International Conference under the auspices of:

IGA International Goat Association

Available sensor technologies for precision farming and welfare assessment in dairy goats

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TECH CARE
Integrating innovative TECHnologies along the value Chain to improve small ruminant welfARE management

European Commission

Horizon 2020
European Union funding for Research & Innovation

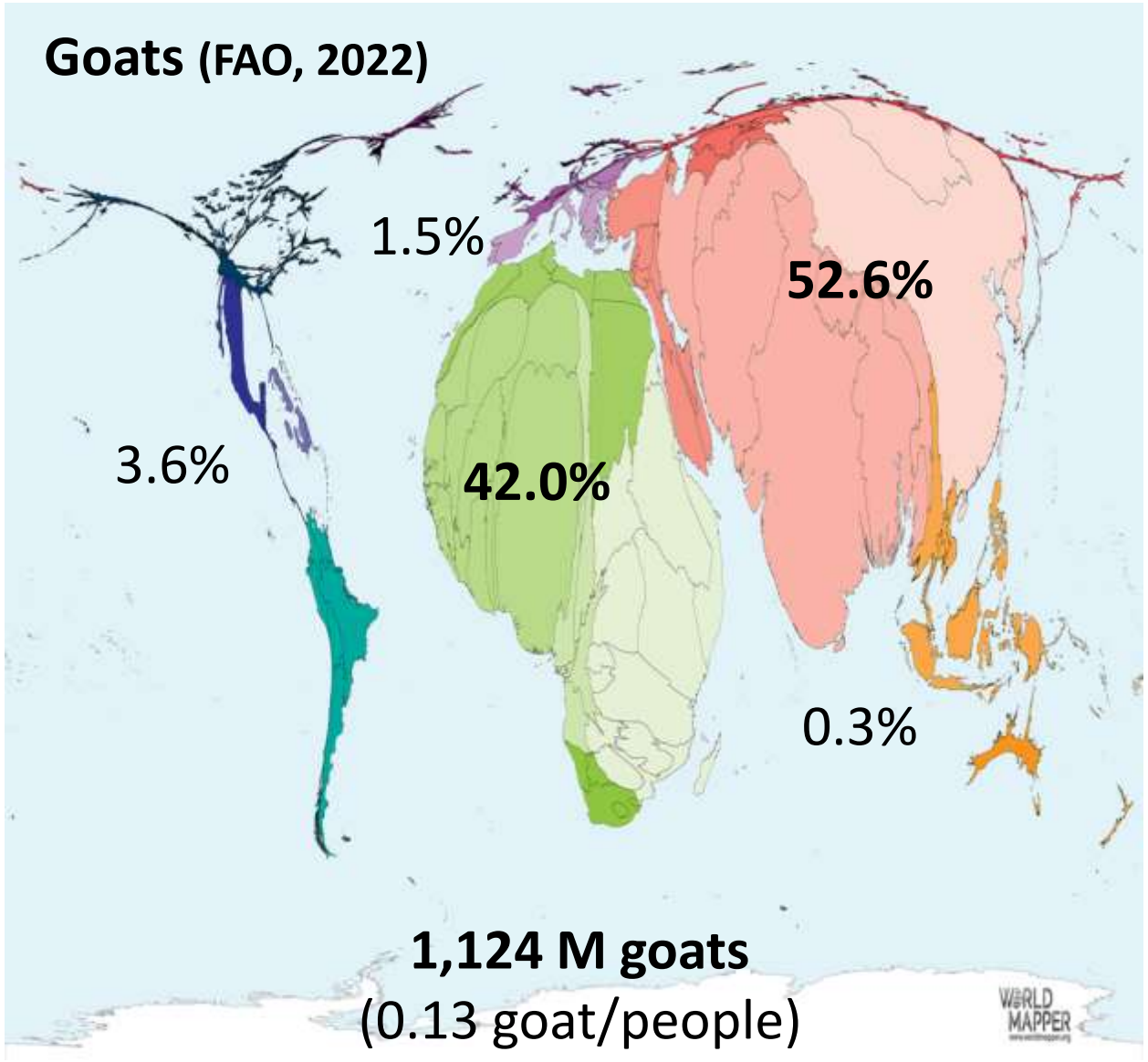
The goat production systems scenario for new technologies:1/2

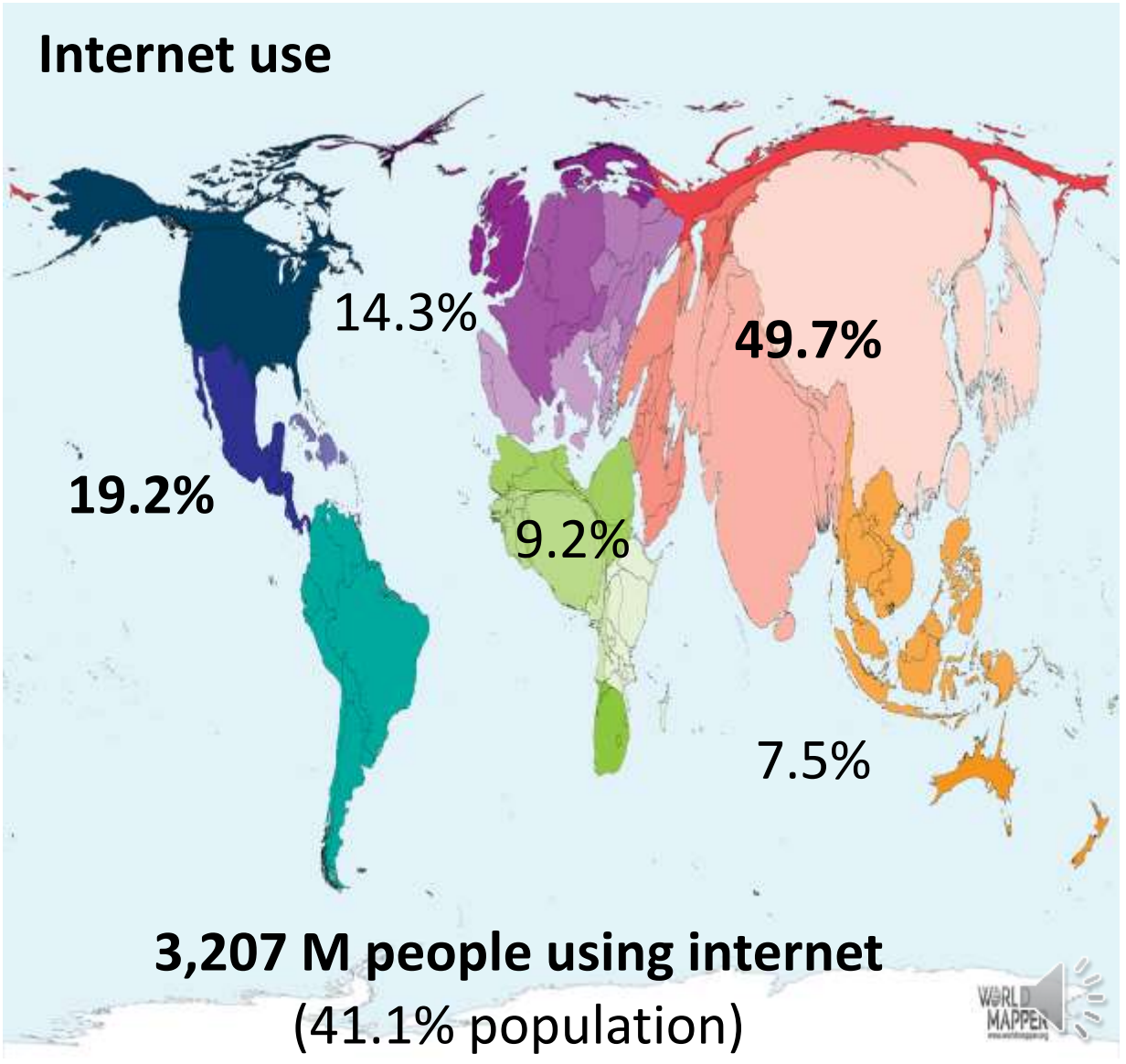
- Small ruminants (SR) are the **greatest livestock population in the world** (excl. poultry): **2,391 Mhead** (FAOstat, 2022) sheep:**goats** = 53:**47%**.
- Located on areas of **poor resources and facilities**, but rich in biodiversity, and where they are a key resource for **employment and capitalization** (*pecora*).
- SR products are **favorably considered by consumers,** mainly in Asian and Mediterranean countries (health, quality, welfare).
- **Farm size increased** during the last years in SR to compensate the rise of costs and profits decline.

