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Planimetric Determination of the Static Space of Cull Sows as the First Step towards a Recommendation of Loading Densities for Cull Sows during Road Transportation in the European Union

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Abstract: The available floor space is an important welfare factor for cull sows during transportation. Sows of modern genetics reach a size and weight far exceeding those of fattening pigs. In most countries, there are no binding, consistent regulations for the maximum loading densities, especially for sows during road transportation. As a first step towards such recommendations, the physical floor space requirement (static space) of 100 sows of a current breed, while standing and lying down, were determined using contrast-based planimetry. An average sow covered about 0.42–0.47 m^2 (standing postures) up to 0.53–0.63 m^2 (lying postures). The largest measured area was 0.72 m^2 for a sow lying in the belly-chest position. We detected a significant dependency of the covered floor area and the live weight, which supports the common practice to derive space requirements and recommendations based on live weight. Also, our results suggest that especially heavy sows, under currently usual loading densities, are at risk of having insufficient floor space requirements during transport. The results cannot be used to define the space required by a sow to carry out movements or sustain the individual need for distance (social/dynamic space) but provide data on the static space covered by sows of current breeds.

Keywords: animal transportation; animal welfare; planimetry; space requirements; static space; stocking density

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1. Introduction

The space allowance on the transport vehicle is an important factor for the well-being and health maintenance of pigs during transportation [1–3]. Sows are usually slaughtered after several production cycles because of fertility disorders, their age, lameness, or other health problems, and consequently, due to their condition, cull sows run a greater risk of suffering welfare problems during transportation than, for example, fattening pigs [4–7].

In most countries, no loading densities for transports on the road are legally specified, neither for sows, fattening pigs, or other animals. In some countries (e.g., Canada), there are regulations referring to the avoidance of overcrowding, which should ensure that animals can take their preferred position during transportation [8]. Already in 2001, the Canadian National Farm Animal Care Council provided recommendations on space allowance for different animal species, including pigs weighing up to 280 kg, but not for heavier sows [9]. The World Organisation for Animal Health (OIE) demands that during transportation, animals "should be able to adopt a normal lying posture, without being on top of one another", and calculations on the space allowance should be based on "a relevant national or international document" [10]. In the following, emphasis is given to the European situation, with its relatively extensive legal regulations on animal transport in general, but lack of recommendations for cull sows.

Despite the large number of sows kept in Europe (approximately 11.8 million sows [11]), there is no consistent, binding regulation for the maximum loading densities for cull sows during road transportation in the European Union. European legislation demands that "all pigs must at least be able to lie down and stand up in their natural position" during road transportation [12]. To enable this, Council Regulation (EC) No 1/2005, which applies to intra-European transportations, dictates a maximum stocking density of 235 kg/m^2 for pigs with an approximate weight of 100 kg for street transportations [12]. Moreover, Council Regulation (EC) No 1/2005 stipulates, "the breed, size and physical condition of the pigs may mean that the minimum required surface area given above has to be increased" and "a maximum increase of 20% may also be required depending on the meteorological conditions and the journey time" [12]. Originally, this maximum stocking density of 235 kg/m^2 for pigs during road transportation was recommended for finishing pigs as a compromise of "animal welfare, meat quality aspects and economy of transport" by Lambooy et al. in 1985 [13], and was included in the Council Directive 95/29/EC [14]. This requirement was later adopted in the Council Regulation (EC) No 1/2005 without adjustments because the European Member States could not agree on a revision of this point [15]. The Commission intended a proposal for a revision of stocking densities for animals in transport before the end of 2009 [16]. However, even a decade later, there are no specific requirements for pigs with a significantly higher weight than 100 kg in Council Regulation (EC) No 1/2005. Nowadays, breeding sows already reach weights of about 300 kg in the course of their lives (see weight recordings of Norring et al. [17]). It is not known whether the European requirements are also suitable for sows of such weights.

Most European Member States adopt the Council Regulation (EC) No 1/2005 into their national legislation without specifying requirements for loading density. For national transports, individual European member states, such as Germany and Denmark, define minimum floor space requirements for pigs during street transportation more precisely than the European regulation does, and determine minimum floor space values for pigs heavier than 100 kg [18,19]. The top end of the German requirements is a minimum floor area of 0.70 m^2 for pigs with a live weight of over 120 kg [18]. There are no further levels of weight classification for heavier pigs. For road transport within Denmark, it is explicitly stated that it must be ensured that pigs have enough space to get up and lie down [19]. Also, the mandatory minimum floor space for pigs up to a weight of 250 kg is precisely listed in 1-kg steps. For example, for a pig weighing 200 kg and for transport with a duration of less (more) than 8 h, a maximum loading density of 1.429 (1.190) pigs per square-meter required, which corresponds to a floor space offer of 0.70 (0.84) m^2 [19] per pig. For pigs weighing 250 kg, there is a maximum loading density of 1.250 (1.042) pigs/m^2, corresponding to a floor space offer of 0.80 m^2 (0.96 m^2), [19]. According to Danish legislation, commercial transportations of sows are limited to 8 h [19]. However, it has not been clarified whether these regulations are sufficient for the transportation of sows and whether they could be adopted as the standard in the European Union.

