amyloglucosidase method
$Starch_e$	Starch that is digested by endogenous enzymes before the terminal ileum
$Starch_f$	Starch that is fermented by bacteria, mainly in the hindgut
Sugars	Crude sugars content analysed according to the Luff Schoorl method
$Sugars_e$	Sugars that can be absorbed from the ileal chyme, either directly or after enzymatic digestion
$Sugars_f$	Sugars that are fermented by bacteria, mainly in the hindgut

1. Net energy (NE) in growing pigs

1.1. Definition of NE

Growing pigs require energy for support of metabolism during maintenance and growth (production). Energy is expressed in kilo joules (kJ) and is derived from three nutrients: fats (lipids), carbohydrates, and proteins. The gross energy (GE) is the enthalpy value of a feed and can be measured by complete combustion of the feed in a bomb calorimeter. The transformation of GE to net energy (NE) can be described by three steps (see Figure 1). In the first step, the energy of the indigestible and unfermentable fraction of the feed is subtracted from GE to determine digestible energy (DE). The second step takes the energy losses by urine (urea) and by fermentation gases (methane, hydrogen) into account and yields the metabolisable energy (ME). Finally, in a third step, the heat lost during biochemical processes in post-absorptive metabolism is subtracted from ME to obtain NE. The NE value can be measured indirectly in energy balance trials in which total heat production (HP) is (indirectly) measured and retained energy (RE) is calculated. The NE for maintenance (NEm) is the amount of energy required to stay alive. Ingested energy above the maintenance requirement can be used for production. In a growing animal the RE represents the NE for production (NEp).

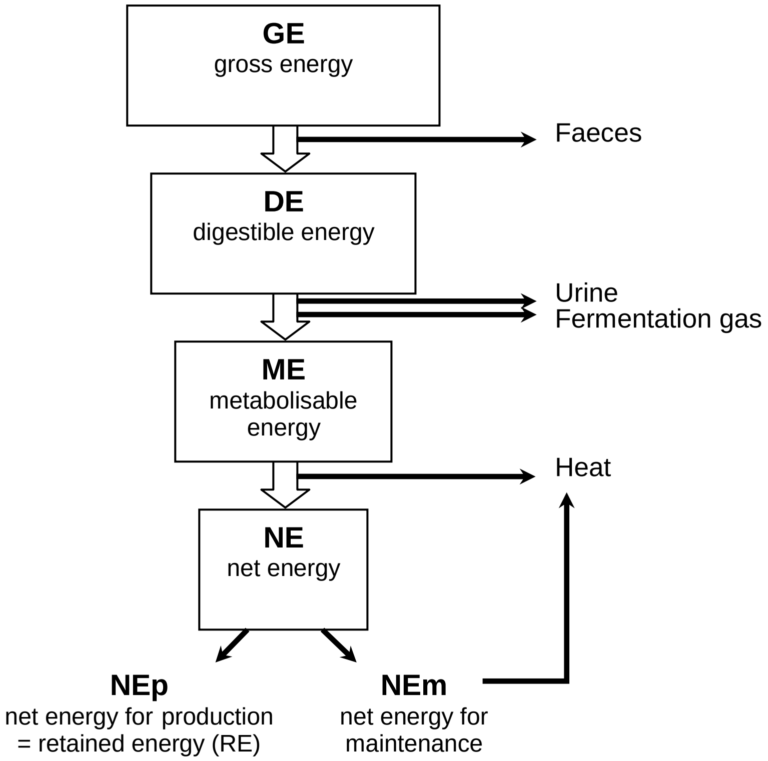

Figure 1. Principle of energy evaluation and energy requirements in growing pigs.

1.2. Measurement of NE

The Dutch energy evaluation system for growing pigs is based on studies evaluating the energy requirements for maintenance and production. These studies evaluate the energy balance of pigs in climate-respiration chambers. Furthermore, the chemical composition and the faecal digestibility of crude protein (CP), crude fat (CFat), starch, sugars, and fermentable carbohydrates of a feed are measured. The results from these studies, together with an assumed NEm, are used to develop a formula to calculate the NE value of a feed or feedstuff for growing pigs. With this formula, it is possible to calculate the NE value based on the chemical composition and faecal digestibility coefficients of the feed or feedstuff.

1.3. Calculation of NE

Since 1973, the Rostock formula for estimation of the NE value of a feed or feedstuff has been used. The Rostock formula was based on the methodology of Schiemann et al. (1971) and was described as follows:

[F1]

$$\mathrm{NE\ (MJ/kg)} = (10.8\times \mathrm{dCP} + 36.1\times \mathrm{dCFat} + 6.3\times \mathrm{dCF} + 12.7\times \mathrm{NFE} - 0.63\times \mathrm{Sugars})/1000$$

Where:
dCP = digestible CP in g/kg (= CP × faecal digestibility coefficient [dc])
dCFat = digestible CFat in g/kg (= CFat × dc)
dCF = digestible crude fibre in g/kg (= CF × dc)
dNFE = digestible nitrogen-free extractives in g/kg (= NFE × dc)

The correction of the NE value for sugars was only applied if a feed or feedstuff contained more than 80 g sugars/kg of air-dry matter.

In 1992 the accuracy of the estimation of the NE value of the carbohydrate fraction was discussed. The NE value for feeds high in starch appeared to be underestimated. The CVB introduced, therefore, a new NE formula in June 1993 (CVB, 1993) that replaced the Rostock formula. This formula was derived in a rather pragmatic manner. The NE coefficients for dCP and dCFat were not adjusted because there were no indications in practice that these values were incorrect. The starting point for the new formula was a standard pig feed containing an energy value of 1.03 EW and 350 g/kg starch that was assumed to be correctly predicted using the Rostock formula. Furthermore, it was assumed that a standard pig feed contained 65 g CF/kg (with an average digestibility of 35%), 540 g NFE/kg (with an average digestibility of 91%), and 25 g Sugars/kg. The faecal digestibility of starch and sugars was assumed to be 100%. Based on a literature survey (CVB, 1993), it was decided to set the NE coefficient of fermentable non-starch polysaccharides (fNSP) at 70% of that of starch. The resulting new CVB formula (CVB, 1993) was as follows:

[F2]

$$\mathrm{NE\ (MJ/kg)} = (10.8\times \mathrm{dCP} + 36.1\times \mathrm{dCFat} + 13.5\times \mathrm{Starch\_C} + 12.7\times \mathrm{Sugars\_C} + 9.5\times \mathrm{fNSP})/1000$$

Where
dCP = digestible CP in g/kg (= CP × faecal digestibility coefficient [dc])
dCFat = digestible CFat in g/kg (= CFat × dc)
Starch_C = Starch × CF_Starch/100
Starch = starch in g/kg (based on starch analyses according to Ewers; if it was evident that this method gave incorrect results, the amyloglucosidase method was used)
CF_Starch = Correction factor indicating the starch fraction (in %) that is digestible by endogenous amylase
Sugars_C = Sugars×CF_Sugars/100
Sugars = gross sugars content (according to the method of Luff Schoorl) in g/kg, expressed in disaccharide content
CF_Sugars = Correction factor indicating the sugars fraction (in %) that is digestible by endogenous enzymes / gross sugars content analysed according to Luff Schoorl
fNSP = fermentable non-starch polysaccharides in g/kg calculated as dOM - dCP - dCFat - Starch_C - Sugars_C

In the report in which the CVB published the new NE formula (CVB, 1993), also several critical notes were presented concerning the basis for the Rostock formula and CVB formula:

- The energetic contributions of dCF and dCFat were based on theoretical considerations and not on calculations using multiple regression.
- The amount of variance in the Rostock database explained by the formula was not high (R^2 =0.68).
- The derived formula was based on feeds that varied little in ingredient composition and were high in cereals.
- The derived formula was based on experiments in which heavy pigs (BW>130 kg) were used that deposit mainly fat whereas growing pigs in practice deposit mainly protein.
- There was no discrimination in energy value between different carbohydrate fractions.

Despite these critical notes, and even more important the absence of an alternative dataset, it was decided to develop the NE formula based on the energy balance trials that make up the foundation of the Rostock formula. In addition to this, the following should be mentioned:

- Schiemann et al. (1971) used an estimated energy requirement for maintenance of 0.289 MJ NE/kg $BW^{0.75}$ instead of a measured value.
- The starch content of the standard pig feed used for the prediction of the NE value with the Rostock formula was analysed using the method of Ewers.
- The method of starch content analysis according to Ewers gives for some feedstuffs an false value. Hence, this method should not be used according to the standard regulations for these feedstuffs. This was addressed in the CVB Documentation Report of 1993 (CVB, 1993), where it was explicitly indicated that for several feedstuffs (e.g. sugars beet pulp, citrus pulp, lupines, and soybean meal) the calculation of the NE value should be based on (much lower) starch contents analysed with a method using amyloglucosidase.
- As a result of improved analytical knowledge, the number of feedstuffs that require the amyloglucosidase method for correct prediction of the NE value was extended (e.g. peas, specific expellers and meals produced as co-products during extraction of oils from oil rich seeds).

In 1995, the working group 'Veevoedertabel' decided to express the Sugars_C in glucose equivalents. The NE coefficient for Sugars was therefore adjusted from 12.7 to 12.2 MJ/kg.

In 1996, the formula was extended allowing estimation of the NE value of wet feedstuffs. Soluble starch, acetic acid, lactic acid, and ethanol were included in the formula. For dry feeds and feedstuffs, the formula remained unchanged.

In 1997, the formula was further improved. For wet feedstuffs, propionic and butyric acid were included in the formula. In the calculation of the fermentable carbohydrate fraction in wet feedstuffs the dOM fraction has to be corrected for the fermentation products present, and, in some cases, also for starch degradation products that are not precipitated in 40% ethanol (GOS = glucose oligosaccharides). It was, therefore, decided to define the fNSP fraction for wet feedstuffs as dOM - dCP - dCFat - Starch - CF_Di×Sugars - Lactic acid, Acetic acid, Ethanol, Propionic Acid - Butyric acid - GOS. As it was assumed that in dry feedstuffs no fermentation products and GOS were present, the calculation of the fNSP fraction of dry feedstuffs did not change. Furthermore, the Starch and Sugars fractions were divided in digestible starch and sugars ($Starch_e$ and $Sugars_e$) and fermentable starch and sugars ($Starch_f$ and $Sugars_f$). So, the formula for dry feeds and feedstuffs was described as follows:

[F3]

$$\text{NE (MJ/kg)} = (10.8\times dCP + 36.1\times dCFat + 13.5\times Starch_e + 12.2\times Sugars_e + 9.5\times(fNSP + CF\_Di\times Sugars_f + Starch_f)) /1000$$

Where

$Starch_e$ = replacing Starch_C

$Starch_f$ = enzymatically indigestible but fermentable Starch (Starch - $Starch_e$)

$Sugars_e$ = replacing Sugars_C (= Sugars × factor $Sugars_e$/Sugars)

$Sugars_f$ = enzymatically indigestible but fermentable sugars (= Sugars - $Sugars_e$)

CF_Di = mass-correction factor to calculate glucose equivalents from disaccharide content in feedstuffs
fNSP = fermentable non-starch polysaccharides in g/kg calculated as dOM - dCP - dCFat - Starch - CF_Di×Sugars

The CVB formula for wet feeds and feedstuffs is described in Appendix I (in Dutch).

In 2002, an improved method of starch analysis came available. In this method, the enzyme amyloglucosidase converts starch to glucose, which is then quantified using the hexokinase method. One critical step in this analysis is the solubilisation of starch prior to incubation with amyloglucosidase. The solubilisation is achieved using dimethylsulfoxide (DMSO) and hydrochloric acid. This new analytical method directly quantifies the starch content (Starch_{AM}) as opposed to the Ewers method that quantifies the starch indirectly (Starch_{EW}).