The goat production systems scenario for new technologies:2/2

- **SR are fully e-ID (radio frequency)** in the EU and UK, because the BSE crisis (1996) and the EU Regulations on SR's ID (2005, 2015): **tool for PLF (precision livestock farming) implementation.**
- Many cost-benefit studies proved the **benefits of e-ID in SR**.
- **Low IoT** (Internet of things) **penetration in livestock (4%) and in SR (<0.1%)**.
- Expected **development of PLF technologies** for monitoring the production and welfare of SR.

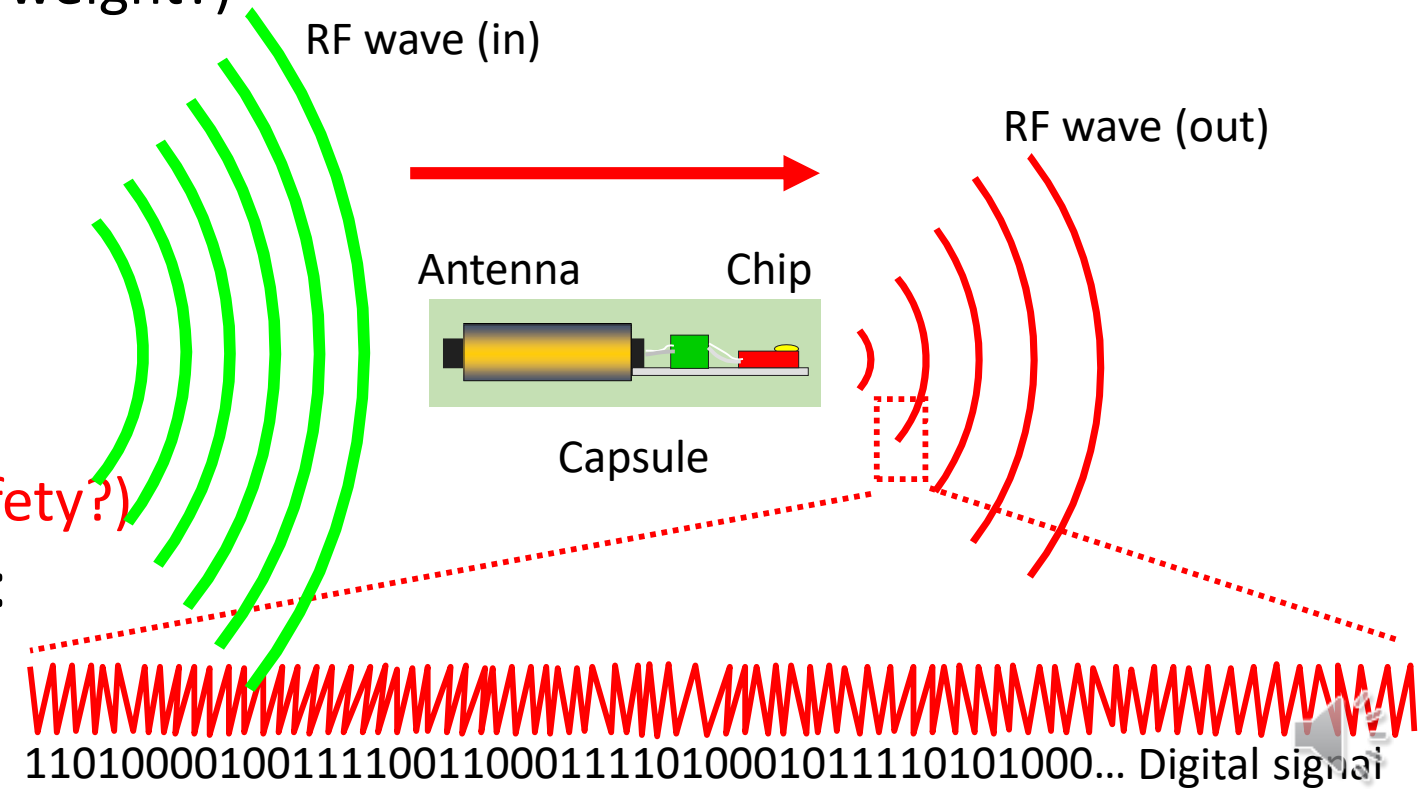
Goat's population and communication technologies maps
(World Mapper)





Transponders vs. Sensors: 1/2

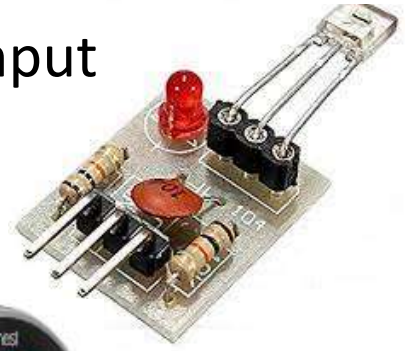
- **Transponder (Transmitter-responder)**:
  So-named ‘microchip’
  Electronic device which uses radio-frequency (RF) for sending a **fix response** (e-ID).
- **Typology:** Modifies their reading performances (key aspect)
  - Size: ‘**the greater the better**’ (max weight?)
  - Power source:
    - Passive (no battery)
    - Active (with battery)
  - RF band:
    - **Low** (LF): 134.2 kHz (collision)
    - **High** (HF): 13.56 MHz (printed tags)
    - **Ultra High** (UHF): 860-960 MHz (safety?)
  - RF technology (operation mode):
    - Full-Duplex (2-ways transmission)
    - Half-Duplex or Simplex (1-way)



Transponders vs. Sensors: 2/2

- **Sensor (Transducer)**:
  Input device which **produces an output** (**signal**) according to the **input quantity** (physical, chemical or biological). It is a part of a recording or control system.

- **Taxonomy** (NRC, 1995):
  - **Self generating sensors**: direct response (e.g. Faraday's thermistor)
  - **Modulating sensors**: able to vary their output according to a second input (e.g. fiberoptic magnetic-field, saver laser receiver…)
  - **Smart sensors**: their complexity concealed by an interface and on-chip signal (e.g. temperature controllers…)
  - Aim-related sensors: 12 main types according to technology.
  - **Animal based** classification: **Wearables** or **non-wearables**



Animal based sensors: 1/2

- **Wearables:** on/in the animal (Caja et al., 2020)

Type	Technology	Indicator	Device	Usage
Transponder (not a sensor)	Radio frequency	Individual data	• Ear tag • Bolus • Inject	Sorting, feeding, mating
Geographical positioning system (GPS/GNSS)	Satellite network	Position	• Collar	Virtual fencing, spatial location, grazing monitoring
	Bluetooth	Relative distance	• Collar + ear tag	Mother-offspring relationship

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		Bluetooth	Relative distance	• Collar + ear tag	Mother-offspring relationship
Sensor	**Temperature**	Thermistor	Rectal, rumen or vaginal	• Ear tag • Bolus • Inject	Health (fever), stress, heat, drinking bouts
	pH	Voltage	Rumen pH	• Bolus	Feeding, rumen function (health)
	Pressure	Several	Rumen activity	• Bolus	Rumination
	Sound	Microphone	Sound	• Bolus • Halter	Heart rate, rumination, coughing
	Acceleration	3-axial piezoelectric	Motion	• Ear tag • Bolus • Collar • Pedometer	Motion, resting, feeding, rumination, lameness (health)
	Biomarker	Several	Several	• Ear tag	Metabolites (health)

Animal based sensors: 2/2

- **Non-Wearable**: on/in the facilities (Caja et al., 2020)

Type	Technology	Indicator	Device	Usage
Cameras	Optical imaging	Shape	Handheld or fixed camera	Behavior, growth, supervision
	Infrared imaging (IR)	Temperature	Handheld or fixed camera	Thermometric monitoring, udder health (mastitis), head and hoof health, stress (eye)
	Near infrared (NIR)	Milk flow	Absorbance/reflectance meters	Milk volume and flow meters
	3D imaging	3D shape	Fixed camera	Body reserves
	Laser beam	Height	Fixed laser	Size, growth

Caja et al. (2020). J. Dairy Res. 87S1:34-36 (open access).
https://www.cambridge.org/core/journals/journal-of-dairy-research/article/sensing-solutions-for-improving-the-performance-health-and-wellbeing-of-small-ruminants/27931C4E696F45D282D8DE8C8F1194F0