Besides the mentioned legal documents, there are several scientific studies on the loading density for pigs during transportation. Most of these studies derive recommendations from comparisons of physiological and behavioral effects on fattening pigs and transport losses during transportations, with various loading densities [2,13,20,21]. Pereira et al. [22] found less "physiological damage" or "evident density-related injuries" for fattening pigs loaded at a density of 251 kg/m^2 than for those transported at 236 kg/m^2 and 275 kg/m^2. By examining blood parameters and meat quality as stress indicators of fattening pigs transported with loading densities of 230 kg/m^2, 275 kg/m^2, and 325 kg/m^2, Chai et al. [23] concluded: "that the most adequate pre-slaughter transport time was 3 h for medium stocking density (less than 275 kg/m^2) and at warm environmental temperature in Chinese commercial transport conditions". Gerritzen et al. [24] reported better adaptability to transport for fattening pigs stocked at a density lower (179 kg/m^2) than the EU standard of 230 kg/m^2. There are also initial studies that deal with the transport conditions of cull sows [7,25], which, however, do not contain any specific recommendations on loading density for sows.

Other recommendations take static space as a starting point. The static space corresponds to the space that the animal body actually needs [26]. There are some studies that determined the static space of sows by measuring the length, width, height, or depth of sows' bodies using calipers, rulers, and measuring tapes [27,28]. Petherick and Phillips derived the static space from allometric estimations based on measurements on pigs from the years 1981 and 1983 [29,30]. On this basis for transports, which should enable all animals to lie down simultaneously, Petherick and Philips estimated a minimum space allowance of a (m^2) = 0.027 × W$^{2/3}$ (a = calculated floor area, W = live weight) per animal, resulting in a loading density of 225.5 kg/m^2 [31]. This is slightly below the loading density prescribed by the European legislation. The European Food Safety Authority (EFSA) took up this recommendation of a (m^2) = 0.027 × W$^{2/3}$ (W = live weight) in their "Opinion Concerning the Welfare of Animals during Transport", which was originally prepared on request of the European Commission in 2004 and revised in 2011 [32]. However, Petherick and Phillips [31] note that they cannot answer whether this loading density enables the animals to feed and drink during transportation. For long-term spatial restriction (whether during transport or housing), during which drinking (and eating) is necessary, they demand a minimum space allowance of a (m^2) = 0.033 × W$^{2/3}$ (a = calculated floor area, W = live weight), resulting in a loading density of 167 kg/m^2 [31].

To determine such recommendations for loading densities in addition to the physically needed space (static space) of sows of current breeds, the space required to carry out movements (dynamic space) or sustain the individual need for distance (social space) must be taken into account [26,30]. Each of these three factors varies depending on species- or breed-specific, individual, or situational needs. Though, to the authors' knowledge, there is no widely recognized scientific recommendation for an optimal loading density based on the static space of modern breed sows.

The aim of this study was to determine the floor area coverage of breeding sow's bodies as a very first step towards the development of such recommendations. The assessed static space should be discussed in relation to scientific and legal space regulations, and the remaining dynamic/social space at different floor space requirements.

2. Materials and Methods

One-hundred sows of a modern genetic breed (DanBred International, Herlev, Denmark) were weighted individually with a beam balance (Bosche GmbH & Co. KG, Damme, Germany), and the physical floor area coverage was determined by contrast-based planimetry using the KobaPlan method [33], as previously described [34–36]. The study was carried out in a commercial German piglet production farm with about 600 sows within 4 days in November 2013 (11/25–11/28/2013).

2.1. Animals

The animals were randomly selected from three groups within the gestation area. The average age of the sows was 24.2 ± 7.3 months (n = 95, 1 month = 31 days, Table 1). On average, the sows had farrowed 4.2 ± 1.6 times (n = 95, Table 1) and were pregnant for 72.8 ± 15.3 days (n = 94, Table 1).