Based on the difference between both analytical methods, it was decided by the working group ‘Veevoedertabel’ in 2004 that for all feed evaluation systems in which the starch content is incorporated as a relevant parameter, only the starch content analysed with the amyloglucosidase method should be used. This has also resulted in slightly higher NE coefficients for Starch, Sugars_e, and fNSP (see below). The magnitude of the change in NE value of a feed or feedstuff is dependent of the difference between both methods. The analysed starch content with the amyloglucosidase method is generally lower than that with the Ewers method. This lower Starch_{AM} content would result in a (slight) decrease in NE value. However, the current formulas used to calculate the dNSP content were derived from digestibility studies in which dNSP as calculated by subtracting the Starch_{EW} content (and other components) from the dOM content. As it was assumed that Starch_{EW} is completely digestible, the difference between Starch_{EW} and Starch_{AM} (which now is part of the dNSP fraction) also had to be considered as completely digestible. This has resulted in slightly altered estimation formulas to calculate the dNSP content. This will also affect the estimation of the dNSP content of a feed or feedstuff. Furthermore, a pig feed will, independent of the type of the starch content analysis, have one specific energy value for a pig. In order to prevent changes in the NE value of a (reference) diet, due to the changes in starch and NSP contents indicated above, only the coefficients for the carbohydrate fractions in the NE formula should be changed. Initially, it was decided to implement the consequences of the new starch analysis method for the calculation of the NE value in a pragmatic manner, similar to the approach in 1993. In 2003, however, the large dataset of climate-respiration studies of Dr. J. Noblet (INRA) accompanied with a large amount of feed samples became available for the CVB. It was decided to use this new dataset to bring the Dutch NE formula for growing pigs up to date.

Finally, in 2004, it was decided to define the NSP fraction as dOM - dCP - dCFat - Starch - CF_Di×Sugars. Since that time, the following formula were used for calculation of the estimated NE value of dry (F4a) and wet (F4b) feeds and feedstuffs:

[F4a] For dry feeds and feedstuffs
NE (MJ/kg) =
$(10.8\times\text{dCP} + 36.1\times\text{dCFat} + 13.7\times\text{Starch}_{AM} + 12.4\times\text{Sugars}_e + 9.6\times\text{fCH})\ /1000$

Where
fCH = fermentable carbohydrates (= fNSP + Starch_f Sugar_f)
fNSP = fermentable non-starch polysaccharides in g/kg calculated as dOM - dCP - dCFat - Starch - CF_Di×Sugars

[F4b] For wet feeds and feedstuffs
NE (MJ/kg) = $(10.8\times\text{dCP} + 36.1\times\text{dCFat} + 13.7\times(\text{Starch}_{AM} + \text{GOS}) + 12.4\times\text{Sugars}_e + 9.6\times\text{fCH} + 11.5\times\text{LA} + 9.8\times\text{AA} + 14.2\times\text{PA} + 17.9\times\text{BA} + 21.7\times\text{Eth})\ /1000$

Where
fCH = fermentable carbohydrates (= fNSP + Starch_f + Sugars_f)

fNSP = fermentable non-starch polysaccharides in g/kg calculated as dOM - dCP - dCFat - Starch - CF_Di×Sugars - LA - AA - Eth - PA - BA - GOS
GOS = Glucose oligosaccharides (oligoglucose fragments of incomplete starch hydrolysis, soluble in 40% ethanol) in g/kg
LA = Lactic acid in g/kg
AA = Acetic acid in g/kg
PA = Propionic acid in g/kg
BA = Butyric acid in g/kg
Eth = Ethanol in g/kg

2. Development of a new NE formula for growing pigs

In 2003, the large dataset of energy balance trials with growing pigs of Dr. J. Noblet (INRA, France) accompanied with a large number of feed samples became available for the CVB. These trials give information about ME, RE and HP. It was decided to use this new dataset to develop a new NE formula for growing pigs up to date. The diets used in the studies of J. Noblet were analysed for CFat with and without acid hydrolysis. For the determination of the CFat content in faeces, all samples were hydrolysed with acid prior to fat extraction. In line with the CVB guidelines for faecal digestibility studies, the working group 'Veevoedertabel' declared that the CFat data used in the new NE formula should be based on acid-hydrolysed CFat ($CFat_h$) contents of feed and faeces. Only the $CFat_h$ digestibility data were, therefore, used for the development of the new NE formula. The following sections describe the dataset of Noblet, the estimation of NEm, the development of the new NE formula for growing pigs, and the validation of the new formula using the dataset of Van der Honing et al.

2.1. Description of dataset of J. Noblet

The dataset of Noblet contained an evaluation of 61 diets. For 52 of these diets there was made available to the CVB a sufficient amount of material for additional chemical analyses. In the beginning of 2003 these 52 feed samples were analysed for:

- $Starch_{EW}$: the aim was to evaluate the agreement between the laboratories of INRA and a Dutch reference laboratory for this method (Labco, Europoort, NL) for this type of starch content analysis. The results of this evaluation are presented in Appendix II. The starch content of the diets analysed by both laboratories was similar.
- $Starch_{AM}$: as this was in line with the transition from $Starch_{EW}$ to $Starch_{AM}$ for feed evaluation in growing pigs.
- Sugars-total: the aim was to evaluate the agreement between the laboratories of INRA and ID-Lelystad (now part of WUR-Livestock Research) for this analysis. The results of this evaluation are presented in Appendix III. Again, the sugars content of the diets analysed by both laboratories was similar. It was decided to use the sugars content data from INRA for the development of the new NE formula because these were performed in more fresh feed samples.
- Sugars composition using the HPLC method: the aim was to separate the $Sugars_e$ and $Sugars_f$ fractions. The results from this analysis was dubious for five feed samples. It was decided that for these samples the ratio $Sugars_e$/Sugars-total was estimated based on the ingredient composition (see Appendix IV).

Table 1 shows the description of the most important characteristics of the dataset of Noblet. This table shows that for all the parameters the subset of 52 diets (in which additional analyses were performed) was in close agreement with the total dataset. It was decided to use the subset of the 52 diets as it was expected to give more reliable results compared to inclusion of the remaining nine diets for which the $Starch_{AM}$ and the $Sugars_e$ and $Sugars_f$ fractions had to be calculated from the ingredient composition and table values for these nutrients.

Table 1. Description of the most important characteristics of the dataset of J. Noblet.

Parameter	**Total dataset (61 diets)**			**Subset with additional analyses (52 diets)**		
	Mean	**Min.**	**Max.**	**Mean**	**Min.**	**Max.**
Chemical composition (in g/kg DM)						
CAsh	75	49	108	75	54	108
CP	198	110	274	199	110	274
CFat$_{h}$	50	18	110	50	18	110
Starch$_{EW}$ (INRA)	428	230	636	425	235	618
Starch$_{AM}$ (ID-Lelystad)	NA	NA	NA	394	189	597
Sugars-total (INRA)	60	17	282	56	17	155
Sugars$_{e}$/Sugars-total	NA	NA	NA	0.67	0.46	0.99
NSP (with CFat$_{h}$ and Starch$_{EW}$[1])	194	47	295	198	47	295
Digestibility coefficients (in %)						
OM	82.9	69.5	95.2	82.4	69.5	95.2
CP	78.9	64.1	94.1	78.5	64.1	94.1
CFat$_{h}$	57.8	31.8	80.3	57.4	31.8	80.3
NSP (with CFat$_{h}$ and Starch$_{EW}$[1])	50.1	20.0	68.9	49.7	20.0	68.9
Other						
Mean BW per treatment (kg)	43.1	38.2	46.7	43.1	38.2	46.7
Feed level (g DM/BW$^{0.75}$)	91	80	107	91	80	107
RE in MJ/kg DM of diet	5.80	3.93	7.52	5.74	3.93	7.44
NE determined in MJ/kg DM of diet (= RE + NEm; NEm according to Noblet)	10.49	8.23	12.79	10.42	8.23	12.52

Abbreviations: DM, dry matter; CAsh, crude ash; CP, crude protein; CFat, crude fat; CFat$_{h}$, acid-hydrolysed crude fat; Starch$_{EW}$, starch content analysed with the Ewers method; Starch$_{AM}$ starch content analysed with the amyloglucosidase method; Sugars$_{e}$, enzymatically digestible sugars; NSP, non-starch polysaccharides; OM, organic matter; BW, body weight; RE, retained energy; NE, net energy; NEm, net energy for maintenance; NA, not analysed.

[1] In this table, that is only meant to give an overview of the dataset of Noblet, it was decided to use the Starch$_{EW}$ content for the calculation of the NSP fraction as this information was available for all 61 diets. For the 52 diets used to derive a new NE formula, NSP was calculated by subtracting (among other chemical fractions) Starch$_{AM}$ from the OM content.

2.2. Estimation of NEm for growing pigs

To derive the NE value of the ingested feed an estimation of the NEm is required. The theoretical background concerning the estimation of the NEm requirement is described in a report by Everts (2011). It was concluded that 0.60 can be correctly used as an exponent to express metabolic BW of growing pigs and that the NEm can be estimated as 750 kJ per BW$^{0.60}$.

The dataset of J. Noblet is based on observations from individually housed growing pigs. In practice, growing pigs are housed in groups. The NEm formula from J. Noblet may, therefore, not be valid for group-housed growing pigs. The CVB requested the Department of Animal Sciences to evaluate if there were energy balance trials performed that were suitable for the assessment of the effect of housing condition (individual *vs*. group) on RE. The results of this evaluation are described in the report of Bosch et al. (2010). The parts of interest for this report are included in Appendix V. The type of behaviour performed by group-housed and individually housed pigs may differ (e.g. stereotypic behaviour in individually housed pigs), but this did not result in clear differences in NEm between both housing conditions. It was concluded that there is no reason to assume that group-housed pigs have a higher NEm than individually housed pigs. So, the NEm based on individually housed pigs (NEm = 750 kJ per BW$^{0.60}$) seems also to be suitable for estimation of NEm in group-housed growing pigs.

2.3. Development new NE formula

This section describes in short the derivation of the new NE formula based on the 52 trials from the dataset of J. Noblet. The NEm according to Noblet was used in the regression analyses conducted by the CVB. Several models were evaluated using the regression analyses (see Appendix VI for models evaluated and obtained results). Before conducting the evaluation of the models, the following model was preferred:

NE (MJ/kg) = $(a\times dCP + b\times dCFat_h + c\times(Starch_{AM} + 0.9\times Sugars_e) + d\times(fNSP + CF\_Di\times Sugars_f))/1000$

Comments:

- NE = RE + NEm, where RE = retained energy and NEm is calculated according to Noblet (NEm (MJ) = $0.750*BW^{0.60}$)
- Taking into account the ingredients used in the trials, it was assumed that $Starch_{AM} = 0$ (and therefore could be omitted from the regression model)
- Sugars contents are based on analyses by INRA.
- $Sugars_e$ and $Sugars_f$ are calculated from the sugars value from INRA, using the $Sugars_e$/Sugars-total ratio calculated from individual HPLC sugars analysis.
- The model contains the combination ($fNSP + CF\_Di\times Sugars_f$) instead of the separate fNSP and $CF\_Di\times Sugars_f$ components because it is assumed that both fermentable components will have similar NE values.
- The models contained the combination ($Starch_{AM} + 0.9\times Sugars_e$) instead of the separate $Starch_{AM}$ and $Sugars_e$ components because the $Sugars_e$ is expressed as glucose equivalents, of which the GE value is 0,9 * GE of starch.

Regression analysis using this model resulted in the following coefficients in the NE formula:

[F5]
NE (MJ/kg) = $(11.70\times dCP + 35.74\times dCFat_h + 14.14\times(Starch_{AM} + 0.9\times Sugars_e) + 9.74\times(fNSP + CF\_Di\times Sugars_f))/1000$

It appeared that three observations had a strong influence on the results of the regression analyses. Step-wise elimination of these observations did not have a large effect on the NE coefficients for this formula (Appendix VII).
The ratio NE-($fNSP + CF\_Di\times Sugars_f$)/NE-$Starch_{AM}$ is 9.74/14.14 = 0.689. This ratio is in strong agreement with the value of 0.70 used in the current NE formula (F4a). The value of 0.70 was chosen rather pragmatically (CVB, 1993) and based on a number of considerations. Furthermore, Noblet and Le Goff indicated that this ratio of 0.70 would be most realistic (Noblet & Le Goff, 2001). Based on this value, another formula was developed to be able to compare it with formula F5. The model for this formula was:

NE (MJ/kg) = $(a\times dCP + b\times dCFat_h + c\times(Starch_{AM} + 0.9\times Sugars_e + 0.70\times(fNSP + CF\_Di\times Sugars_f)))/1000$

For this model, it assumed that the NE value of fermentative carbohydrates is 0.70 times the NE value of $Starch_{AM}$. Regression analysis using this model resulted in the following coefficients in the NE formula:

[F6]
NE (MJ) = $(11.64\times dCP + 35.65\times dCFat_h + 14.12\times(Starch_{AM} + 0.9\times Sugars_e + 0.70\times(dNSP + CF\_Di\times Sugars_f)))/1000$

If F5 is compared with F6 it appears that the differences are small. Because the coefficients in F5 are the result of regression analysis and the ratio in NE between fermentative

carbohydrates and starch was fixed in F6 based on the evaluation of several data, F5 was considered to be the preferred NE formula.
In addition to the regression analyses according to the models depicted in Annex VII and using NEm according to Noblet, regression analyses were made for the same models and using NEm according to Rostock (NEm (MJ) = $0.290 \times BW^{0.75}$). From these analyses it appeared that not only the absolute values of the coefficients for the various fractions in the NE formula changed, but that also the values relative to Starch changes. This is illustrated in Table 2 for the regression model used to derive F5.