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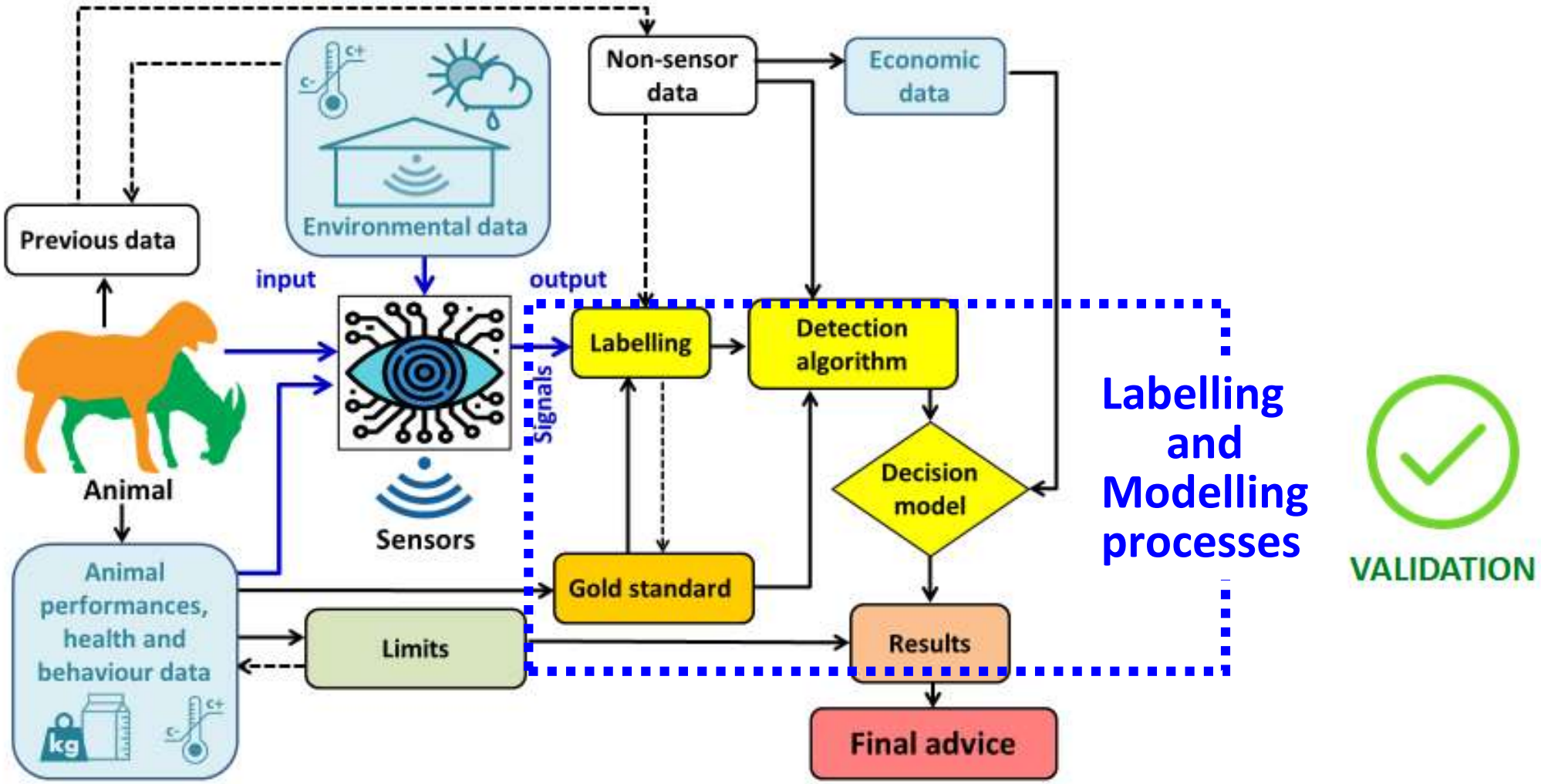
	Laser beam	Height	Fixed laser	Size, growth
Microphones	Sound	Intensity and frequency	Fixed microphone	Coughing, lambing, acute stress
Weighing cell	Electromagnetic force restoration	Weight	Automatic scale	Growth, weight, gait recording (lameness)
Ambient sensors	Several	Environmental data	Several sensors	Comfort and health monitoring

Caja et al. (2020). J. Dairy Res. 87S1:34-36 (open access).
https://www.cambridge.org/core/journals/journal-of-dairy-research/article/sensing-solutions-for-improving-the-performance-health-and-wellbeing-of-small-ruminants/27931C4E696F45D282D8DE8C8F1194F0

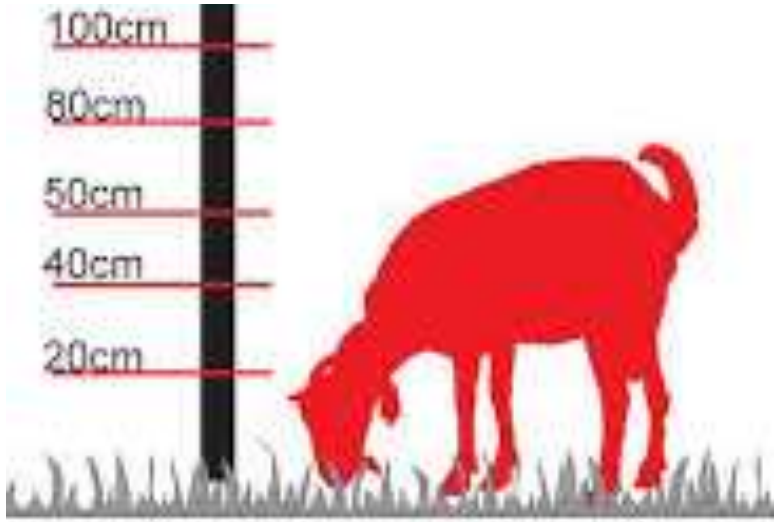
Implementation of a PLF sensor system on farm conditions

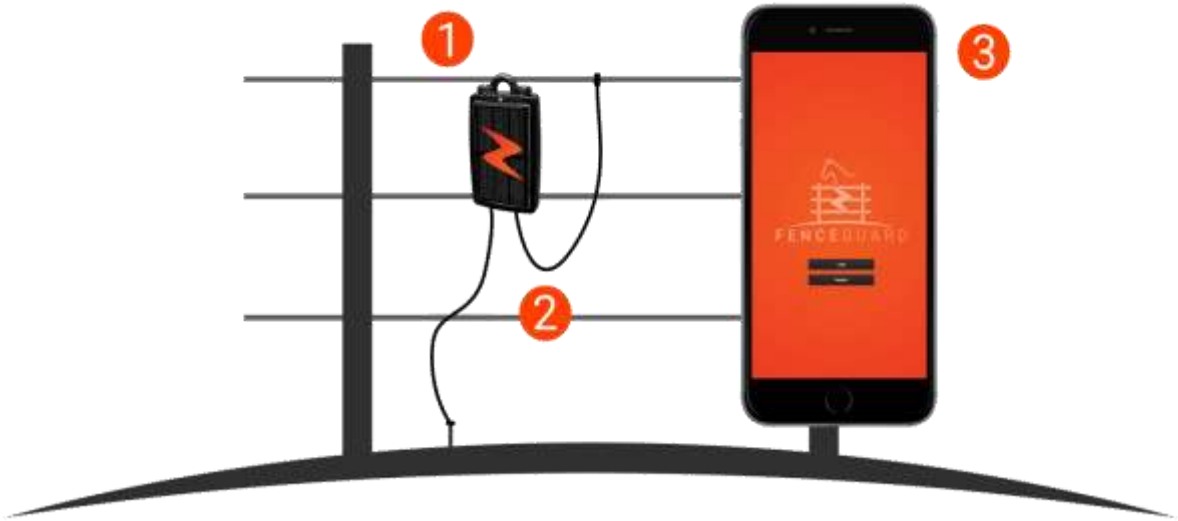
(Caja et al., 2020)



https://www.cambridge.org/core/journals/journal-of-dairy-research/article/sensing-solutions-for-improving-the-performance-health-and-wellbeing-of-small-ruminants/27931C4E696F45D282D8DE8C8F1194F0

Non-wearable: Smart monitoring and alert of SR electric fences





- Need for permanent care of electric fences in SR.
- Measuring fence voltage (0-10^4 V) every 10 min.
- Alerting immediate fence problems (e-mail, SMS, App).
- GPS sensor for device position location.
- Data transmission without mobile card (e.g. Sigfox network).
- Self-sufficient operation (solar panel and Li-ion battery).