All animals in this study were kept in accordance with European Union guidelines and were housed in accordance with EU (European Directive 2008/120/EC) [37] and German national law [38,39]. In compliance with European Directive 2010/63/EC Article 1 5. (f) [40], this study did not imply any invasive procedure or treatment to the animals. The study was reviewed by and received approval from the animal welfare officer of the University of Veterinary Medicine, Hannover, Foundation.T

Table 1. Age, number of farrowings, and stage of pregnancy of the sows according to the farmer's documentation (with STDEV = Standard Deviation, CV = coefficient of variation, Min = minimal value, Max = maximal value).

	n	Mean	STDEV	CV	Min	Max
Age (months)	95	24.2	7.3	30.1	14.8	46.4
Farrowings (number)	95	4.2	1.6	38.6	2.0	9.0
Stage of pregnancy (days)	94	72.8	15.3	21.1	41.0	101.0

2.2. Experimental Setup and Measurement Procedure

Two-dimensional, top view photographs of individual sows were taken inside a specially designed planimetry box, which is an updated version of the experimental setup described for fattening pigs by Arndt et al. [41]. The planimetry box was enlarged, and additional UV lamps increased the contrast between the photographed animal and the environment. The same reflex camera (Canon EOS 600D; Canon Deutschland GmbH, Krefeld, Germany) equipped with a standard camera lens (18-55 IS II; Canon Deutschland GmbH, Krefeld, Germany) and the same control software (EOS Utility, Canon Deutschland GmbH, Krefeld, Germany) were used as tested in the previous study with fattening pigs [41]. The entire setup is shown in Figure 1.

The sows were encouraged to take up different body positions by feeding, stroking, scratching, or playing with water. The aim was to receive images of each sow in four different, predefined body positions. These positions were chosen based on previous experience with fattening pigs in order to obtain the smallest and largest possible body contour of the sows while standing and lying down [41], and they are listed in Table 2.

Table 2. Different body positions and the number of sows in each body position.

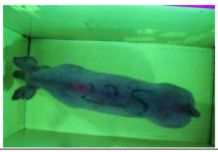
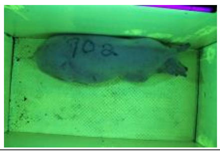
Body Positions	Sample Photographs	*n* (Sows)
SHB Standing head bowed	 	99
SHR Standing head half or fully raised	 	90
LBC Lying in the belly chest position	 	3
LL Lying in the lateral position		1

Figure 1. Experimental setup: (**a**) Planimetry box with (A) the centrally fixed camera, (B) fluorescent painted floor and side plates and (C) the UV light sources (exemplary shown), (**b**) the beam balance in a corridor and (**c**) the computerized camera control; the detailed description in Arndt et al. 2019 [41].

Almost every sow was photographed in the two intended standing body positions: standing body position with a bowed head (SHB, *n* = 99, Table 2); standing body position with head half or fully raised (SHR, *n* = 90, Table 2). Each sow stayed in the planimetry box for up to fifteen minutes, but let out earlier if behaving excited, trying to get out, manipulating the box or appearing to feel uncomfortable. The sows were less willing to lie down in this study situation, and more likely to manipulate the planimetry box than the authors had expected after previous experiences with fattening pigs. Consequently, only a few sows were photographed in a lying position: lying in the belly-chest position (LBC, *n* = 3, Table 2); lying in lateral position (LL, *n* = 1, Table 2).

2.3. Image Analysis

One picture per sow of each photographed body position was further processed, so that 193 images (SHB: *n* = 99, SHR: *n* = 90, LBC: *n* = 3, LL: *n* = 1, Table 2) were analyzed in total. The fluorescent inner coating and the UV illumination of the "planimetry box" yielded a high contrast between the animals and their surroundings. This contrast was manually increased using image editing software. Most of the pictures had to be edited additionally to avoid incorrect calculations caused by shadows, food, or fecal contaminations (Adobe Photoshop CS6, Adobe Systems GmbH, Munich, Germany; Microsoft.MSPaint 3D.Ink, Microsoft Corporation, Redmond, WA, USA; IrfanView for Windows Version 4.53-64-bit, Irfan Skiljan, Graduate University of Technology). Subsequently, the KobaPlan software (Version "KobaPlan v.01.teta"; © Briese 2007–2013, eduToolbox@Bri-C GmbH, Sarstedt, Germany) was able to recognize the sow in the picture by means of contrast. The software counted the number of pixels with a sow and converted this information into square millimeters using a reference surface. The reference surface had a size of 171 × 40 cm and was photographed at the height of the approximate top line of standing (89 cm) and lying (41 cm) sows. These values were determined by measurements of the height of sows from the study population (Table 3). For standing sows, the mean of the back height was taken (Table 3). For sows lying in the belly chest position or lateral position, the mean of the three averages of the shoulder, back and croup heights were calculated (Table 3).

Table 3. Shoulder-, back-, and croup heights (cm) of standing and lying sows from the study population (with STDEV = Standard Deviation, Min = minimal value, Max = maximal value).