Table 2. Illustration that the coefficients in the NE formula, derived by regression analyses, relative to starch depend on the NEm used (together with RE) in the calculation of the NE value of a feed.

Parameter in NE formula	Absolute value of NE coefficient in regression formula			Value of NE coefficient relative to $Starch_{AM}$		
	CVB (2004)	F.5 [a]	F.7 [b]	CVB (2004)	F.5	F.7
dCP	10.8	11.70	9.34	0.80	0.83	0.75
$dCFat_h$	36.1	35.74	32.07	2.57	2.53	2.56
$(Starch_e + 0.90 \times Sugars_e)$	13.5	14.14	12.51	1.00	1.00	1.00
(fNSP + CF_Di×$Sugars_f$)	9.5	9.74	7.51	0.70	0.69	0.60
R^2		0.953	0.944			
s.e. prediction (MJ/kg DM of diet)		0.221	0.225			

[a] Formula derived by regression analysis using the model NE (MJ/kg) = (a×dCP + b×$dCFat_h$ + c×($Starch_{AM}$ + 0.9×$Sugars_e$) + d×(fNSP + CF_Di×$Sugars_f$))/1000, in which NE = RE + NEm according to Noblet (NEm (MJ) = $0.750 \times BW^{0.60}$).
[b] Formula derived by regression analysis using the same model, in which, however, NE = RE + NEm according to Rostock (NEm (MJ) = $0.290 \times BW^{0.75}$).

The unexpected and up till now unexplained observation that the net energy coefficients relative to starch in the regression formula was dependent on the NEm that was used, greatly retarded the introduction of a new NE formula.

One of the actions done was a thorough literature review by Everts (CVB, 2011) of all publications of the group of Noblet in which directly or indirectly data can be found concerning the NEm formula he used. For growing pigs it was concluded that the use on an exponent of 0.60 to express the metabolic BW resulted in smaller residual standard errors than the use of the exponent 0.75. The estimation of NEm on the basis of fasting heat metabolism knows some complications, but can be measured rather easily under standardized conditions. Taking into account the outcome of all experimental work from Noblet and his co-workers in the period 1989-2010, a value of 750 kJ NE per $kg^{0.60}$ is proposed as an estimate for the NEm for growing pigs.

As the NEm according to the formula of Noblet is relatively high compared to the amount of energy retained, this automatically implies that the efficiency with which energy is retained is also high. This is illustrated in Figure 1, in which the relation between the RE and the ME is depicted. From the slope of the line it can be seen that ME is retained with an efficiency of 0.79. A high efficiency for the retention of ME was not only found in the experiment of Noblet. A very similar high value was found in the study of Van der Honing (Figure 2). The very comparable high retention of ME as found in these two independent studies, was an extra strong argument to use the NEm formula of Noblet in the derivation of a new NE formula for growing and finishing pigs.[1] The relationship between ME and RE in the dataset of Bosch et al. (2010, see below) was even somewhat higher, i.e. 0.86.

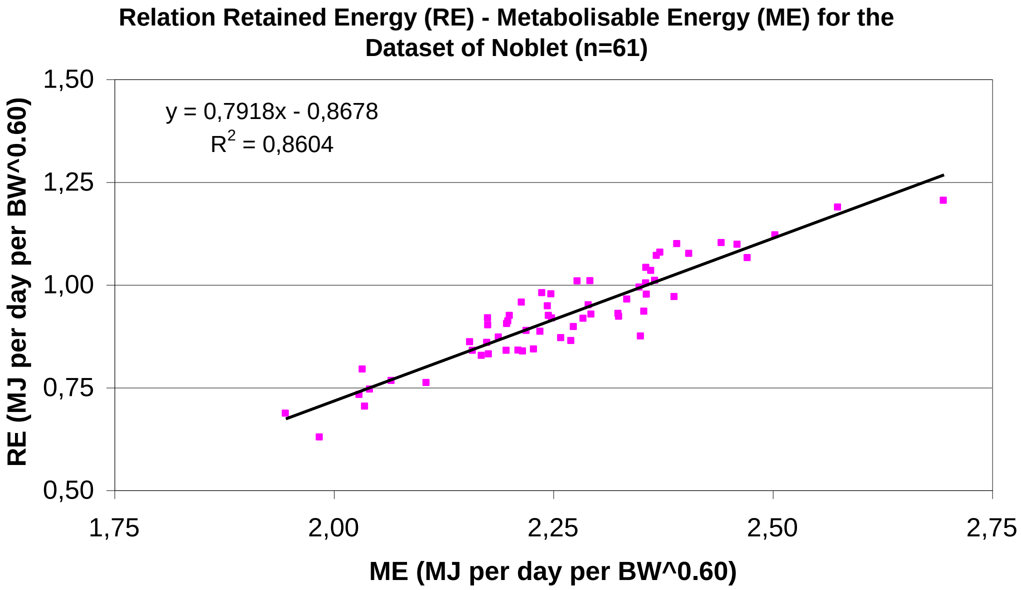

Figure 1. Relation between the Retained Energy and the Metabolisable Energy for the dataset of Noblet.

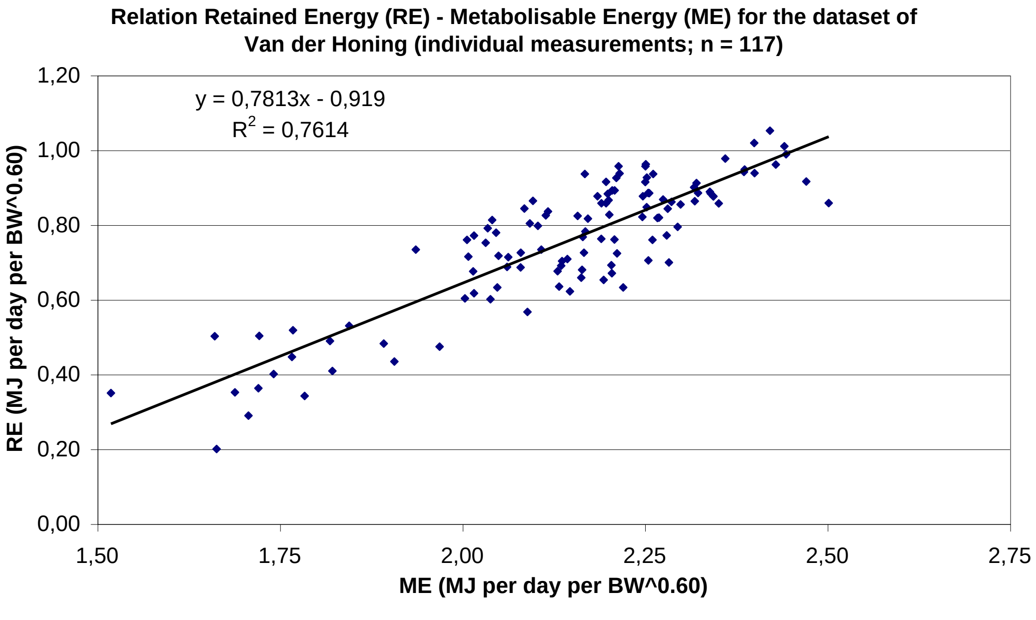

Figure 2. Relation between the Retained Energy and the Metabolisable Energy for the dataset of Van der Honing et al.

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[1] De Lange et al. (2005) suggested for NEm the following formula: NEm = $0.489 \times BW^{0.60}$. In the BW range in which Noblet did his energy balance experiments (min. 38.3; max. 46.7; mean 43.1 kg) NEm calculated according to this formula (4.36 - 4.91 MJ) relatively closely resembles that calculated with the Rostock NEm formula (NEm = $0.290 \times BW^{0.75}$) (4.46 - 5.18 MJ). As a result of this the regression formula derived by regression analysis according to model 5 also is rather comparable to that obtained by using NEm Rostock to calculate RE: NE (MJ/kg) = $(9.31 \times dCP + 31.54 \times dCFAT_h + 12.45 \times Starch_{AM} + 0.90 \times Sugars_e) + 7.20 \times dNSP + CF\_Di \times Sugars_f))/1000$.

The observation that a high efficiency for the retention of ME is not only found in the study of Noblet but also in that of Van der Honing et al. and in the desk study of Bosch et al., in which they collected a number of energy balance study executed at Wageningen University, was considered as relevant additional evidence to rely on a new net energy formula using the NEm as proposed by Noblet.

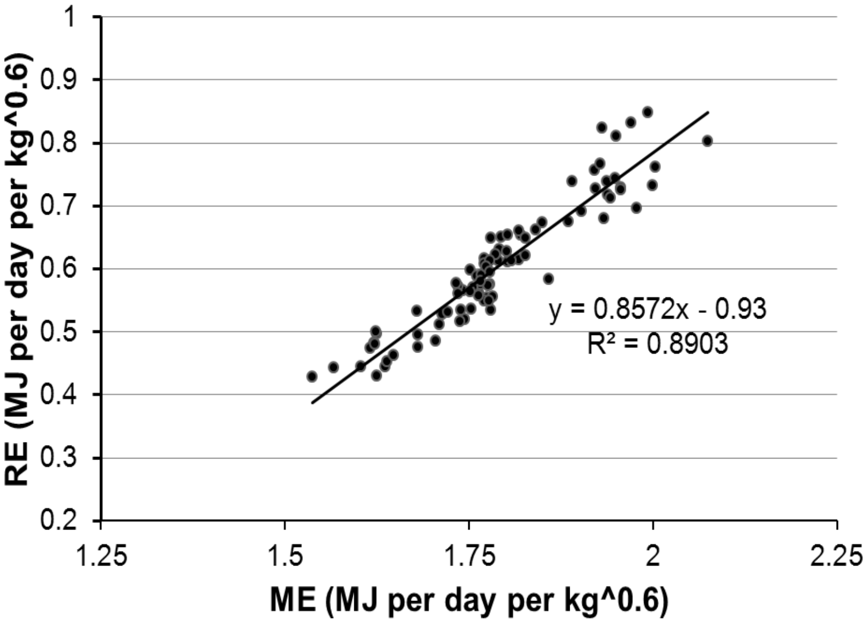

Figure 3. Relation between the Retained Energy and the Metabolisable Energy for the dataset of Bosch et al.

The preferred formula F5 has been derived from the database of Noblet, consisting of observations with concentrates in which almost no or (in the case corn gluten feed was included in the diet) only small amounts of organic acids may have been present.

Although the formula has been derived from experiments with complete concentrates, it will be frequently used in practice to calculate the net energy value of individual feed ingredients. As in many wet industrial by-products and in some dry feed ingredients organic acids (mainly lactic acid), ethanol and glycerol may be present, it is desirable to extend the formula by adding the relevant components that may be present in these ingredients. For an explanation on the net energy values of these compounds that are assumed to be 100% digestible, see Annex X.