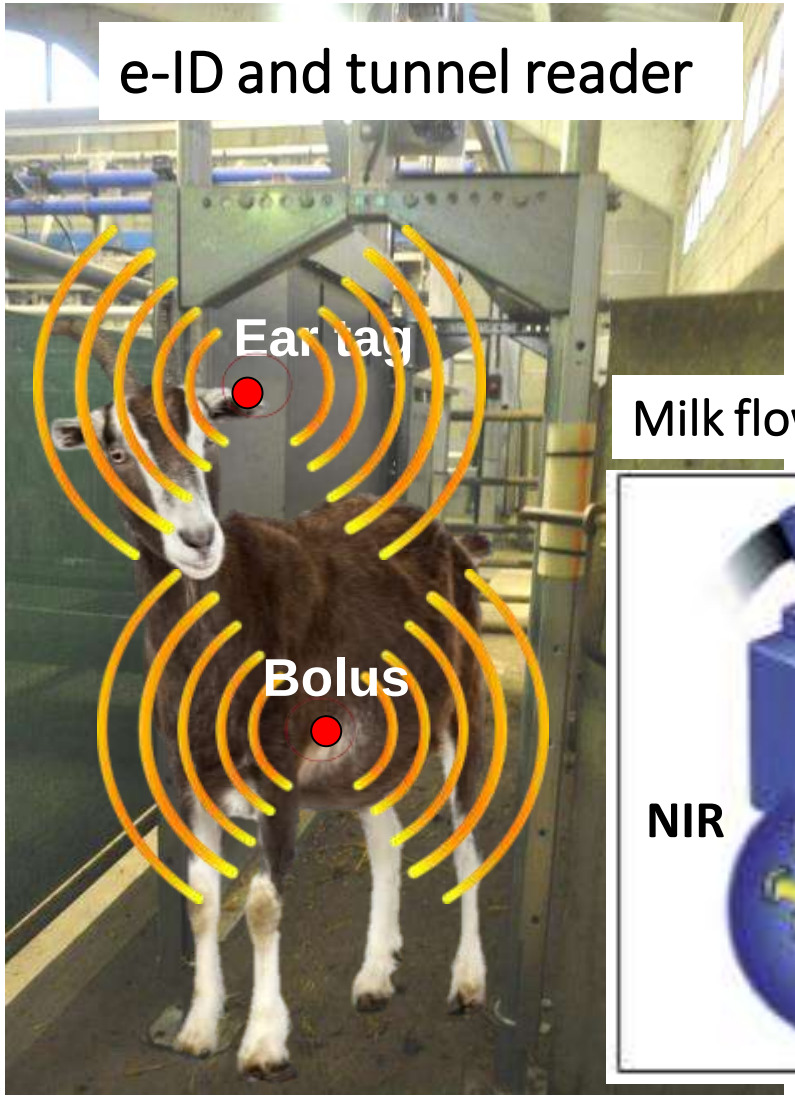
Wearable: Virtual fencing by using Global Positioning System

Inefficient learning in sheep (≈1/3) needing at least 3 interactions (Brunberg et al., 2017; Marini et al., 2018). **Efficient learning in goats (>80%), but the paper was retracted** (Muminov et al., 2019). Further research is needed!!!.

- GPS sensor and Bluetooth (beacon).
- Grazing map drawing.
- Total weight carried 505 g.
- Battery operated (8-10 h).

Electric shock (4000 V, 0.2 s) and alarm message

Non-wearable: Milk recording using (e-ID) and sensors (NIR)



Milk flow meter (NIR)

Fixed order by stall number

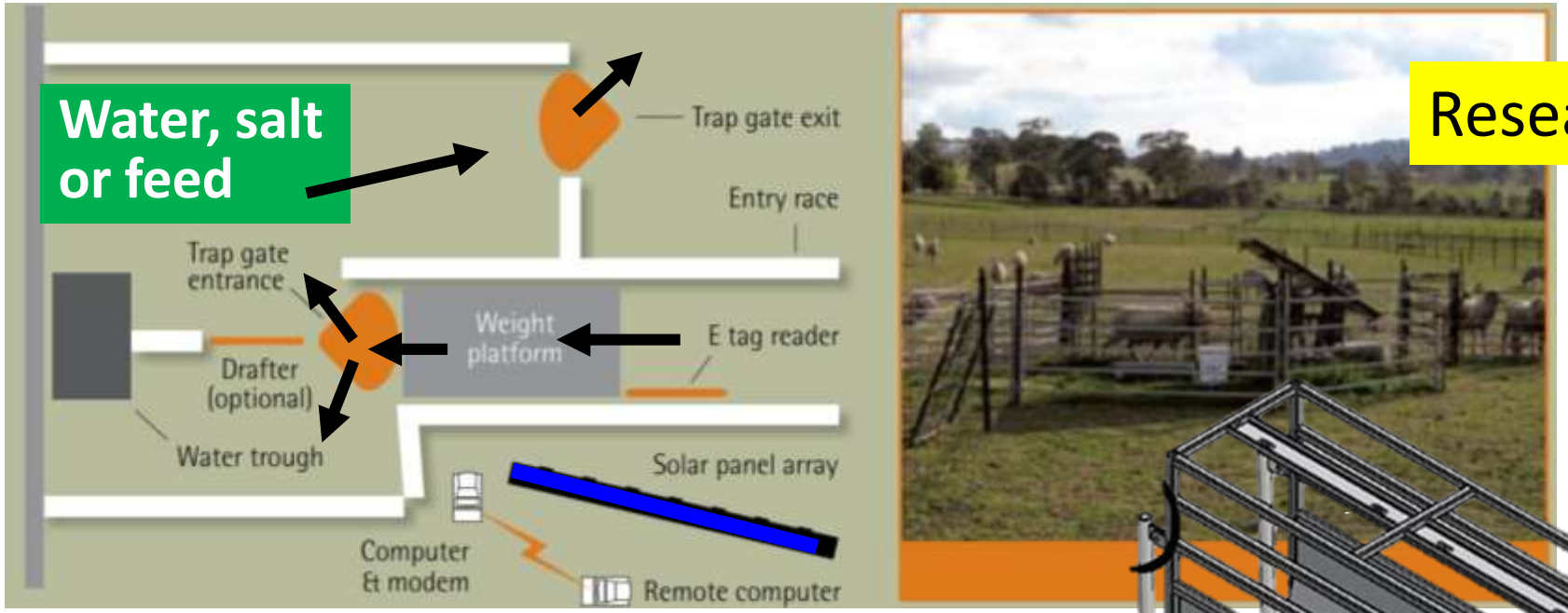
Reading efficiency 96-99% (Nieddu & Caja, 2017) line error?

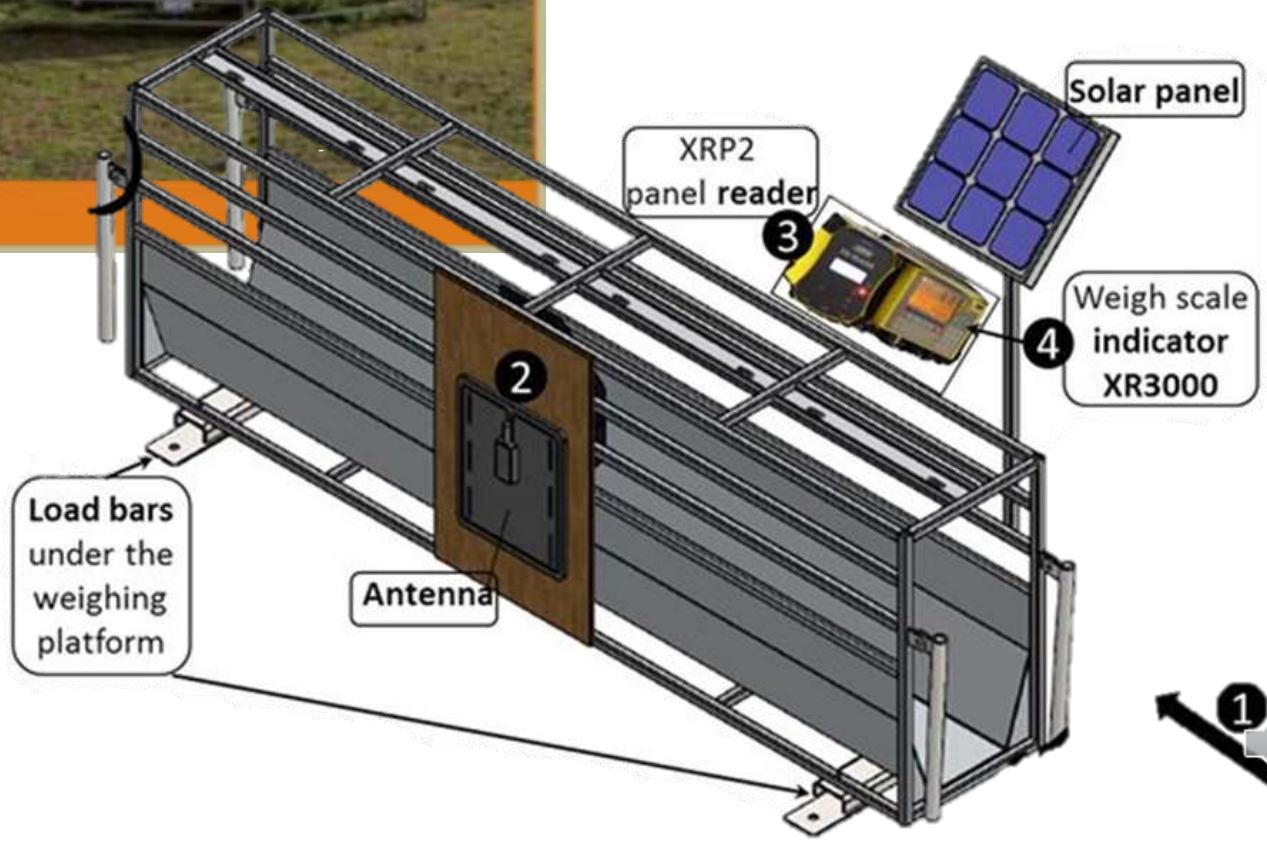
Milking order in goats seems to be influenced by **habits** more than by measurable traits like yield or weight (Sambraus & Keil, 1997; Gorecki & Wojtowski, 2004.