	Standing Position			Lying in the Belly Chest Position			Lying in the Lateral Position		
	Shoulder Height in cm *n* = 24	**Back Height in cm *n* = 27**	**Croup Height in cm *n* = 25**	**Shoulder Height in cm *n* = 5**	**Back Height in cm *n* = 6**	**Croup Height in cm *n* = 4**	**Shoulder Height in cm *n* = 3**	**Back Height in cm *n* = 4**	**Croup Height in cm *n* = 2**
Mean	83.1	88.6	87.3	43.2	43.0	39.0	44.3	42.0	34.0
STDEV	3.7	4.6	3.7	4.4	4.1	2.8	5.7	6.6	1.4
Min	74	80	81	37	37	37	38	35	33
Max	96	96	94	48	48	43	48	49	35

2.4. Statistical Analysis and Comparison with Space Requirements in Legislation and Literature

The statistical analysis was carried out with SAS Enterprise Guide 7.1 ('SASApp', X64_SRV19; SAS Institute Inc., Cary, NC, USA). Normal distributions were tested, and descriptive statistical analysis parameters were calculated by the procedures PROC UNIVARIATE, PROC MEANS, PROC STD, PROC MIN, PROC MAX, PROC P10, PROC P25, PROC P75 and PROC P90. The coefficient of variation (CV) was calculated with the formula CV = (standard deviation/mean) × 100. Comparisons of means were carried out using the procedure PROC TTEST. Correlations between mean weights and the covered floor area within the groups of body positions were calculated using the procedure PROC CORR Spearman. Results were considered statistically significant if the related *p*-values were <0.05.

To calculate the remaining space (social/dynamic space) under various transport conditions, the covered floor areas for each body position (the minimum, the mean and the maximum) were subtracted from the minimum floor space requirements from the German and Danish national legislation [18,19]. The stocking density required by the European Regulation EG 1/2005 for pigs with a live weight of about 100 kg, and loading densities proposed or positively tested by scientific studies were adapted to the mean live weight of sows in each position group [12,22–24,31]. In this study, the focus is laid on the European situation and scientific papers. Both the deviations between measured values and requirements or recommendations and the figures for static and social/dynamic space were generated using Excel (Microsoft EXCEL 2016, Microsoft Corporation, Redmond, WA, USA). The loading densities, the minimum floor space requirements, and the following abbreviations are given in Table 4.

Table 4. Loading densities and minimum floor space requirements used for comparison with covered floor areas measured for sows.

	Minimum Floor Space Requirement (m^2)	Abbreviation
Requirements from Legislation		
German legislation for sows with a weight of more than 120.0 kg [18].	0.700	GL120
Danish legislation transports less than 8 h [19] [1]	/	/
LL: 192.0 kg	0.678	DL192.0
SHB: 235.6 kg (rounded up to 236.0)	0.772	DL235.6
SHR: 236.0 kg	0.772	DL236.0
LBC: 250.5 kg (final requirement at 250.0 kg)	0.960	DL250.5
Maximum loading density from the European Regulation for pigs with a live weight of around 100 kg (235 kg/m^2) [12] [1]	/	/
192.0 kg	0.817	EUL192.0
235.6 kg	1.003	EUL235.6
236.0 kg	1.004	EUL236.0
250.5 kg	1.066	EUL250.5
Tested under Transport Conditions		
Loading density of 251 kg/m^2 according to Pereira et al. [22] [1]	/	/
192.0 kg	0.765	P192.0
235.6 kg	0.939	P235.6
236.0 kg	0.940	P236.0
250.5 kg	0.998	P250.5
Loading density less than 275 kg/m^2 according to Chai et al. [23] [1]	/	/
192.0 kg	0.698	C192.0
235.6 kg	0.857	C235.6
236.0 kg	0.858	C236.0
250.5 kg	0.911	C250.5
Loading density of 179 kg/m^2 according to Gerritzen et al. [24] [1]	/	/
192.0 kg	1.073	G192.0
235.6 kg	1.316	G235.6
236.0 kg	1.318	G236.0
250.5 kg	1.399	G250.5
Equations Based on an Allometric Formula		
Space allowance of $m^2 = 0.027 \times W^{2/3}$ (W = live weight) according to Petherick and Phillips [31] for situations, in which all animals should be able to ly simultainously [1]	/	/
192.0 kg	0.899	PPL192.0
235.6 kg	1.030	PPL235.6
236.0 kg	1.031	PPL236.0
250.5 kg	1.072	PPL250.5
Space allowance of $m^2 = 0.033 \times W^{2/3}$ (W = live weight) according to Petherick and Phillips [31] for situations of long term restriction, in which the animals must be able to eat or drink [1]	/	/
192.0 kg	1.098	PPFD192.0
235.6 kg	1.258	PPFD235.6
236.0 kg	1.260	PPFD236.0
250.5 kg	1.311	PPFD250.5

[1] calculated for average weights of the measured postures.