[F7]

NE (MJ/kg) = (11.70×dCP + 35.74×dCFat$_h$ + 14.14×(Starch$_{AM}$ + 0.9×Sugars$_e$) + 9.74×(fNSP + CF_Di×Sugars$_f$) + 10.61xAcetic acid + 19.52*Butyric acid + 14.62xPropionic acid + 12.02xLactic acid + 20.75xEthanol + 13.83xGlycerol) /1000

2.4. Validation of NE formula using dataset of Van der Honing et al.

2.4.1. Description of dataset of Van der Honing et al.

The complete dataset of Van der Honing et al. (1984) contained data on 29 diets. For four diets, the effect of feed level (low *vs*. high) was evaluated. It was decided to exclude the low feed level treatments from the dataset. No respiration data was reported for one feed. This feed was, therefore, not included in the dataset of Van der Honing et al. (resulting in *n*=28 diets). Table 3 shows the description of the most important characteristics of the dataset of

Van der Honing et al. including 28 diets. Detailed information of the ingredient composition, the analysed chemical composition and the digestibility and respiration data of these diets is shown in respectively Table A, B and C of Appendix VIII.

The number of replicates (consisting out of groups of two animals) per feed was not similar among studies and varied from 2 to 4 per feed. Furthermore, the mean BW of the groups of animals (i.e. the replicates) varied among diets under investigation. The mean BW of the animals used for the evaluation of the diets by Van der Honing et al. varied between 67 to 99 kg. These animals were considerable heavier than those used in the studies of Noblet (38.2 to 46.7 kg). The animals used in the studies of Van der Honing et al. were expected to deposit relatively more fat and less protein than those animals used in the studies of Noblet.

The starch content of the diets used were analysed using the amyloglucosidase method of that time. The CFat content in all feed and faecal samples was analysed without the acid hydrolysis step. The $CFat_h$ content of feed and faeces was only analysed for 12 treatments. Based on the analytical methods used, the results of subset of 12 diets could be directly compared to the dataset of Noblet. The relation between $dCFat_h$ with dCFat was derived from the dataset of Van der Honing et al. ($CFat_h = 1.00 \times CFat + 5.0$ in g/kg DM). Based on this relationship, the $dCFat_h$ was calculated from the dCFat for the remaining 16 of 28 diets. In addition, the dNSP fractions were corrected for the difference between dCFat and new $dCFat_h$ values.

A correlation matrix was made to evaluate possible confounding factors related to diet composition (see Appendix IX) that might be important for the interpretation of the statistical analysis in this validation.

Table 3. Description of the most important characteristics of the dataset of Van der Honing et al.

Parameter	**Total dataset (28 diets)**		
	Mean	**Min.**	**Max.**
Chemical composition (in g/kg DM)			
CAsh	72	52	121
CP	203	176	230
CFat	69	14	160
$Starch_{AM}$	320	148	569
Sugars-total	67	31	101
$Sugars_e$/Sugars-total	0.83	0.72	1.00
NSP (with CFat and $Starch_{AM}$)	271	151	380
Digestibility coefficients (in %)			
OM	80.4	73.7	88.1
CP	75.5	64.8	84.9
CFat	69.9	5.6	87.2
NSP (with CFat and $Starch_{AM}$)	58.2	46.1	76.8
Other			
Mean BW per treatment (kg)	75	67	99
Feed level (g DM/$BW^{0.75}$)	80	69	90
RE in MJ/kg DM of diet	5.28	3.74	6.58
NE determined in MJ/kg DM of diet (= RE + NEm; NEm according to Noblet)	10.18	8.18	12.19

Abbreviations: DM, dry matter; CAsh, crude ash; CP, crude protein; CFat, crude fat; $Starch_{AM}$ starch content analysed with the amyloglucosidase method; $Sugars_e$, enzymatically digestible sugars; NSP, non-starch polysaccharides; OM, organic matter; BW, body weight; RE, retained energy; NE, net energy; NEm, net energy for maintenance.

2.4.2. Validation of new NE formula

It is important to note that the aim of the studies performed by Van der Honing et al. was not related to the development of a new NE formula. The aim of these studies was to evaluate the interaction between fat and carbohydrate digestion. The composition of the diets used in these studies varied, therefore, considerable in CFat and carbohydrate contents and the variation in (digestible) CP content was relatively low. Furthermore, there were differences between Noblet and that of Van der Honing in some of the methodologies used to evaluate the energy balance of pigs in climate-respiration chambers. These differences were described in a memo by Everts (2011). Such differences include, the genotype, sex, and BW of the animals, experimental design (parallel vs. Latin square), feeding level (lower in the last stage for the trials of Noblet), NEm of 750 kJ NE per $kg^{0.60}$ according to Noblet or 279 kJ NE per $kg^{0.75}$ according to Van der Honing, calculation of heat production according to Brouwer (Noblet) or according to an average heat production combined with the C&N balance (Van der Honing), the Kjehldahl method for all N analyses (Noblet) or the Dumas method for dietary and faecal N, the Kjehldahl method for urinary N, and the NEN 3104 for N in condense water and the outflow of air (Van der Honing). The effect of the sum of these differences are, however, difficult to quantitate. The lower feeding level in the last stage for the trials of Noblet could result in a slight overestimation of RE. The most important difference was, however, the calculation of NEm. For a pig with a BW of 45 kg, this difference would be approximately 1.4 MJ NE per kg DM.

Figure 4 shows the relationship between the calculated NE value using F5 and the measured NE value for 28 diets evaluated by Van der Honing et al.

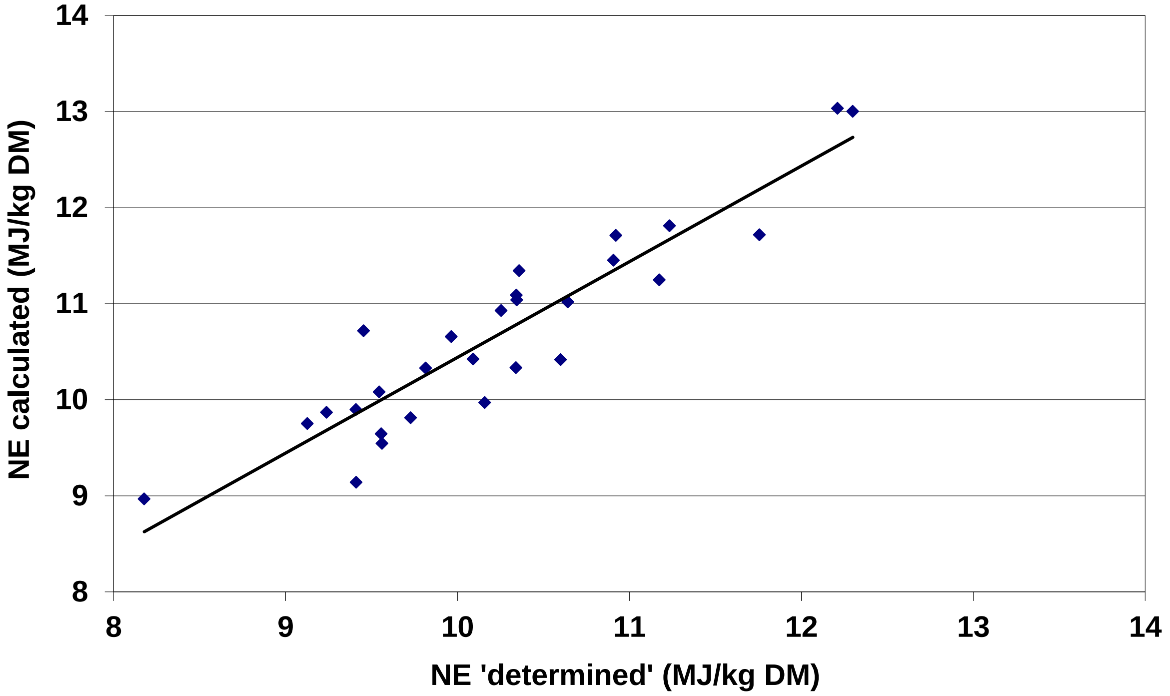

Figure 4. Relationship between the calculated NE value using F5 and the measured NE value for 28 diets evaluated by Van der Honing et al.

The found relationship between NE predicted (NE-pred. in MJ/kg DM) according to the new NE formula based on the dataset of Noblet and the NE measured (NE-meas. in MJ/kg DM) in the dataset of Van der Honing was:

NE-pred. = 1.023 × NE-meas. + 0.304
Standard error: 0.102 1.044

P-value: <0.001 0.773
R^2: 0.703
Standard error estimate: 0.471 MJ/kg DM

Results of the additional statistical evaluation of the relationship between NE predicted and NE measured is presented in Table 4.

Table 4. Statistical evaluation of the relationship between NE predicted and NE measured.

Mean NE		**s**	**s_a**	**s_p**	**r**
Predicted	**Measured**				
10.676	10.162	0.472	0.938	1.060	0.90
			RMSPE%		
MSPE	0.472	1.000	6.43	relative error	0.01
$(Pg\text{-}Ag)^2$	0.265	0.561	3.61	error: difference in level	
$(sp\text{-}sa)^2$	0.015	0.031	0.20	error: difference in variation	
2(1-r)spsa	0.192	0.408	2.62	error: low correlation	

Taken into account the methodological differences between the datasets of Noblet and Van der Honing et al. and the fact that the diets of Van der Honing et al. were not formulated to validate the NE formula. it can be concluded that the new formula can be used to accurately predict the NE value of diets and feedstuffs for growing pigs.

2.5. Validation of NE formula using dataset of Bosch et al.

2.5.1. Description of dataset of Bosch et al.

The new NE formula was also evaluated by Bosch et al. In this study, a selection was made from all experiments with growing pigs since the early 90’s in the climate respiration chambers of the Department of Animal Sciences of Wageningen University. Eligibility criteria were age (older than 7 weeks-of-age) and availability of data on feed composition, energy balance and faecal nutrient digestibility. In addition, the nature of the treatments in each experiment was examined and, if necessary, on one or more treatment groups from an experiment were omitted. Furthermore, only those studies were included for which both feed and faeces were analysed for their nutrient compositions. The studies used in this dataset are fully described in the confidential report Bosch et al. (2010) (i.e. the dataset referred to as ‘dataset 1b’). An overview of the variation in nutrient composition of diet, animal weight, and diet intake for this dataset is shown in Table 5 in which only the studies with group-housed are included. The digestibility of starch and sugars were assumed to be 100%.

Table 5. Description of the most important characteristics of the dataset of Bosch et al. (*n*=87 observations).

Parameter	**Mean**	**Min.**	**Max.**
dCP (g/kg DM)	163.1	120.6	196.2
dCFat (g/kg DM)	33.0	7.1	131.2
Starch + sugars (g/kg DM)	406.5	281.6	595.6
fNSP (g/kg DM)	194.2	81.1	294.4
BW (kg)	49.6	27.4	60.8
Feed intake (g DM/(animal day))	1281	792	1704
Feed intake (g DM/(kg $BW^{0.75}$ day))	68.7	61.9	79.1

Abbreviations: dCP, digestible crude protein; DM, dry matter; dCFat, digestible crude fat; fNSP, fermentable non-starch polysaccharides; BW, body weight.

2.5.2. Validation of new NE formula

The relationship between calculated NE intake and energy retention in group-housed pigs is shown in Table 6.

Table 6. Relationship between calculated net energy intake (MJ/(kg$^{0.60}$ day)) and retained energy (MJ/(kg$^{0.60}$ day)) in group-housed pigs (*n*=87) for several NE formula.

NE formula	Slope	SE	Intercept	SE	RE=0	R^2	rMSE
F5 (new formula)	0.915	0.061	-0.591	0.080	0.646	0.728	0.0532

Abbreviations: NE, net energy; SE, standard error; RE, retained energy; rMSE, root of mean square error.