Non-wearable: Walk-over-weighing (WoW) using e-ID and sensors

González-García et al. (2018)

Research in goats is needed!!!

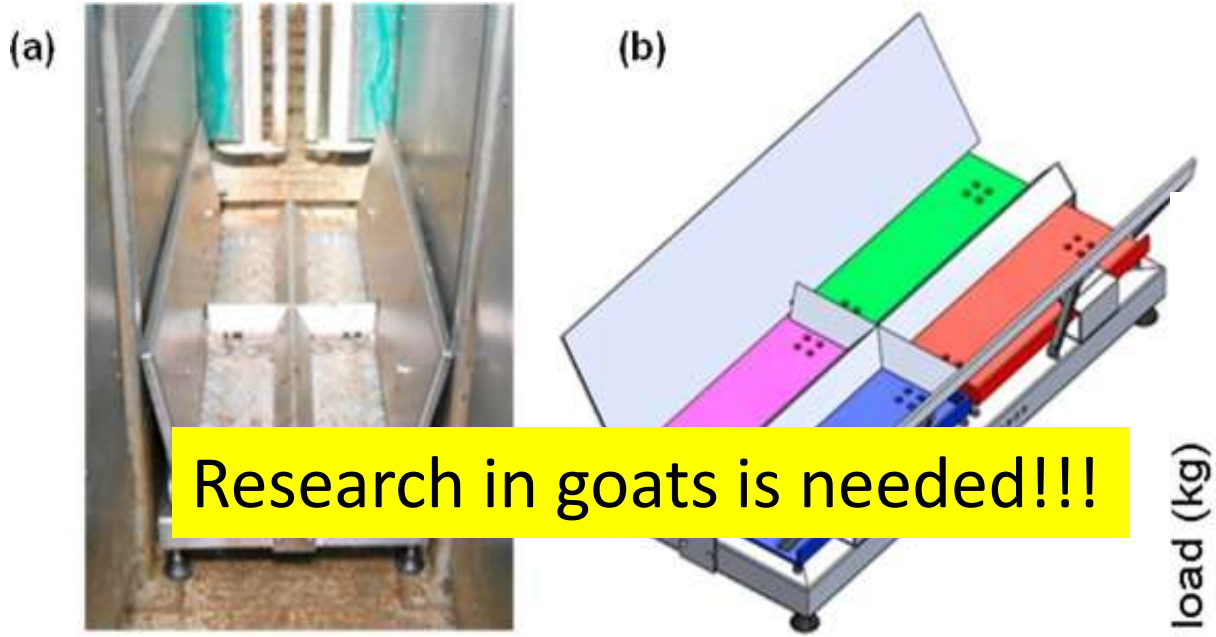




Approximate cost (CRC project, AU)

Indicator	=	2,600 €
e-ID reader	=	1,700 €
Load bars	=	750 €
		5,050 €
Solar panels and batteries	=	2,000 €

Non-wearable: Lameness detector using hoof weigh sensors



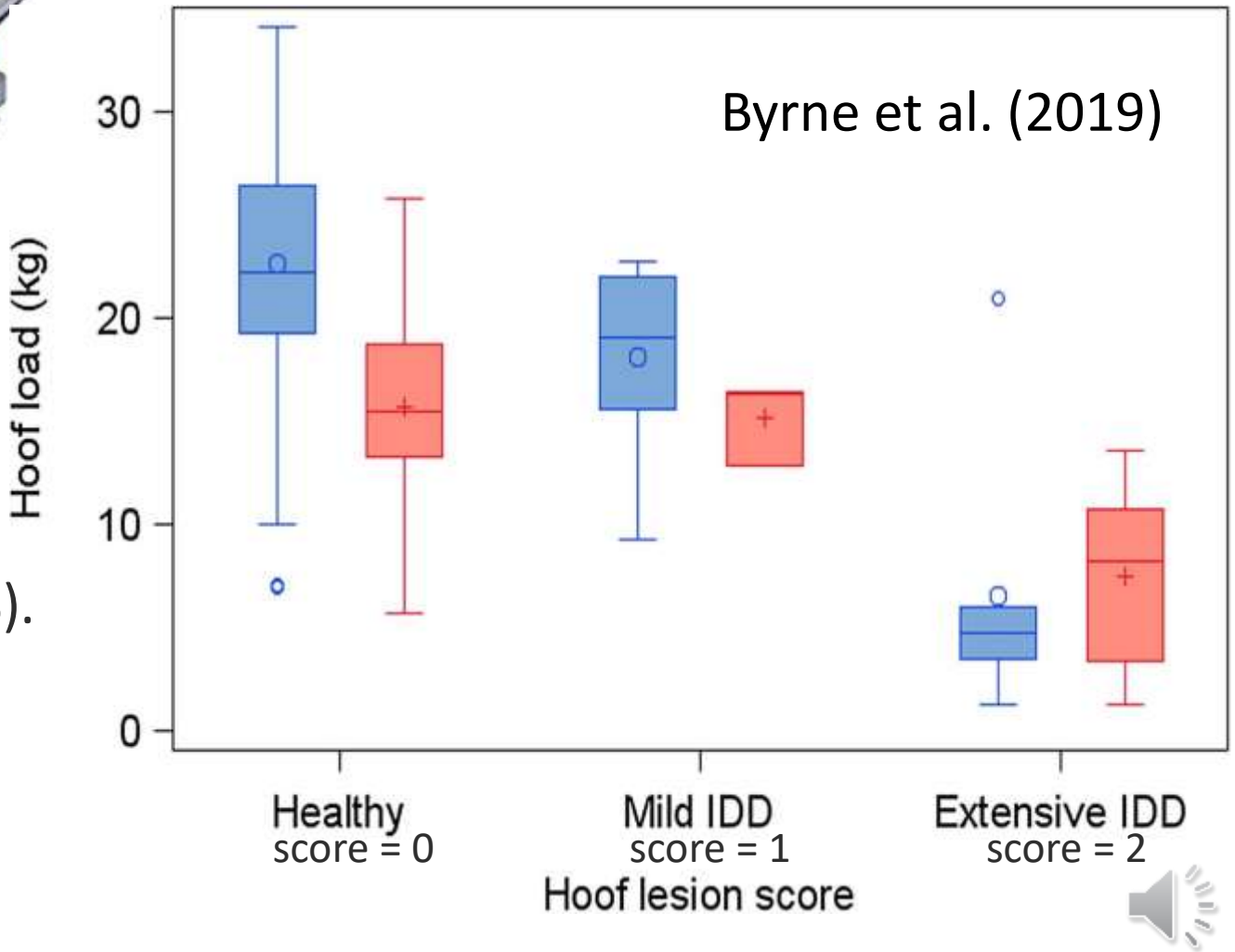
Research in goats is needed!!!