3. Results

3.1. Floor Area Covered by a Sow's Body in Various Body Positions

A sow in standing position covered, on average, a floor area of 0.42 ± 0.04 m^2 (SHB, n = 99) to 0.47 ± 0.04 m^2 (SHR, n = 90). For the heaviest sow of this study (310 kg, Table 2), a floor area of 0.53 m^2 (SHR) to 0.59 m^2 (SHB) was measured. A sow in lying body position occupied 0.63 ± 0.09 m^2 (LBC; n = 3) and 0.53 m^2 (LL: n = 1). The maximum floor coverage was 0.71 m^2 for a sow in body position LBC. The measured floor area values are shown in Table 5.

Table 5. Measured floor area covered by an individual sow's body in different body positions (with SHB = Standing head bowed, SHR = Standing head half or fully raised, LBC = Lying in belly chest position, LL = Lying in the lateral position, STDEV = Standard Deviation, CV = coefficient of variation, Min = minimal value, Max = maximal value).

		Covered Floor Area (m^2)								
Body Position	n	Mean	STDEV	Min	Lower Percentile	Lower Quartile	CV	Upper Quartile	Upper Percentile	Max
					Standing Positions					
SHB	99	0.42	0.04	0.34	0.36	0.39	9.9	0.45	0.48	0.53
SHR	90	0.47	0.04	0.36	0.41	0.43	9.5	0.51	0.53	0.59
					Lying Positions					
LBC	3	0.63	0.09	0.52	/	/	15.1	/	/	0.71
LL	1	0.53	/	/	/	/	/	/	/	/

3.2. Weights of Sows and Relation of Weight to the Covered Floor Area

The weights of all examined sows (n = 100) ranged between 187.5 kg and 310.0 kg (Table 6). The average weight was 235.8 ± 28.6 kg (Table 6). For both standing position groups (SHB: n = 99, SHR: n = 90), there were minimal, insignificant deviations of the mean weight within the same weight range (SHB: 235.6 ± 28.7 kg; SHR: 236.0 ± 29.2 kg, Table 6). The average weight of the three sows in the LBC position (250.5 ± 52.5 kg, Table 6) overlapped within a half standard deviation interval with the mean weights of SRH and SHB, and span a range from 192.0 kg to 293.5 kg. The weight of the sow in the LL position (192.0 kg, Table 6) was at the lower edge of the total weight range.

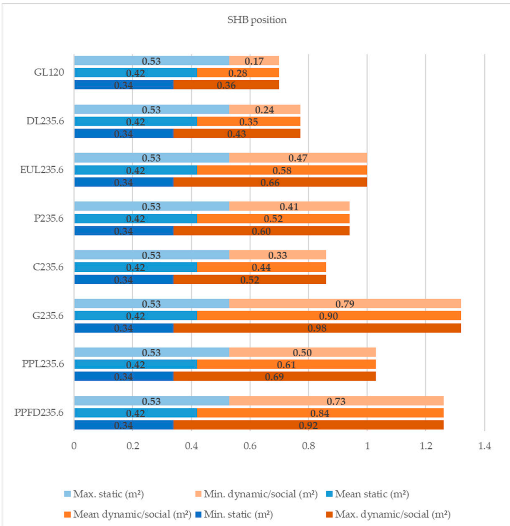
Table 6. Measured weights of sows according to body position groups (with SHB = Standing head bowed, SHR = Standing head half or fully raised, LBC = Lying in belly chest position, LL = Lying in the lateral position, STDEV = Standard Deviation, CV = coefficient of variation, Min = minimal value, Max = maximal value).

	n (Sows)	Live Weight (kg)				
		Mean	STDEV	CV	Min	Max
Total	100	235.8	28.6	12.1	187.5	310.0
			Standing Positions			
SHB	99	235.6	28.7	12.2	187.5	310.0
SHR	90	236.0	29.2	12.4	187.5	310.0
			Lying Positions			
LBC	3	250.5	52.5	21.0	192.0	293.5
LL	1	192.0	/	/	/	/

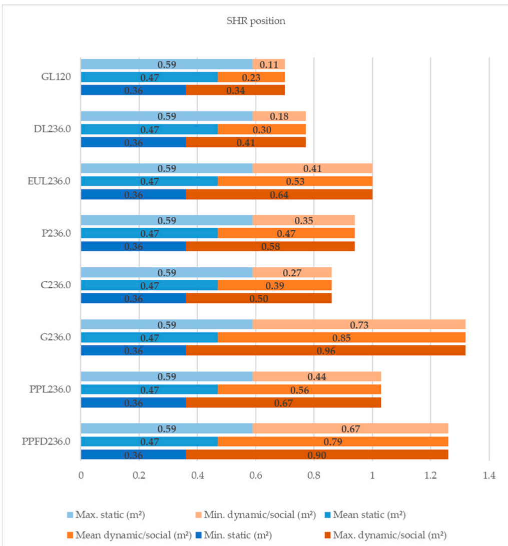
A significant dependency between weight and covered floor area was found in both standing positions ($p < 0.0001$, R > 0.9). This dependence was slightly lower for SHR (R = 0.912) than for SHB (R = 0.939) position.