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4. Appendices

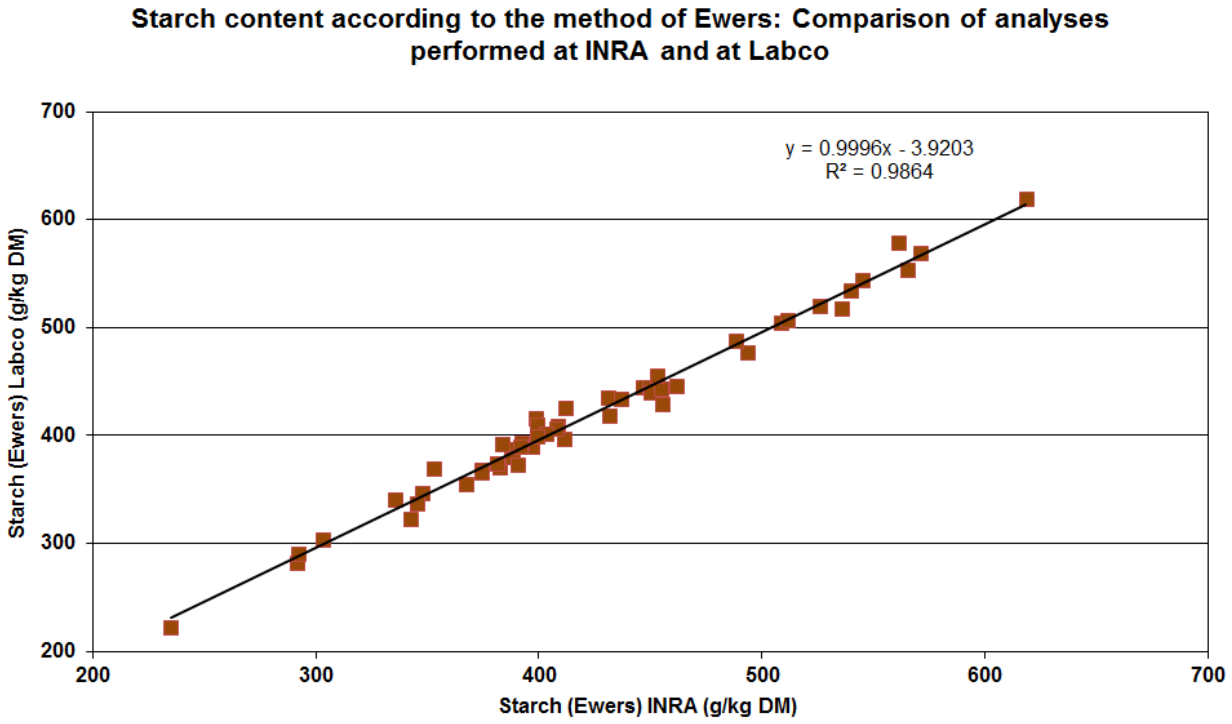
Appendix I: The CVB formula for wet feedstuffs (1996)

$$\text{NE (MJ/kg)} = (10.8 \times \text{dCP} + 36.1 \times \text{dCFat} + 13.5 \times \text{Starch\_C} + 12.2 \times \text{Sugars\_C} + 9.5 \times \text{fNSP} + 4.0 \times \text{SStarch} + 4.8 \times \text{AA} + 2.7 \times \text{LA} + 21.3 \times \text{Eth})/1000$$

Where
dCP = digestible CP in g/kg (= CP×digestibility coefficient [dc])
dCFat = digestible CFat in g/kg (= CFat×dc)
Starch_C = Starch×CF_Starch/100
Starch = starch in g/kg (based on starch analyses according to Ewers; if it was evident that this method gave wrong results. the amyloglucosidase method was used)
CF_Starch = correction factor indicating the starch fraction (in %) that is digestible by endogenous amylase
Sugars_C = Sugars×CF_Sugars/100
Sugars = gross sugars content (according to the method of Luff Schoorl) in g/kg. expressed in disaccharide content
CF_Sugars = correction factor indicating the sugars fraction (in %) that is digestible by endogenous enzymes / gross sugars content analysed according to Luff Schoorl
fNSP = fermentable non-starch polysaccharides in g/kg calculated as dOM – dCP - dCFat – Starch_C – Sugars_C
SStarch = soluble starch in g/kg
LA = lactic acid in g/kg
AA = acetic acid in g/kg
Eth = ethanol in g/kg

Appendix II: Comparison between Starch$_{EW}$ content analysed by INRA and by Labco

Source: CVB report EW-VV-10. Actualisatie van het NE-systeem voor vleesvarkens, Bijlage 1


Starch content according to the method of Ewers: Comparison of analyses performed at INRA and at Labco

The relation between both laboratories that performed the of starch analyses according to the method of Ewers was as follows:

Starch$_{EW}$ (Labco) =	0.9996 * Starch$_{EW}$ (INRA) -	3.9
s.e.	0.0166	7.2
t-prob.	<0.001	0.58
R^2:	0.986	
s.e. of the prediction:	9.3 g/kg DM	

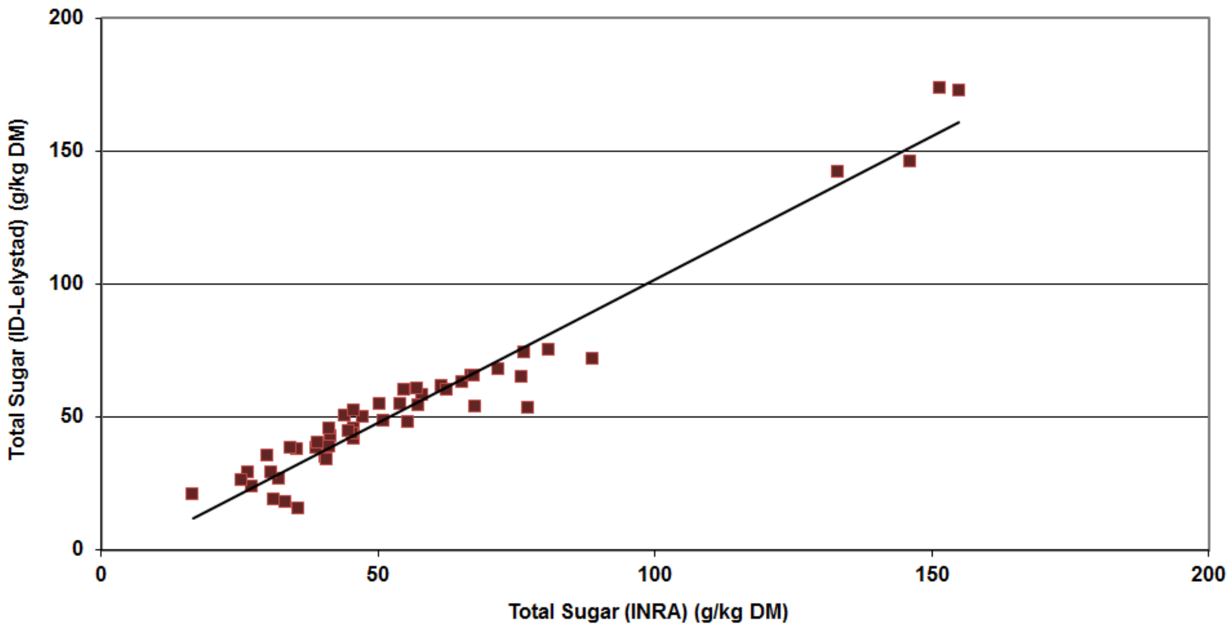
Because the constant did not significantly differ from 0, the intercept was also removed resulting in the following relation:

Starch$_{EW}$ (Labco)=	0.9907 * Starch$_{EW}$ (INRA)
s.e.	0.0030
t-prob.	<0.001
R^2:	0.986;
s.e. of the prediction:	9.3 g/kg DM

Based on this relation, it was concluded that there was a strong agreement between the laboratory of INRA and Labco with regard to the Starch$_{EW}$ analysis. Furthermore, the it did not appear that the samples deteriorated during storage making them inappropriate for further Starch$_{AM}$ analysis.

Appendix III: Comparison between Sugars-total analysed by INRA and by ID-Lelystad

Vergelijking van het bruto SUI gehalte, zoals oorspronkelijk geanalyseerd door INRA en zoals in voorjaar 2003 geanalyseerd in Nederland (door ASG. ID-Lelystad)
Source: CVB report EW-VV-10. Actualisatie van het NE-systeem voor vleesvarkens, Bijlage 3



Comparison of the total sugar content according to Luff Schoorl at INRA and at ID-Lelystad

The relation between both laboratories that performed the of sugars analyses according to the method of Luff-Schoorl was as follows:

Sugars (ID-Lelystad) =	1.075 * Sugars (INRA) -	5.54
s.e.	0.034	2.25
R^2:	0.949	
s.e. of the prediction:	7.7 g/kg DM	

Appendix IV: Explanation of the results of the sugars analyses by HPLC

(CCL Nutricontrol, Veghel)

The aim of the HPLC sugar analysis was to distinguish between Sugar_e and Sugar_f. The following sugars were analysed:

- Enzymatically digestible sugars (Sugars_e): Galactose, Glucose, Sacharose, Maltose
- Fermentable sugars (Sugars_f): Arabinose, Xylose,Raffinose, Stachyose, Verbascose

It appeared during analyses that some samples contained very low amounts of sugars. This observation was related to the poor quality of these substrates. In addition, it appeared that for some substrates, the content of sugars decreased after extraction.

The CVB could correlate those substrates that were lowest in quality and the sugar content analysed by the laboratories of INRA and ID-Lelystad[1]. Based on this observation, it was decided not derive the new NE formula based on the Sugar_e and Sugar_f contents. The Sugar content analysed by INRA and the HPLC analyses of individual sugars in the diets were used for the separation of the sugar fractions Sugars_e/Sugars. For the samples of poor quality (5 in total) this fraction was estimated based on their ingredient compositions.

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[1] There was no correlation between these samples and a possible difference in Starch_{EW} content, as determined by the laboratories of INRA and Labco. It was therefore concluded that the starch in these samples of poor quality has not been degraded yet, and could be used for addition Starch_{AM} analysis.

Appendix V: Comparison of NE formula and assessment of the effect of housing condition on RE (Bosch et al. 2010)

This Appendix describes the assessment of housing condition of pigs (group vs. individual) on NEm and RE as part of the report of Bosch et al. (2010). The complete report (in Dutch) can be requested at the Product Board Animal Feed (Productschap Diervoeder).

In section 2.5 of this report, the dataset described in Bosch et al. (2010) was used for the evaluation of the validity of the new NE formula (F5). The same dataset was used to compare several NE formula. The results of these evaluations can also be used to study the effect of housing condition (group *vs*. individual) on net energy requirements for maintenance (NEm). The dataset used was based on a selection of experiments with growing pigs in the climate respiration chambers of the Department of Animal Sciences of Wageningen University. Eligibility criteria were age (older than 7 weeks-of-age) and availability of data on feed composition, energy balance and faecal nutrient digestibility. In addition, the nature of the treatments in each experiment was examined and, if necessary, on one or more treatment groups from an experiment were omitted. The studies used in this dataset (dataset 1a) are fully described in the report Bosch et al. (2010). As second dataset (1b) was based on dataset 1a in which only those studies were included for which both feed and faeces were analysed for their nutrient compositions. An overview of the variation in nutrient composition of feed, animal weight, and feed intake for dataset 1b is shown in Table 1. The results for dataset 1a are described in Bosch et al. (2010).

Table 1. Overview of the variation in nutrient composition of feed, animal weight, and feed intake for group-housed pigs (*n*=87 independent observations) and individually housed pigs (*n*=15) (dataset 1b).

Parameter	**Total dataset**		
Group-housed	**Mean**	**Min.**	**Max.**
dCP (g/kg DM)	163.1	120.6	196.2
dCFat (g/kg DM)	33.0	7.1	131.2
Starch + sugars (g/kg DM)[1]	406.5	281.6	595.6
fNSP (g/kg DM)	194.2	81.1	294.4
BW (kg)	49.6	27.4	60.8
Feed intake (g DM/(animal day))	1281	792	1704
Feed intake (g DM/(kg $BW^{0.75}$ day))	68.7	61.9	79.1
Individually housed			
dCP (g/kg DM)	191.9	183.2	207.1
dCFat (g/kg DM)	23.7	17.2	41.2
Starch + sugars (g/kg DM)	456.7	347.0	554.2
fNSP (g/kg DM)	177.3	69.4	278.7
BW (kg)	49.6	45.2	53.9
Feed intake (g DM/(animal day))	1138	994	1243
Feed intake (g DM/(kg $BW^{0.75}$ day))	60.9	54.6	64.6

Abbreviations: dCP, digestible crude protein; DM, dry matter; dCFat, digestible crude fat; fNSP, fermentable non-starch polysaccharides; BW, body weight.

[1] The digestibility of starch and sugars were assumed to be 100%.