Lameness prevalence: 10 to 33%

- Healthy hooves: front > back load (60:40%).
- **Extensive infected hooves: same load**.
- Mild infected hooves: difficult to assess.
- Sensitivity 66-100% (**Score 2 = 85-100%**)
- Specificity: 51-100% (**Score 2 = 95-100%**)

Inter-digital dermatitis (IDD) assessment

Front (■) and back (■) hooves:



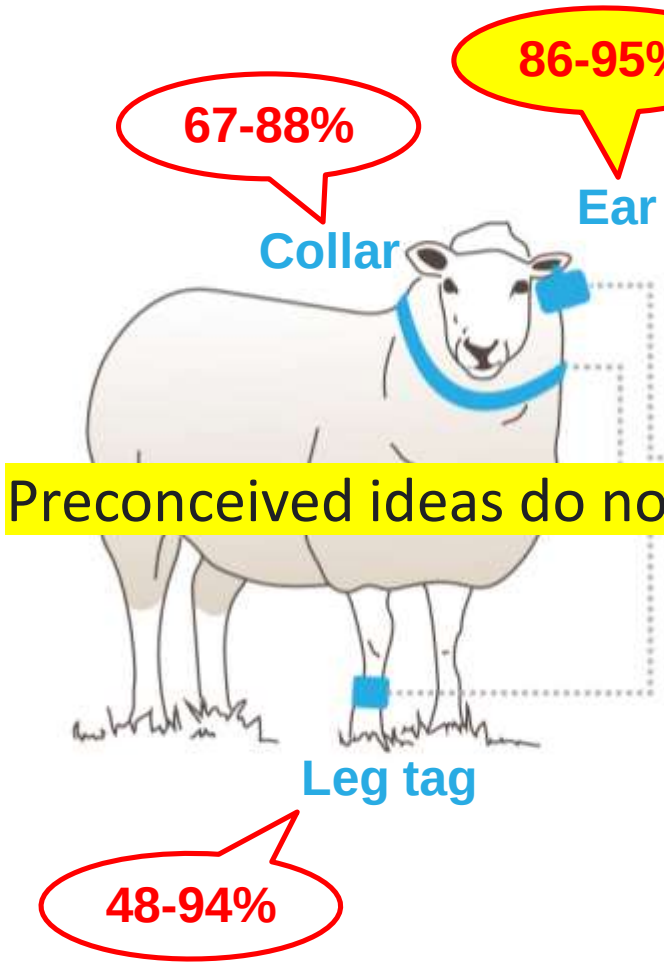
Wearable: Accelerometers responses according to body site attachment in sheep (Barwick et al., 2020)

- **Behavior study:**
  - Grazing
  - Standing*
  - Walking
  - Laying*

  * = includes rumination

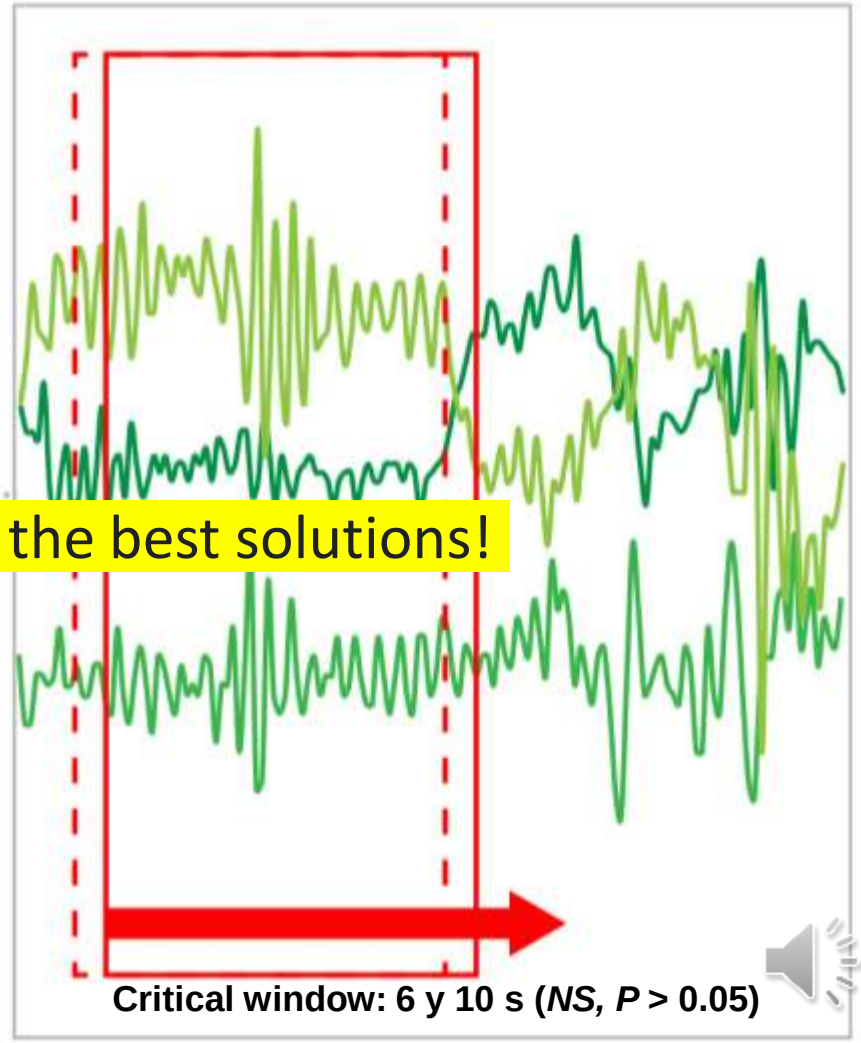
Merino x Poll Dorset (n = 5)
Validated by video recording

Research in goats is needed!!!



Accuracy of behavior identification varies according to body site's attachment ($P < 0.05$):

Preconceived ideas do not fit the best solutions!

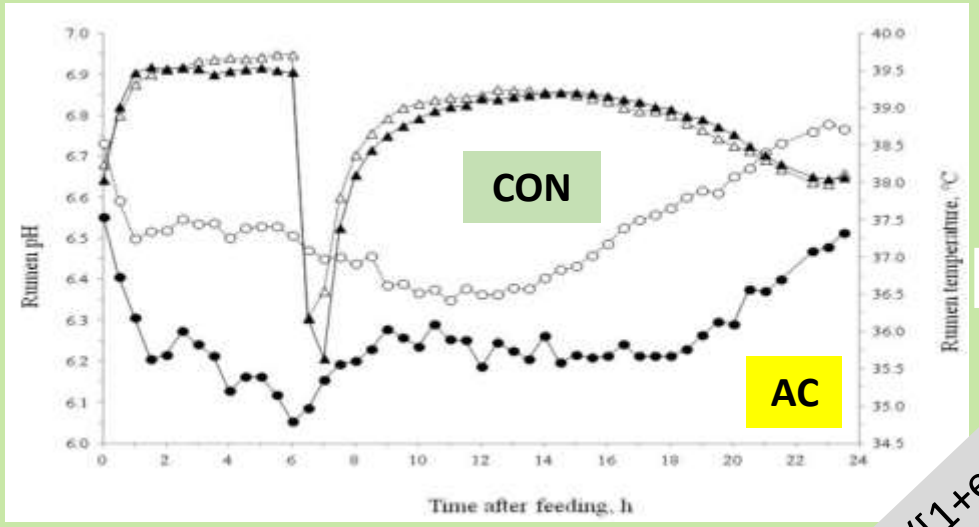


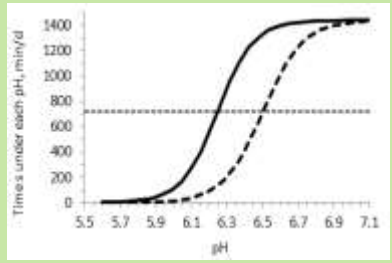
Wearable: Rumen temperature and pH in dry goats according to feeding and ambient conditions (Castro-Costa et al., 2015)

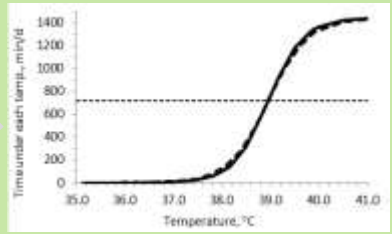
Rumen bolus (n = 8)

Needing < 70 × 20 mm !