3.3. Comparison of the Measured Values with Space Requirements from Legislation and Literature

The floor area covered by a sow's body corresponds to the static floor space a sow needs due to her body dimensions. The calculated difference between recommended or legally required space and the measured values for the static space is available as social/dynamic space. In both standing positions (SHB and SHR), a social/dynamic space remained at all investigated recommendations and requirements (Figure 2). According to the measured means, the remaining social/dynamic space was between 0.23 m^2 (SHR and GL120) to 0.90 m^2 (SHB and G235.6, Figure 2) for an average pig in standing body posture. A social/dynamic space of 0.11 m^2 (SHR and GL120) to 0.79 m^2 (SHB and G235.6) remained for the heaviest sow (310.0 kg, Table 2) of this study (Figure 2). The social/dynamic space for pigs with the smallest body dimension ranged from 0.34 m^2 (SHR and GL120) to 0.98 m^2 (SHB and G235.6). This minimum social/dynamic space of 0.11 m^2 corresponds to an area of about 1.8 DIN A4 sheets.



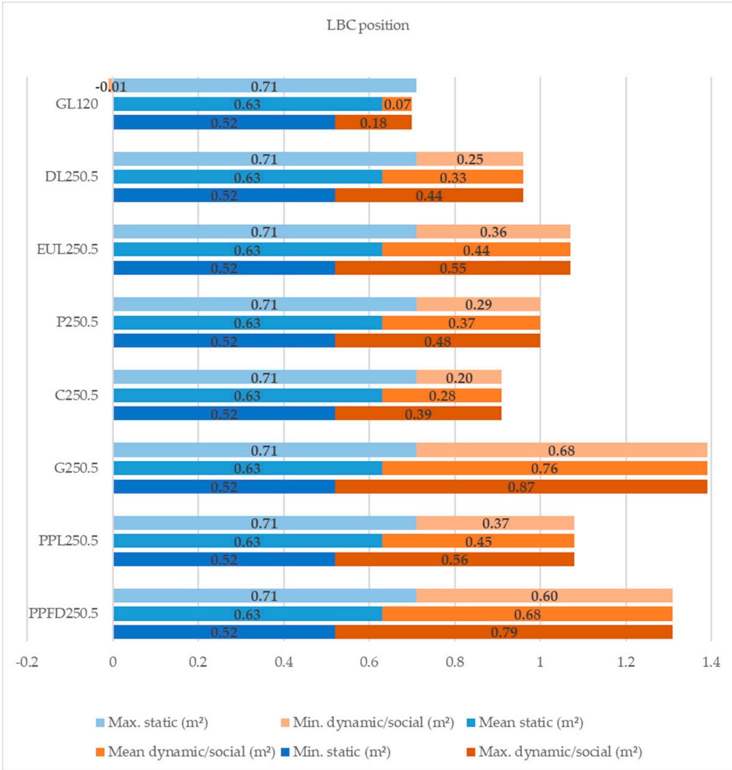
(**a**)



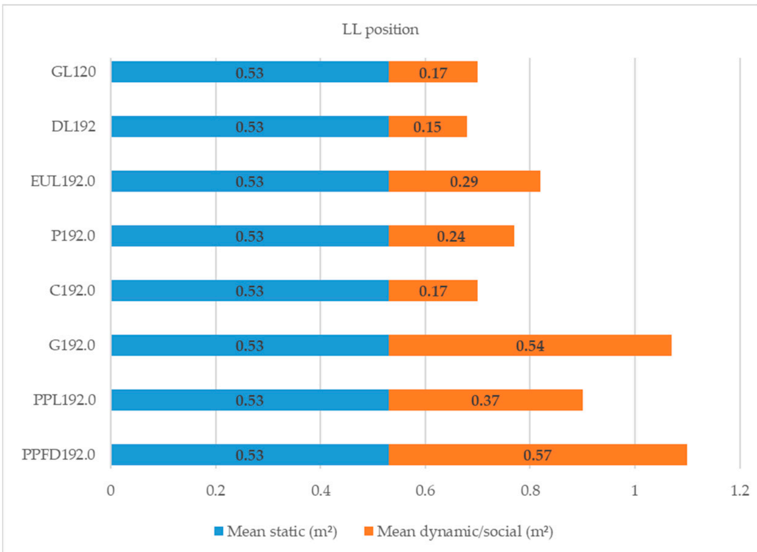
(**b**)

Figure 2. Static and social/dynamic space for sows in standing position (**a**) SHB and (**b**) SHR with a different minimum space available (with SHB = Standing head bowed, SHR = Standing head half or fully raised, Min = minimal value, Max = maximal value, static = static space, social/dynamic = social and dynamic space, abbreviations on the *y*-axis: see Table 4).