Comparison NE formula

The coefficients described in Table 2 were used for the calculation of the NE value of the feeds used in dataset 1b. The different NE formulas in this table were the result of the use different estimates for the NEm. For the development of the Rostock formula NEm was estimated as 0.290 MJ/$BW^{0.75}$ and for the De Lange formula NEm was estimated as 0.489 MJ/$BW^{0.60}$.

Table 2. Coefficients for the calculation of the NE value of a feed according to the coefficients of old CVB formula (F4a), new coefficients based on the dataset of Noblet (F5), the coefficients of Rostock, and the coefficients of De Lange.

NE formula	dCP	dCFat	Starch	Sugars	fNSP
F4a (CVB, 2004)	10.80	36.10	13.70	12.40	9.60
F5 (new formula)	11.70	35.74	14.14	12.73	9.74
Rostock	9.34	32.07	12.51	11.26	7.51
De Lange	9.13	31.54	12.45	11.20	7.20

Abbreviations: NE, net energy; dCP, digestible crude protein; dCFat, digestible crude fat; fNSP, fermentable non-starch polysaccharides.

Daily NE intake for each animal (MJ) was calculated as NE value of feed (MJ/kg DM) multiplied by daily DM intake (kg DM). For calculation of daily NE intake in per kg $BW^{0.75}$, the NE intake was divided by $BW^{0.75}$. Daily energy retention (MJ/kg $BW^{0.75}$) was calculated as the daily ME intake (MJ/kg $BW^{0.75}$) minus heat production (MJ/kg $BW^{0.75}$). Energy retention (MJ/kg DM) was calculated as the daily energy retention for each animal (MJ/kg $BW^{0.75}$) multiplied by the average $BW^{0.75}$ of each animal and divided by daily DM intake (kg DM). The predictive value of each of the NE formula for group-housed pigs was evaluated using linear regression analyses. Linear regression was performed for NE intake (MJ/(kg $BW^{0.75}$ day)) and energy retention (MJ/(kg $BW^{0.75}$ day)) and for NE value of feed (MJ/kg DM) and energy retention (MJ/kg DM) using Proc GLM of Statistical Analysis Systems (SAS) statistical software package version 9.1.3 for windows (SAS Institute Inc., Cary, NC, USA).

The relationship between calculated NE intake and energy retention in group-housed pigs (dataset 1b) is shown in Table 3. The amount of explained variation (R^2) was in general comparable between the NE formula tested. The slopes of the regression lines, however, showed more variation with the lowest value for the new formula (0.883) and highest value for that of De Lange (0.981). The explanation for this difference remained unclear. The value for the coefficients used by De Lange were in general lower as the result of a lower assumed NEm. The largest difference between the coefficients of CVB and De Lange is that for fNSP (9.6 and 7.2 MJ/kg, respectively; Table 2). The relatively high amount of variation in fNSP intake by the growing pigs in dataset 1b (Table 1) resulted in a lower variability in NE intake for De Lange than that for the NE-other formula. This would result in a higher slope if the variation in measured energy retention remained constant. The estimated amount of daily NEm (RE=0) varied with lowest estimate for the NE formula of De Lange (0.174 MJ/$kg^{0.75}$) and highest estimate for the formula of Noblet (0.347 MJ/$kg^{0.75}$).

Table 3. Relationship between calculated net energy intake (MJ/(kg $BW^{0.75}$ day)) and retained energy (MJ/(kg $BW^{0.75}$ day)) in group-housed pigs (dataset 1b, *n*=87) for several NE formula.

NE formula	Slope	SE	Intercept	RE=0	R^2	rMSE
F4a (CVB, 2004)	0.903	0.050	-0.300	0.332	0.794	0.0286
F5 (new formula)	0.883	0.050	-0.306	0.347	0.786	0.0291
Rostock	0.934	0.055	-0.241	0.258	0.773	0.0300
De Lange	0.981	0.061	-0.171	0.174	0.750	0.0314

Abbreviations: SE, standard error; RE, retained energy; rMSE, root of mean square error.

The relationship between calculated NE value of feed and energy retention in group-housed pigs (dataset 1b) is shown in Table 4. The amount of explained variation (R^2) was again in general comparable between the NE formula tested. The slopes of the regression lines showed somewhat less variation than those in Table 3 with the lowest value for the new NE formula (0.853) and highest value for that of De Lange (0.977). The estimated NEm (RE=0) varied with lowest value for the NE formula of De Lange (2.53 MJ/kg DM) and highest for the new formula (4.87 MJ/kg DM).

Table 4. Relationship between calculated net energy value of feed (MJ/kg DM) and retained energy (MJ/kg DM) in group-housed pigs (dataset 1b, *n*=87) for several NE formula.

NE formula	Slope	SE	Intercept	RE=0	R^2	rMSE
F4a (CVB, 2004)	0.876	0.049	-4.10	4.68	0.787	0.427
F5 (new formula)	0.853	0.050	-4.15	4.87	0.776	0.438
Rostock	0.910	0.055	-3.31	3.64	0.766	0.447
De Lange	0.977	0.061	-2.47	2.53	0.750	0.462

Abbreviations: SE, standard error; RE, retained energy; rMSE, root of mean square error.

Effect of housing condition on RE

For the evaluation of the effect of housing condition on energy retention, dataset 1b and three separate datasets (2a, 2b, 2c) were used. Details of the datasets are shown in Table 1 of the full report (Bosch et al. 2010). For the calculation of the NE value of the feeds formula F4a was used (CVB, 2004).

The difference in energy retention between individually housed and group-housed growing pigs was evaluated using analysis of variance (ANOVA) by Proc GLM of SAS. The following statistical model was used:

RE = HC + NE intake + e

where HC represents housing condition (individual or group).

The model was applied for dataset 1b with NE intake in MJ/(kg$^{0.75}$ day) and in kJ/DM. For those observations based on individually housed growing pigs in dataset 1b, linear regression was performed for NE intake (MJ/(kg BW$^{0.75}$ day)) and energy retention (MJ/(kg BW$^{0.75}$ day)) and for NE value of feed (MJ/kg DM) and energy retention (MJ/kg DM) using Proc GLM of SAS. The ratio between activity-related heat production and total heat production (HPact/HPtot) and the ratio between total heat production and ME intake (HPtot/ME intake) were calculated. The effect on NEm, HPact/HPtot, and HPtot/ME intake of housing condition, type of animal (dataset 2a) or dietary treatment (datasets 2b and 2c) and the interaction between both were analysed using ANOVA by Proc GLM of SAS.

The relationship between calculated NE intake and energy retention in individually housed and group-housed pigs for dataset 1b is shown in Table 5. A difference between individually housed and group-housed pigs in energy requirement for maintenance could theoretically be derived from the point of interception with the x-axis where energy retained equals 0 (RE=0). For individually housed pigs the energy retained equaled 0 when NE intake of 0.395 MJ/(kg BW$^{0.75}$ day) and for group-housed pigs this was 0.332 MJ/(kg BW$^{0.75}$ day).

Table 5. Relationship between calculated NE intake (MJ/(kg BW$^{0.75}$ day)) and energy retention (MJ/(kg BW$^{0.75}$ day)) in individually housed (*n*=12 observations) and group-housed pigs (*n*=87 observations) (dataset 1b).

Housing	Slope[1]	Intercept[2]	RE=0	R^2	rMSE
Individual	1.170	-0.426	0.395	0.728	0.0335
Group	0.903	-0.300	0.332		

Abbreviations: RE, retained energy; rMSE, root of mean square error.

[1] P-value for housing condition (individual vs. group) = 0.46.

[2] P-value for housing condition (individual vs. group) = 0.04.

Heat production parameters for individually housed and group-housed pigs for dataset 2a and 2b are shown in Table 6. For dataset 2a, the interaction between animal type and housing condition was not significant for any of evaluated parameters (P>0.10, data not shown). Housing condition significantly affected evaluated parameters. Compared to individually housed gilts, group-housed gilts showed less physical activity as indicated by

HPact and HPact/HPtot values. The total heat produced per unit ME intake was lower for group-housed gilts than for individually housed gilts.

For dataset 2b, the interaction between dietary treatment and housing condition was not significant for any of evaluated parameters (P>0.10, data not shown). Housing condition did not significantly affect evaluated parameters.

For dataset 2c, HPact and HPact/HPtot were higher for individually housed pigs than for group-housed pigs (respectively 116 *vs*. 83 kJ/(kg$^{0.75}$ day), P<0.001; 0.17 *vs*. 0.12, P<0.001).

Table 6. Heat production parameters for individually housed and group-housed pigs for dataset 2a (gilts) and dataset 2b (barrows).

	Individual		**Group**		**P-value**
	Mean	**SEM**	**Mean**	**SEM**	
Dataset 2a					
HPact	104.7	7.5	65.4	2.9	<0.001
HPact/HPtot	0.23	0.01	0.16	0.01	<0.001
HPtot/ME intake	0.83	0.01	0.75	0.01	<0.001
Dataset 2b					
HPact	71.8	61	75.8	3.0	0.56
HPact/HPtot	0.11	0.01	0.12	0.00	0.29
HPtot/ME intake	0.65	0.01	0.65	0.01	0.88

Abbreviations: HPact, activity-related heat production (kJ/(kg$^{0.75}$ day)); HPtot, total heat production (kJ/(kg$^{0.75}$ day)); ME intake, metabolisable energy intake (kJ/(kg$^{0.75}$ day)); SEM, standard error of mean.

Conclusion

Based on the analyses of different datasets, there is no reason to assume that group-housed pigs have a higher NEm than individually housed pigs. Obtained results point out to the other direction. A regression analyses of different studies showed that NE intake at 0 energy retained was numerically higher for individually housed pigs. Comparison of HPact of pigs between both housing conditions show similar results for datasets 2a and 2c whereas dataset 2b did not show an effect of housing condition.

Appendix VI: Evaluation of several regression models for the analyses of the dataset of Noblet including 52 diets

Table A. Regression models for the analyses of the dataset of Noblet including 52 diets.

Model	**NE =**	**CFat$_h$**	**CFat**
1	a*dCP + b*dCFat + c***Starch$_{EW}$** + d*Sugars + e*fNSP (**61 diets)**[a]	Yes	Yes
2	a*dCP + b*dCFat + c***Starch$_{EW}$** + d*Sugars + e* fNSP (**52 diets)**[a]	Yes	Yes
3	a*dCP + b*dCFat + c***Starch$_{AM}$** + d*Sugars + e* fNSP	Yes	Yes
4a	a*dCP + b*dCFat + c*Starch$_{AM}$ + d***Sugars$_e$** + e*(fNSP + **CF_Di*Sugars$_f$)**[b]	Yes	Yes
4b	a*dCP + b*dCFat + c*Starch$_{AM}$ + d***Sugars$_e$** + e*(fNSP + **CF_Di*Sugars$_f$)**[c]	Yes	Yes
4c	a*dCP + b*dCFat + c*Starch$_{AM}$ + d***Sugars$_e$** + e*(fNSP + **CF_Di*Sugars$_f$)**[d]	Yes	Yes
5a	a*dCP + b*dCFat + c*(Starch$_{AM}$ + **0.90*Sugars$_e$)** + e*(fNSP + **CF_Di*Sugars$_f$**)[b]	Yes	Yes
5b	a*dCP + b*dCFat + c*(Starch$_{AM}$ + **0.90*Sugars$_e$)** + e*(fNSP + **CF_Di*Sugars$_f$**)[c]	Yes	Yes
5c	a*dCP + b*dCFat + c*(Starch$_{AM}$ + **0.90*Sugars$_e$)** + e*(fNSP **+ CF_Di*Sugars$_f$**)[d]	Yes	Yes
6a	a*dCP + b*dCFat + c***(Starch$_{AM}$ + 0.90*Sugars$_e$ + 0.7*(fNSP + CF_Di*Sugars$_f$))**[b]	Yes	No

Abbreviations: NE, net energy; CFat, crude fat determined without prior acid hydrolysis with HCl; CFat$_h$, crude fat determined after prior acid hydrolysis with HCl; dCP, digestible crude protein; dCFat, digestible crude fat; Starch$_{EW}$, starch analysed according to the method of Ewers (polarimetric Method); fNSP, fermentable non-starch polysaccharides; Starch$_{AM}$, starch analysed according to the Amyloglucosidase method; Sugars$_e$, sugars that can be absorbed from the ileal chyme, either directly or after enzymatic digestion; CF_DI, mass-correction factor to calculate glucose equivalents from disaccharide content in feedstuffs; Sugars$_f$, sugars that are fermented by bacteria, mainly in the hindgut.