Exp. 1
(8 goats)
Diet effects
(F:C ratio):
70:30 (CON, ○)
vs.
30:70 (AC, ●)

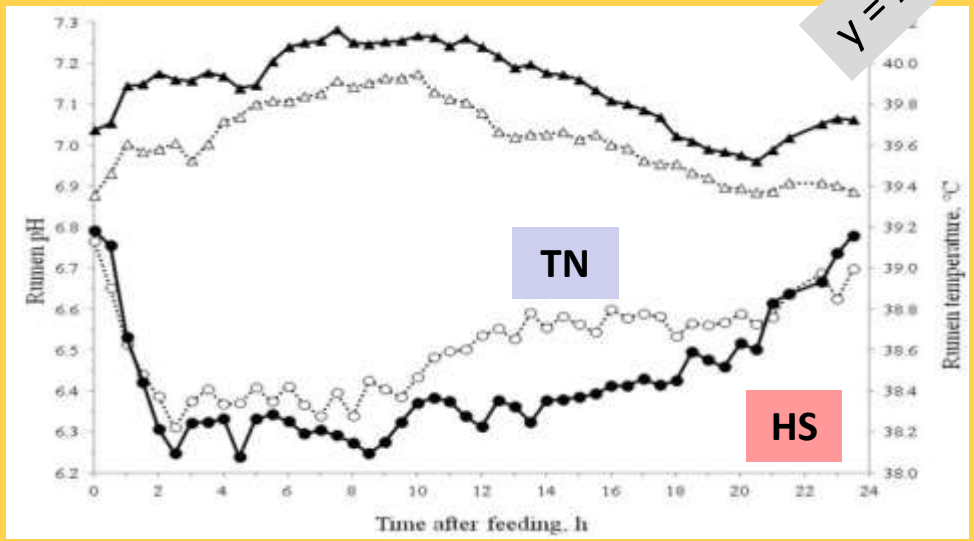


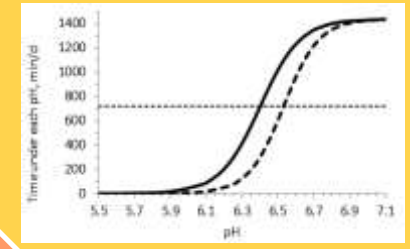


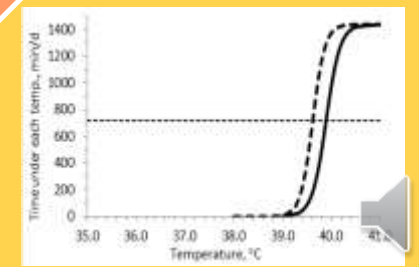


$y = A/[1+e^{-(b+cx)}]$

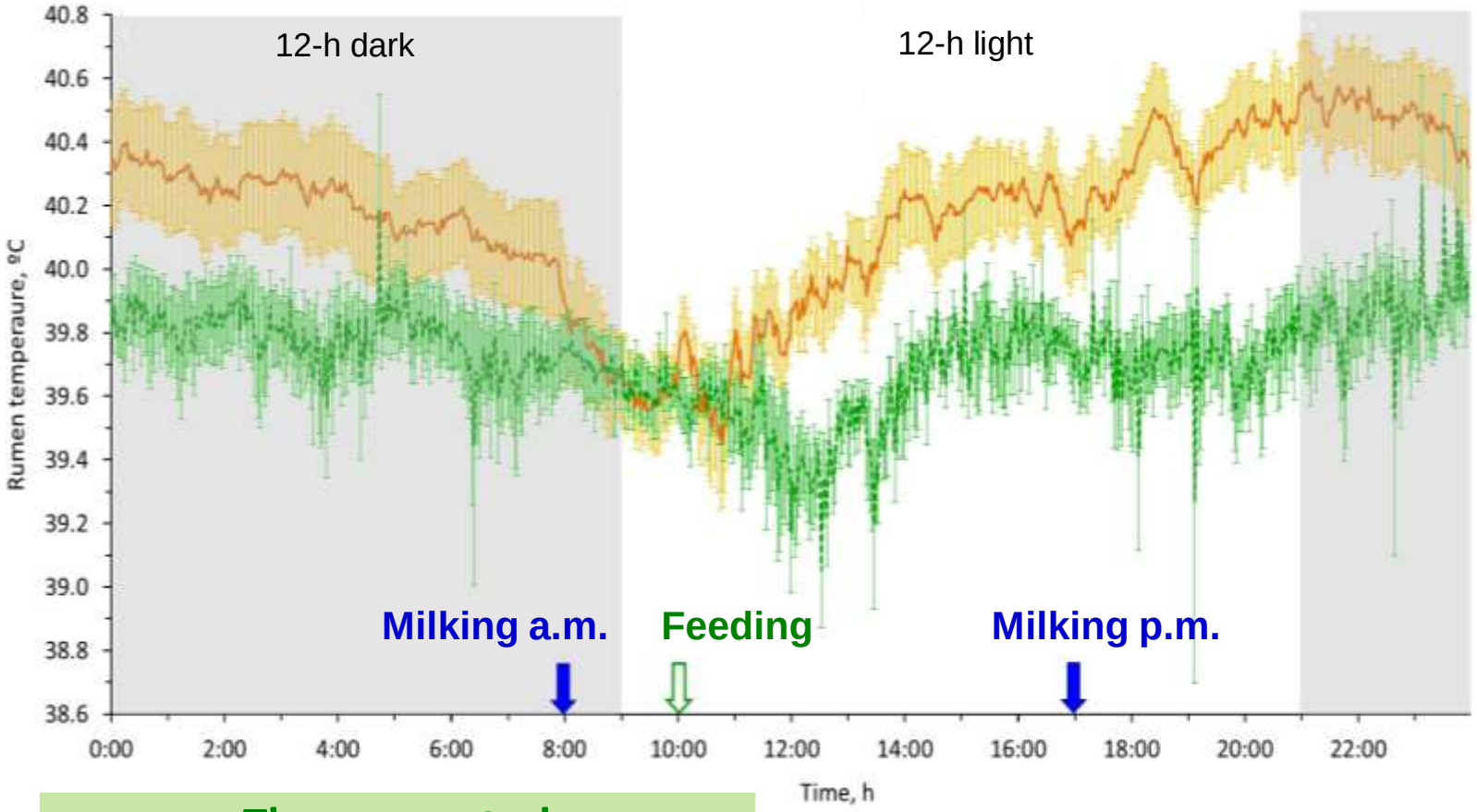
Exp. 2
(9 goats)
Ambient:
Termo neutral
(TN, ○)
vs.
Heat stress
(HS, ●)







Wearable: Rumen temperature of dairy ewes according to ambient conditions (Caja et al., 2020)

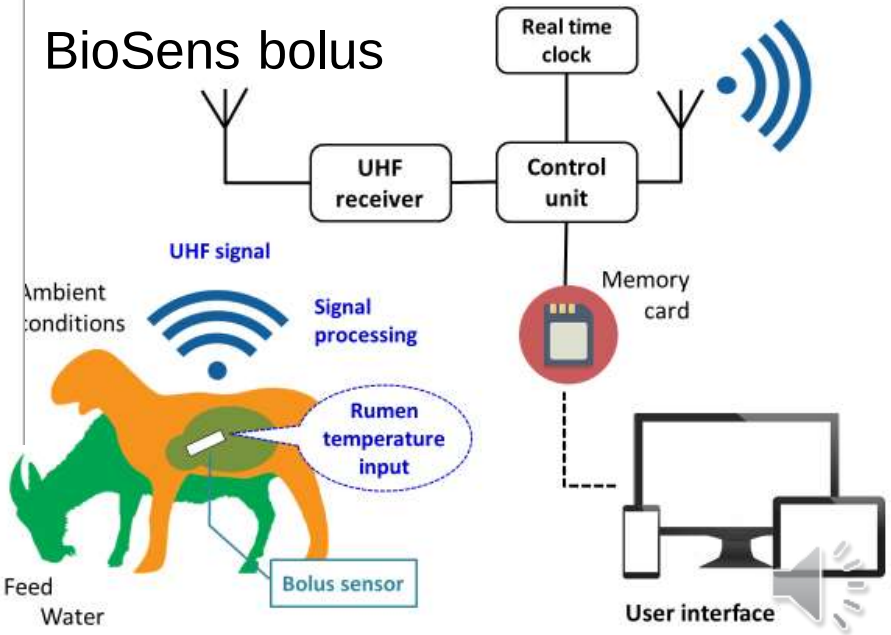


Thermoneutral
(night and day, 20ºC; 50%RH)

Heat stress
(night, 30ºC; day, 37ºC, 50%RH)

Caja et al. (2021)