On average, there remained a social/dynamic space between 0.07 m^2 (LBC and GL120) and 0.76 m^2 (LBC and G250.5) for a lying sow (LBC and LL) at all shown loading densities (Figure 3). This determined minimum social/dynamic space of 0.07 m^2 corresponds to an area of around 1.1 DIN A4 sheets.



(**a**)



(**b**)

Figure 3. Static and social/dynamic space for sows in lying position (**a**) LBC and (**b**) LL with a different minimum space available (with LBC = Lying in belly chest position, LL = Lying in the lateral position, Min = minimal value, Max = maximal value, static = static space, social/dynamic = social and dynamic space, abbreviations on the *y*-axis: see Table 4).

For the maximum covered floor area measured for a sow in lying position (LBC, 293.5 kg), no social/dynamic space remained for GL120 (Figure 3). The sow measured with the largest body dimensions in this study needed 0.01 m^2 more static floor space than GL120 and DL200 provided (Figure 3). A social/dynamic space of 0.20 m^2 (LBC and C250.5) to 0.68 m^2 (LBC and G250.5) remained at the other tested loading densities. The social/dynamic space for pigs with the smallest body dimension in a lying position (LBC) ranged from 0.18 m^2 (GL120) to 0.87 m^2 (G250.5).

4. Discussion

The stocking density is acknowledged as a substantial factor for the health and well-being of fattening pigs during transportation. Insufficient space for all pigs to lie down can lead to physiological stress due to a lack of rest [42,43]. Moreover, too little floor space can cause increased mortality and increased total losses at the slaughter plant [2,44]. In contrast to the situation in housing facilities, and even if it may be less common under conventional transport conditions, too much free space during transport can lead to welfare and health problems. Due to poor roads and inconsiderate driving, animals can lose their footing, tumble around or fall, or be injured by increased fighting [20]. Moreover, various potential stressors, such as extreme climatic conditions (especially the temperature), handling manner and intensity, total transportation time (including rests), or the lack of food and water, can affect physiological stress reaction or transport deaths and reinforce each other [2,45–47]. One of the few studies addressing the transport of cull sows recognized similar key factors for sows as described for fattening pigs and identified a gap of scientific knowledge about risk factors on cull sow transport [7]. For fattening pigs and sows, these examples show the complex interaction of the numerous stressors affecting pigs during transport and demonstrate the challenging endeavor to quantify an optimal loading density considering all other risk factors. With this study, an essential starting point was set towards stocking-density recommendations for cull sow transportations by providing data of the static space, i.e., the actual physically needed floor space, of the current breed sow.

The chosen contrast-based planimetric method was well suited to produce reliable static space values for sows in standing posture. However, a simulation of real-life situation with several pigs in motion, which is necessary to determine the social and dynamic space, cannot be realized with this method. It is a well-established method and has been successfully used for measurements of various smaller animals, such as chickens, rabbits, and piglets [34–36,48–50]. Nevertheless, this method has limitations, as mentioned in a previous study with fattening pigs [41]. Due to the larger size of the animals, the measurements were very labor-intensive. Only a few sows laid down under the study conditions. Instead, most of the sows began to explore the experimental setup. They had to be removed to prevent them from damaging the planimetry box. One drawback of this study was that the method is only applicable to individual animals. Another disadvantage was that data collection and evaluation was limited to still images of the subjects. Consequently, the experimental setup was not sufficient simulating real conditions with pigs in motion and with several sows as it is necessary to determine the needed social and static space. Finally, various manual steps (image editing) made the method prone to errors. In future studies, it is conceivable that new technologies will enable an improvement of the method in terms of capturing more data in less time and with reduced animal handling. This could allow the experiments to be performed with different sow breeds and overcome the limitation of having only still images of the sows. Being able to evaluate video footage of basic movements and social interactions, such as huddling, would provide a more detailed picture.