[a] 61 diets were included in the complete dataset of Noblet; for 52 diets there was sufficient amount of material available for additional chemical analyses. For these 52 diets, the values for total sugars content was based on the results of the laboratory analyses of INRA.

[b] Analysis of total sugars according to INRA. Separation of Sugars$_e$ and Sugar$_f$ based on the ratios derived from the HPLC analyses of individual sugars; for Sugars$_f$ a fixed value of CF_Di 0.95 was used.

[c] Analysis of total sugars according to ID-Lelystad. Separation of Sugars$_e$ and Sugars$_f$ based on the ratios derived from the HPLC analyses of individual sugars; for Sugars$_f$ a fixed value of CF_Di 0.95 was used.

[d] Sugars$_e$ and Sugars$_f$ contents according to reported values by CCL Nutricontrol (Note: Sugars$_f$ was multiplied by 0.95)

In all models, the NSP content was adjusted according to the used parameters.

Table B. Results for the regression models for the analyses of the dataset of Noblet including 52 feeds.

					dCP			**dCFat**			**Starch/ Starch+0.9Sugars_e/ Starch+0.9Sugars_e +0.7*(fNSP+ CF_DI*Sugars_f)[1]**			**Sugars / Sugars_e[2]**			**fNSP/ fNSP+Sugars_f[3]**										
Model	**Analyses**			***n***	**a**			**b**			**c**			**d**			**e**			**expl. var.**	**s.e. est.**	**hl**		**hl*n/p**	**lsr**		**hl+ lsr**
	Fat	**Starch**	**Sugars**		**value**	**s.e.**	**P**	**value**	**s.e.**	**P**	**value**	**s.e.**	**P**	**value**	**s.e.**	**P**	**value**	**s.e.**	**P**			***n***	**max.**		***n***	**max.**	
1[4]	CFat	EW	INRA	61	12.09			35.00			14.31			11.80			9.15										
1	CFat	EW	INRA	61	12.07	0.986	<0.001	35.01	1.380	<0.001	14.32	0.284	<0.001	11.51	0.799	<0.001	8.64	1.020	<0.001	94.0	0.251	5	0.56	6.86	1	2.40	0
2	CFat	EW	INRA	52	11.66	1.120	<0.001	34.53	1.480	<0.001	14.36	0.330	<0.001	11.94	1.260	<0.001	8.83	1.080	<0.001	93.7	0.255	6	0.32	3.33	1	2.51	0
3	CFat	AM	INRA	52	11.86	1.120	<0.001	34.33	1.460	<0.001	14.38	0.333	<0.001	11.20	1.230	<0.001	10.18	0.800	<0.001	93.7	0.255	6	0.27	2.81	0		0
4a	CFat	AM	INRA	52	11.96	1.100	<0.001	34.38	1.480	<0.001	14.35	0.329	<0.001	11.20	1.230	<0.001	10.31	0.739	<0.001	93.7	0.255	6	0.29	3.02	0		0
4b	CFat	AM	ID	52	11.95	1.120	<0.001	34.29	1.480	<0.001	14.36	0.333	<0.001	10.88	1.160	<0.001	10.40	0.732	<0.001	93.6	0.256	6	0.32	3.33	0		0
4c	CFat	AM	CCL	52	12.05	1.130	<0.001	34.08	1.500	<0.001	14.33	0.336	<0.001	10.39	1.350	<0.001	10.59	0.709	<0.001	93.5	0.258	6	0.32	3.33	0		0
5a	CFat	AM	INRA	52	11.56	1.080	<0.001	34.63	1.480	<0.001	14.28	0.327	<0.001				10.43	0.741	<0.001	93.5	0.258	3	0.26	3.43	0		0
5b	CFat	AM	ID	52	11.37	1.090	<0.001	34.55	1.510	<0.001	14.28	0.337	<0.001				10.67	0.732	<0.001	93.3	0.262	4	0.28	3.59	0		0
5c	CFat	AM	CCL	52	11.35	1.100	<0.001	34.49	1.520	<0.001	14.28	0.344	<0.001				10.87	0.710	<0.001	93.2	0.265	2	0.28	3.65	0		0
1	CFat_h	EW	INRA	61	12.01	0.856	<0.001	36.24	1.230	<0.001	14.22	0.245	<0.001	11.63	0.694	<0.001	7.50	0.918	<0.001	95.5	0.218	5	0.56	6.88	0		0
2	CFat_h	EW	INRA	52	11.63	0.944	<0.001	35.76	1.280	<0.001	14.23	0.278	<0.001	12.30	1.060	<0.001	7.74	0.943	<0.001	95.5	0.216	6	0.33	3.43	0		0
3	CFat_h	AM	INRA	52	11.85	0.962	<0.001	35.43	1.280	<0.001	14.25	0.285	<0.001	11.41	1.060	<0.001	9.44	0.708	<0.001	95.3	0.219	6	0.27	2.81	0		0
4a	CFat_h	AM	INRA	52	12.01	0.949	<0.001	35.51	1.300	<0.001	14.20	0.282	<0.001	11.39	1.060	<0.001	9.65	0.653	<0.001	95.3	0.219	6	0.29	3.02	0		0
4b	CFat_h	AM	ID	52	11.95	0.957	<0.001	35.49	1.310	<0.001	14.23	0.285	<0.001	11.16	0.992	<0.001	9.71	0.647	<0.001	95.3	0.220	6	0.32	3.33	0		0
4c	CFat_h	AM	CCL	52	11.97	0.983	<0.001	35.34	1.340	<0.001	14.22	0.291	<0.001	10.96	1.170	<0.001	9.94	0.633	<0.001	95.1	0.224	6	0.32	3.33	0		0
5a	**CFat_h**	**AM**	**INRA**	**52**	**11.70**	**0.923**	**<0.001**	**35.74**	**1.300**	**<0.001**	**14.14**	**0.280**	**<0.001**				**9.74**	**0.654**	**<0.001**	**95.3**	**0.221**	**3**	**0.251**	**3.26**	**0**		**0**
5b	CFat_h	AM	ID	52	11.48	0.932	<0.001	35.76	1.320	<0.001	14.17	0.288	<0.001				9.91	0.649	<0.001	95.1	0.224	4	0.264	3.43	0		0
5c	CFat_h	AM	CCL	52	11.47	0.945	<0.001	35.71	1.340	<0.001	14.18	0.295	<0.001				10.12	0.632	<0.001	95.0	0.227	2	0.269	3.50	0		0
6a	CFat_h	AM	INRA	52	11.65	0.888	<0.001	35.64	1.210	<0.001	14.12	0.261	<0.001							95.4	0.219	4	0.232		0		0

Abbreviations: dCP, dCFat, Sugars_e, Sugars, fNSP, CF_DI, Sugars_f, CFat, CFat_h, Starch_{EW}, Starch_{AM}, see Table A; expl. var., percentage of explained variation; s.e. est., standard error estimate; hl, high leverage observation, i.e. observations that have a big influence on the result of the regression model; hl*n/p, number of hl observations times total number of observations (n) divided by number of explaining variables in the model (p); lsr, large standardized residuals, i.e. observations with large difference between calculated and observed NE values; max., maximum; P, P-value; INRA, analysis of total sugars according to INRA; ID, analysis of total sugars according to ID-Lelystad; CCL, Sugars_e and Sugars_f contents according to reported values by CCL Nutricontrol.

[1] Starch in models 1-4, Starch+0.9 Sugars_e in model 5; Starch+0.9 Sugars_e+0.7*(fNSP+CF_Di*Sugars_f) in model 6a.

[2] Sugars in models 1-3, Sugars_e in models 4 & 5.

[3] fNSP in models 1-3, fNSP+Sugars_f in models 4 & 5.

[4] NE formula as published by Noblet.

Appendix VII: Step-wise elimination of three observations on the NE coefficients

Table A. Results for step-wise elimination of three high leverage observations on the NE coefficients.

					dCP			**dCFat**			**Starch+0.9Sugars$_e$**			**fNSP+Sugars$_f$**										
Model	**Analyses**			**n**	**value**	**s.e.**	**P**	**value**	**s.e.**	**P**	**value**	**s.e.**	**P**	**value**	**s.e.**	**P**	**expl. var.**	**s.e. est.**	**hl**		**hl*n/p**	**lsr**		**hl+ lsr**
	Fat	**Starch**	**Sugars**		**a**	**a**	**a**	**b**	**b**	**b**	**c**	**c**	**c**	**e**	**e**	**e**			***n***	**max.**		***n***	**max.**	
5a	CFat$_h$	AM	INRA	52	11.70	0.923	<0.001	35.74	1.300	<0.001	14.14	0.280	<0.001	9.74	0.654	<0.001	95.3	0.221	3	0.251	3.26	0		0
5a	CFat$_h$	AM	INRA	51	11.62	0.981	<0.001	35.81	1.340	<0.001	14.18	0.313	<0.001	9.70	0.682	<0.001	94.9	0.223	3	0.263	3.35	0		0
5a	CFat$_h$	AM	INRA	50	11.70	1.120	<0.001	35.80	1.350	<0.001	14.15	0.363	<0.001	9.69	0.691	<0.001	94.9	0.226	3	0.223	2.79	0		0
5a	CFat$_h$	AM	INRA	49	11.72	1.130	<0.001	35.74	1.370	<0.001	14.09	0.380	<0.001	9.84	0.749	<0.001	94.4	0.227	3	0.224	2.74	0		0

Abbreviations: see Table B of Appendix VI.

Additional dietary characteristics are shown in Table B for the three observations that may explain why these observations had a big influence on the result of the regression model.

Table B. Dietary characteristics of the three high leverage observations.

Diet nr.	**Ingredient**	**Characteristic**	**Content**
2	100% barley diet	low CP	110 (g/kg DM)
19	semi-synthetic	very low NSP	51 (g/kg DM)
		very low Crude fibre	10 (g/kg DM)
		very high NE	12.51 (MJ/kg DM)
41	high in by-products	very high fNSP	207 (g/kg DM)
	beet pulp/wheat bran	low starch	235 (g/kg DM)
		very high CP	274 (g/kg DM)

Appendix VIII: Ingredient composition, analysed nutrient composition, digestibility's and energy balance data for the diets investigated by Van der Honing et al. (1984).

Table A. Ingredient compositions of diets (*n*=29) investigated by Van der Honing et al. The diets 6A. 6B. 7A and 7B were also examined in the low feed level treatment. No respiration data was found for diet 9B. This diet was, therefore, not included in the dataset of Van der Honing et al. used for the validation of the new NE formula.

	Diet code																												
	1A	**1B**	**1C**	**1D**	**2A**	**2B**	**2C**	**3A**	**3B**	**3C**	**4A**	**4B**	**4C**	**4D**	**5A**	**5B**	**5C**	**5D**	**6A**	**6B**	**7A**	**7B**	**8A**	**8B**	**8C**	**8D**	**9T**	**9G**	**9B**
Potato protein								90	86	86	118	141	100	120	116	138	92	110	75	75		45		15	30	50	51	20	20
Potato fibres						120			100				100	120															
Sugarbeet pulp						100																							
Citruspulp				140			70										110	131		119	68	120	75	71	67	63	70	70	70
Rendering fat												100		103		105		105	30	45		30		30	60	100	32	35	40
Barley	274				240			545			569	679	2	2	566	676			411									481	
Grassmeal					60														60										
Peanut expeller																						150							
Coconut expeller						147	220		288	100			90	108															
Coconut, extracted																							107	101	96	90			100
Linseed expeller			127	190						100																			
Linseed, extracted							131													95									
Maize					215																620								
Maizeglutenfeed		340								100							180	215		220									
Maize feed meal, US						273			460				193	231			180	215				230	144	137	130	121			135
Maize feed, extracted		216																		190			117	112	106	99			110
Maize starch											246		250		250		250												
Min. + vit.	26		31	18	25	22	19	25	28	26	28	32	25	29	28	33	22	26	24	20	22	20	22	24	25	28	19	24	25
Molasses, cane	20	19	19	19	20	20	19	20	19	19	39	47	40	48	40	48	40	48	30	30	20	20	43	40	38	36	40	40	40
Rice bran			170							150												127							
Rice bran, extracted		50	204																										
Soya oil	20	19	19	19	20	20	19	20	19	19																			
Soya beans, extr.	200	190	188	188	200	198	190												70	70	270		182	173	164	153	170	170	170
Cassava root		142	242	289		100	332			260										136			139	132	125	117	457		130
Wheat	460				220			300											300										
Wheat middlings				137									200	240								258	171	163	159	144	160	160	160
Wheat bran										140																			
Sunflower seed, extr.																	126	150											

Table B. Analysed nutrient composition, digestibility's and energy balance data of diets (*n*=28) investigated by Van der Honing et al. (1984). The diets 6A. 6B. 7A and 7B were also examined in the low feed level treatment.