With about 4.2 farrowings, the sows of this study were representative of cull sows in the European Union. Iida et al. [51] determined 4.9 $\pm$ 0.01 parities at removal for 109,373 farrowed sows on 125 Spanish, Portuguese, and Italian farms. The average gestation stage of the sows in the present study was about 73 days, and thereby more advanced than usually expected on transport vehicles. Council Regulation (EC) No 1/2005 regulated that pregnant animals in an advanced Gestation stage of 90% or more may not be transported [12]. However, EFSA [52] recommends reducing the prevalence of animals slaughtered in the last third of pregnancy. The effect of the gestation stage on a sow's body dimensions could not be investigated with the present sample set and should be considered in future studies. Nevertheless, the data provided a good representative starting point to assess the suitability of current regulations and recommendations for cull sow transports in the European Union.

In this study, on average, the sows covered a floor area of about 0.42 to 0.47 m^2 in a standing position (SHB to SHR posture). Petherick and Phillips [31] provided an "allometric formula" (a (m^2) = 0.019 $\times$ $W^{2/3}$ m^2; a = covered area, W = live weight) for the calculation of the covered floor area of a pig's body while "standing". Using this formula, a greater static space of 0.73 m^2 was calculated for a sow with a live weight of 236 kg than measured via planimetry (about 155% of the measured average value for SHB posture and 171% of the measured average value for SHR posture). Petherick and Phillips [31] suggested using the same formula for a pig "lying on sternum/belly with legs folded beneath the body", which corresponded to the measured position LBC. For an average sow lying in LBC posture, the calculated floor area value corresponded to 121% of the measured average. In a previous study, the body dimensions calculated with the help of Petherick and Phillips' formulas also exceeded those measured on the fattening pigs, and the exceed was significant in most cases [41]. On the one hand, it cannot be excluded that the actual floor area coverage was underestimated due to the measurement method, and therefore, modern, more accurate techniques have to be included in future studies in order to achieve a higher, quantifiable validity. On the other hand, these results suggest that measurements directly on sows' bodies are advantageous to develop recommendations for cull sows transports and to adapt and improve allometric formulas.

The covered floor area strongly depended on body weight for both standing positions ($p < 0.0001$, $R > 0.9$). Given the small amount of data gathered from sows in the lying positions, the findings for lying pigs cannot be considered statistically representative. However, previous studies also described a significant correlation between body weight and the covered floor space of lying for piglets and fattening pigs [35,41]. These results support the practice common in science and legislation to give loading densities as a function of live weight [12,18,19,31].

In this study, the optimal social and dynamic space requirements, and thus, also the total space required per sow, could not be determined. This requires measurements of the space occupied by individual sows during movements and the space needed by groups of sows during interaction. At best, such measurements are carried out under various environmental conditions which, according to the current state of scientific knowledge, may have an influence on the space requirement. Such measurements were not feasible with the experimental setup used in this study, but are conceivable with more recent technology. However, the measured static space needed by sows provided representative data to calculate the remaining social and dynamic space for various loading densities from the actual transport praxis or from scientific recommendations. With the assessed data set, the remaining social/dynamic space for several loading densities was calculated as exemplary. For the minimum space conditions specified by the German legislation, an average sow had less than 0.07 m^2 (less than 1.1 DIN A4 sheet) of social/dynamic space in a lying belly chest position. This cannot be supposed to be an adequate space to perform necessary movements and to maintain a comfortable individual distance at transport. For the heaviest sow of this study, there was barely enough static space. This sow exceeded the available floor space by 0.01 m^2. Thus, especially for heavy sows of modern breeds, the current German requirements do not sufficiently consider the spatial needs. On the other hand, the scientific recommendations of Petherick and Philips for long transports [31] and the lowest loading density from the study of Gerritzen [24] would provide almost a square meter free social/dynamic space. There is the possibility that this additional space would lead to tripping, falling, or aggressive interactions.

Whether these remaining floor space areas are sufficient, too low, or too high, depending on specific transport situations, cannot be answered within the scope of this study, and should be clarified in future work. Also, whether the results are applicable to other non-European regions or countries needs to be discussed. However, scientific recommendations do not differ around the world. Consequently, it can be assumed that the results of this study can also be useful for other countries and regions, since this study provides rare planimetric data of cull sows' body dimensions of a current breed. The results of this study can, therefore, be used for various discussions related to space requirements for sows, not only for transport, but also for housing situations, and possibly resulting in adopted and improved recommendations.

5. Conclusions

The European legislation and the national legislation of most member states lack a recommendation on stocking densities for cull sows on transport vehicles. The legal requirements of some non-European countries and scientific recommendations are also lacking. This study provides measurements for the static floor space needed for a modern, large-framed genetic breed of sow (i.e., the floor area covered by a sow's body) as the first step towards such recommendations. The results supported previous approaches that have recommended floor space requirements based on live weight. Also, it can be assumed that the few existing legal regulations are insufficient in some cases to ensure that heavy sows have sufficient floor space during transport. Further studies are needed to provide more extensive data on static space, but also on social and dynamic space requirement of sows of modern genetics.

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