	Diet code																											
Diet code	1A	1B	1C	1D	2A	2B	2C	3A	3B	3C	4A	4B	4C	4D	5A	5B	5C	5D	6A	6B	7A	7B	8A	8B	8C	8D	9T	9G
Mean digestibility data																												
dOM (%)	87.3	74.5	76.3	79.1	84.8	80.4	81.0	87.3	77.9	77.6	86.9	85.0	80.4	76.1	86.6	84.0	77.7	73.7	83.3	75.0	88.1	77.3	74.7	77.0	77.2	78.6	82.9	81.2
dCP (%)	84.6	75.4	73.7	73.4	80.6	66.5	69.0	84.9	71.4	74.7	81.4	84.2	72.9	73.3	80.3	82.5	71.7	74.6	78.8	69.2	81.3	75.7	64.8	69.4	70.1	73.2	77.6	76.7
dCFat (&)	65.3	73.0	77.9	69.6	65.6	75.6	77.5	77.8	86.2	76.7	16.0	82.8	61.8	82.8	5.6	84.7	61.4	87.2	65.2	73.7	74.2	83.5	58.9	73.8	78.3	81.2	69.9	70.0
dCF (%)	30.3	30.3	19.9	42.6	35.6	67.1	50.7	24.8	63.7	38.2	0.1	17.1	52.1	54.5	16.1	14.4	30.1	29.1	21.3	40.1	59.7	47.8	33.4	40.7	38.6	41.3	41.1	40.0
dNFE (%)	92.3	78.7	85.9	87.0	91.7	88.2	90.6	91.9	81.6	83.5	93.0	89.5	86.6	78.2	92.6	88.3	85.7	76.5	90.5	82.1	92.6	82.7	84.4	85.0	85.0	85.6	90.0	88.3
dE (%)	85.5	73.8	74.8	76.7	82.6	78.6	78.7	85.7	77.2	76.2	84.6	83.3	78.3	75.4	83.9	82.3	75.4	74.2	81.0	73.4	86.3	76.2	72.7	75.5	76.0	78.0	80.7	78.5
Mean respiration data																												
Mean BW (kg)	78	76	77	78	70	73	71	67	71	70	70	70	72	70	74	71	71	85	68	67	86	86	73	74	73	70	97	99
DM intake (g/d)	1970	2106	2168	2102	1994	2122	2190	1796	1970	1992	1952	1661	2059	1782	2044	1702	2150	2041	1897	1946	2224	2305	2164	2062	1870	1716	2535	2492
GE intake (MJ/g)	37.20	38.86	40.00	38.91	37.00	39.87	39.77	34.13	38.10	37.75	35.33	34.73	37.89	38.18	37.05	35.45	39.56	43.22	35.88	37.65	41.14	45.90	39.99	39.20	36.91	35.78	46.65	47.45
DE intake (MJ/d)	31.86	28.80	29.98	29.95	30.57	31.32	31.35	29.30	29.45	28.78	29.93	28.96	29.76	28.88	31.15	29.21	29.86	32.05	29.14	27.80	35.65	35.13	29.28	29.80	28.26	28.13	37.65	37.20
CH_4-E (MJ/d)	0.13	0.13	0.13	0.20	0.13	0.30	0.23	0.00	0.03	0.03	0.10	0.03	0.20	0.13	0.05	0.03	0.18	0.20	0.13	0.25	0.30	0.20	0.15	0.20	0.18	0.18	0.30	0.30
U-E (MJ/d)	1.20	1.49	1.39	1.66	1.23	1.18	1.57	0.97	1.25	1.27	1.04	1.04	1.08	1.18	1.16	1.16	1.71	2.07	1.26	1.56	1.58	1.91	1.44	1.49	1.46	1.33	1.58	1.75
ME intake (MG/d)	30.55	27.18	28.48	28.09	29.20	29.85	29.62	28.30	28.20	27.48	28.80	27.88	28.51	27.58	29.94	28.01	28.00	29.80	27.75	26.01	33.81	32.96	27.68	28.11	26.60	26.64	35.78	35.18
HP (MJ/d)	17.95	17.03	17.38	17.80	17.50	17.70	17.33	16.10	16.63	16.53	18.28	17.63	18.48	17.98	18.38	16.80	17.93	19.53	17.55	17.40	21.68	20.93	19.13	18.75	17.90	17.70	23.55	22.65
RE (MJ/d)	11.95	9.95	10.70	9.95	11.67	11.67	11.67	11.80	11.37	11.07	10.45	10.48	10.05	9.53	11.43	11.23	9.95	10.20	10.20	9.00	12.08	12.30	8.10	9.35	8.55	8.60	12.25	12.65

Table C. Analysed nutrient compositions of feeds (n=29) investigated by Van der Honing et al. (1984).

Diet code	Dietary contents (g/kg)									
	Moisture	**Crude ash**	**Crude protein**	**Crude fat**	**Crude fibre**	**Nitrogen-free extractives[1]**	**Total**	**Starch**	**Sugars**	**Starch + Sugars**
1A	143	58	187	41	37	677	1000			501
1B	120	58	187	41	37	677	1000			329
1C	119	121	211	67	81	521	1001			319
1D	126	94	206	52	81	566	999			303
2A	145	65	204	48	46	638	1001			485
2B	112	77	189	59	95	580	1000			314
2C	123	97	206	51	85	561	1000			315
3A	145	53	179	45	35	689	1001			540
3B	119	65	197	79	87	571	999			282
3C	118	95	204	83	68	551	1001			333
4A	141	61	176	16	26	722	1001	546	32	
4B	129	60	209	136	32	563	1000	397	34	
4C	115	68	182	36	62	652	1000	373	56	
4D	104	69	211	160	76	484	1000	192	62	
5A	138	52	179	14	32	722	999	569	36	
5B	131	57	207	136	34	567	1001	387	41	
5C	111	64	192	26	75	642	999	377	65	
5D	99	73	229	151	86	461	1000	148	84	
6A	138	61	211	55	45	628	1000	433	47	
6B	113	69	229	73	72	557	1000	233	75	
7A	139	55	191	34	49	671	1000	444	68	
7B	114	74	230	92	73	531	1000	209	98	
8A	134	82	200	33	81	603	999	241	101	254
8B	119	80	204	64	77	574	999			241
8C	117	79	208	102	74	537	1000	215	90	228
8D	110	77	213	145	71	494	1000			210
9T	126	82	180	54	68	617	1001	346	77	
9G	133	70	197	65	67	601	1000	316	78	
9B	119	89	200	76	79	555	999	228	70	

[1] indicated by investigators.

Appendix IX: Correlations between different feed components of feeds used by Van der Honing et al. (1984).

Table 1. Correlations between different feed components based on the 28 feeds on feed level.

	OM	CP	CFat	Starch$_{AM}$	Starch$_{EW}$	Sugars	Sugars$_e$	Sugars$_f$	NSP$_{AM}$	NSP$_{EW}$
OM	1.0000									
CP	-0.3522	1.0000								
CFat	-0.0418	**0.6275**	1.0000							
Starch$_{AM}$	**0.6138**	**-0.6783**	-0.5279	1.0000						
Starch$_{EW}$	**0.6118**	**-0.6904**	-0.5488	**0.9981**	1.0000					
Sugars	-0.4495	0.3827	0.1021	**-0.7734**	**-0.7585**	1.0000				
Sugars$_e$	-0.4343	0.4049	0.1435	**-0.7922**	**-0.7798**	**0.9923**	1.0000			
Sugars$_f$	-0.4233	0.1991	-0.1096	-0.5214	-0.4984	**0.8216**	**0.7445**	1.0000		
NSP$_{AM}$	-0.5933	0.3738	0.1248	**-0.8847**	**-0.8710**	**0.7851**	**0.7936**	0.5784	1.0000	
NSP$_{EW}$	-0.5963	0.3840	0.1421	**-0.8868**	**-0.8789**	**0.7694**	**0.7818**	0.5477	**0.9949**	1.0000
dOM	**0.7492**	**-0.6308**	-0.3002	**0.8675**	**0.8744**	-0.5954	**-0.6200**	-0.3552	**-0.8278**	**-0.8491**
dCP	0.1475	**0.6150**	0.5265	0.0377	0.0189	-0.2910	-0.2869	-0.2476	-0.4009	-0.3922
dCFat	-0.0429	**0.6302**	**0.9972**	-0.5376	-0.5572	0.1092	0.1528	-0.1142	0.1404	0.1559
dCFath	-0.0505	**0.6245**	**0.9960**	-0.5354	-0.5550	0.1108	0.1528	-0.1060	0.1363	0.1516
fNSP$_{AM}$	-0.5133	0.1687	0.0104	**-0.7674**	**-0.7426**	**0.8005**	**0.7897**	**0.6792**	**0.9254**	**0.9016**
fNSP$_{EW}$	-0.5194	0.1665	0.0239	**-0.7732**	**-0.7552**	**0.7946**	**0.7873**	**0.6581**	**0.9282**	**0.9164**

Abbreviations: OM, organic matter; CP, crude protein; CFat, crude fat; Starch$_{AM}$, starch analysed with the amyloglucosidase method; Starch$_{EW}$, starch analysed with the Ewers; Sugars$_e$, enzymatically digestible sugars; Sugars$_f$, indigestible fermentable sugars; NSP$_{AM}$, non-starch polysaccharides calculated as OM – CP – CFat – Starch$_{AM}$ – Sugars; NSP$_{EW}$, non-starch polysaccharides calculated as OM – CP – CFat – Starch$_{EW}$ – Sugars; dOM, digestible organic matter; dCP, digestible crude protein; dCFat, digestible crude fat; dCFath, digestible acid-hydrolysed crude fat; fNSP$_{AM}$, fermentable NSP$_{AM}$; fNSP$_{EW}$, fermentable NSP$_{EW}$.

Appendix X: Net energy value of organic acids, ethanol and glycerol.

In the Table below the net energy value of a number of organic acids, calculated from their ATP yield relative to starch, is presented.

	Chemical formula	Molar mass	ATP yield (mol/mol) based on chemical pathway	ATP yield (mol/g)	ATP yield relative to starch	NEv strach (MJ/kg)	NEv (MJ/kg)	EW*
Alcohol (Ethanol)	C2H6O	46	15	0.3261	146.76		20.75	2.36
Acetic acid	C2H4O2	60	10	0.1667	75.02		10.61	1.21
Butyric acid	C4H8O2	88	27	0.3068	138.07		19.52	2.22
Citric acid	C6H8O7	192	26	0.1354	60.94		8.62	0.98
Fumaric acid	C4H4O4	116	17	0.1466	65.98		9.33	1.06
Lactic acid	C3H6O3	90	17	0.1889	85.01		12.02	1.37
Malic acid	C4H6O5	134	17	0.1269	57.11		8.08	0.92
Propionic acid	C3H6O2	74	17	0.2297	103.38		14.62	1.66
Propylene glycol (Propane-1,2-diol)	C3H8O2	76	21	0.2763	124.34		17.58	2.00
Glycerol	C3H8O3	92	20	0.2174	97.84		13.83	1.57
Glucose	C6H12O6	180	36	0.2000	90.00		12.73	1.45
Sacharose	C12H22O11	342	72	0.2105	94.73		13.39	1.52
Starch	C6H10O5	162	36	0.2222	100.00	14.14		1.61

*: EW = NEv / 8.8.