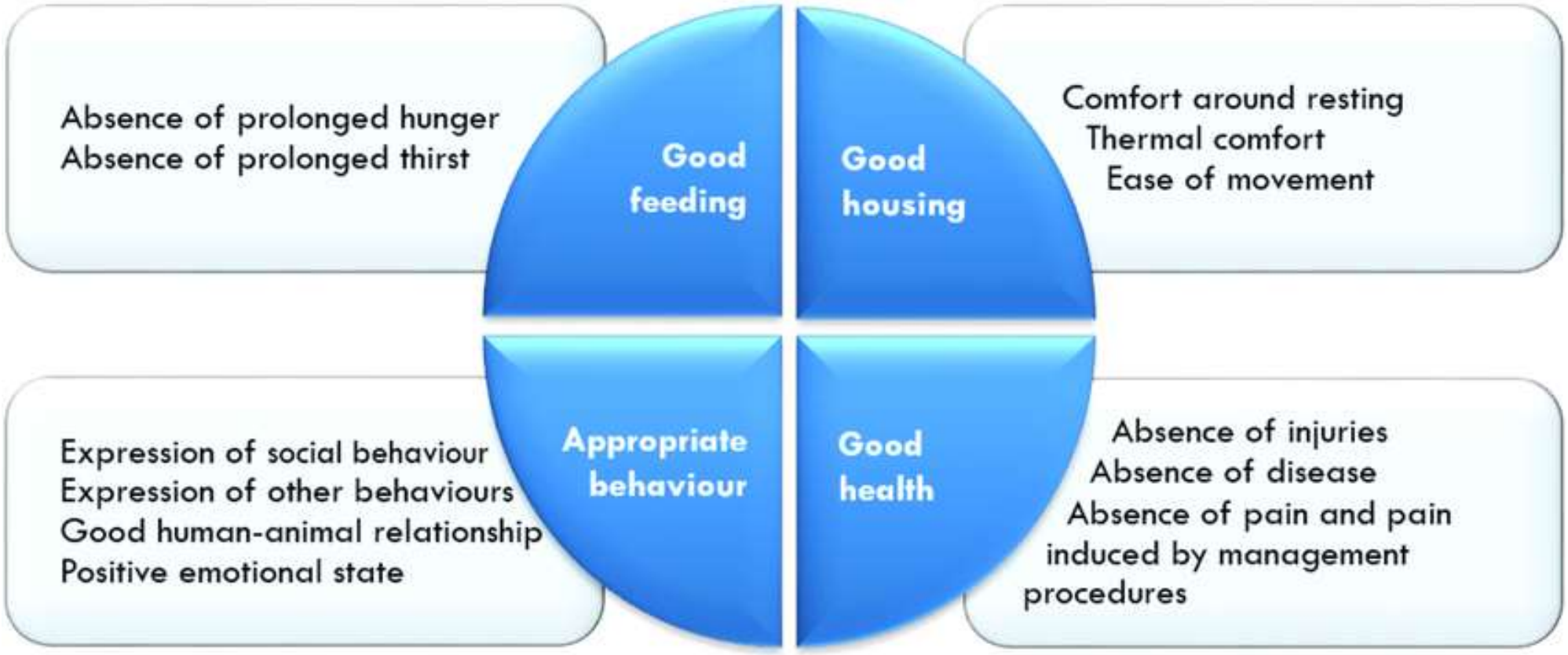
Prototype
(2 × 10 cm)



AWIN assessment protocol for livestock: 4 Principles, 12 Criteria and 24 Indicators

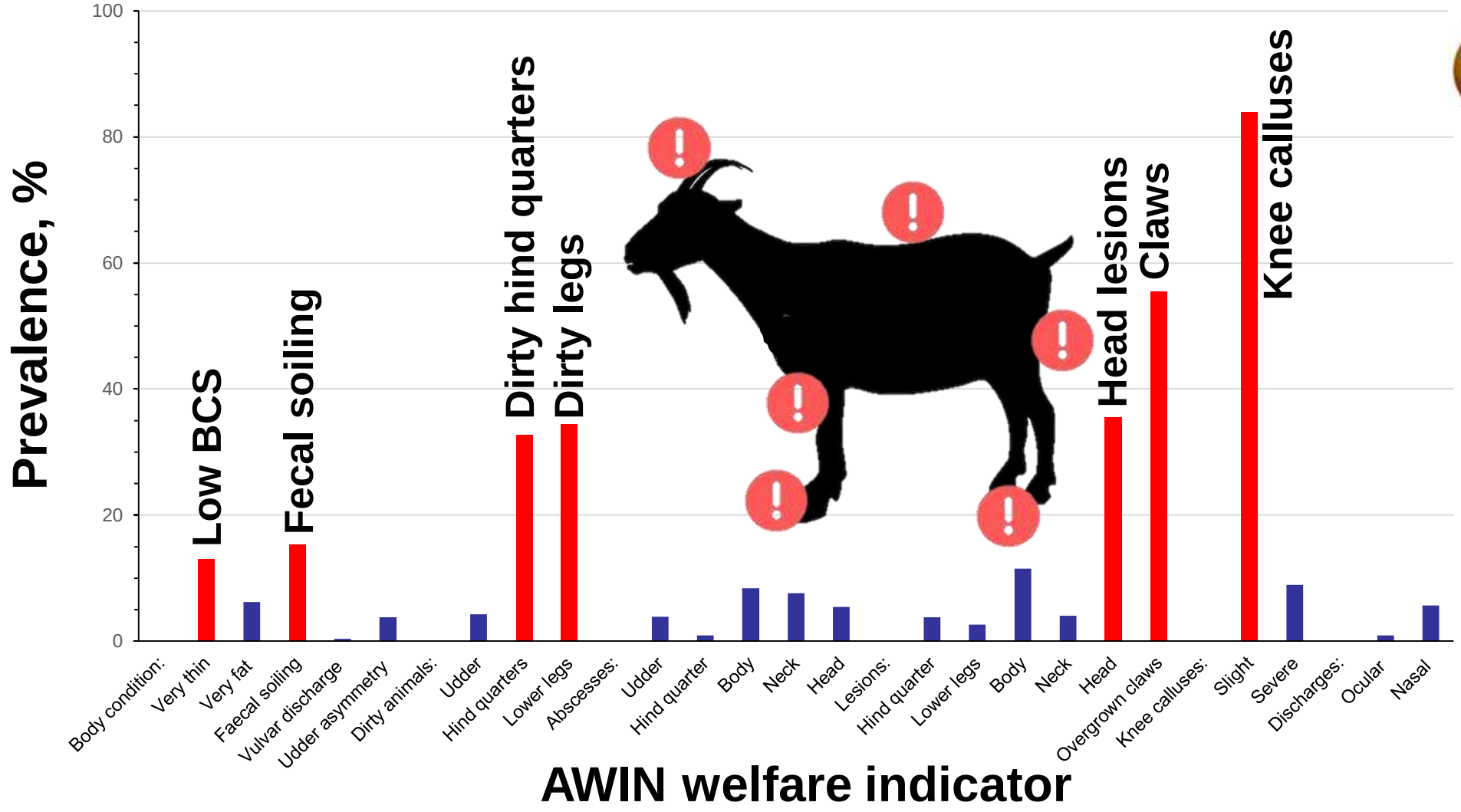
awin ANIMAL WELFARE INDICATORS

4-Welfare Principles



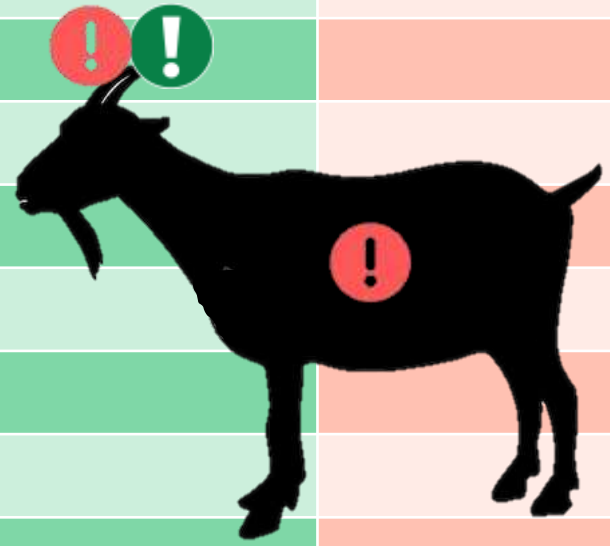
12-Welfare Criteria **×2 = 24 Welfare Indicators**

Results of AWIN 2-steps: Dairy goat farms (n = 30) in Italy
(Battini et al., 2016)



Comparison of AWIN in dairy goat farms: Step 1 (outside pens)

Indicator	Wildbolz-Gallego et al. (2019)	Battini et al. (2016)
Farms (country)	10 (**ES**)	30 (**IT**)
No. goats/farm (breed)	634 (Florida)	894 (Alpine)
Queueing at feeding, %	**0**	**7.2**
Queueing at drinking, %	**0**	**1.4**
Hair condition, %	**0.9**	**24.1**
Dehorning defects, %	**8.2**	**12.7**
Kneeling at feeding, %	0	2.3
Oblivion (depression), %	-	0.1
Heat/cold stress, %	-	0.4 / 3.9
Lameness, %	0.6	3.1
Human contact, %	**36.5**	**2.3**
Contact latency, s	103	53



Comparison of AWIN in dairy goat farms: Step 2 (inside pens)

Indicator	Wildbolz-Gallego et al. (2019)	Battini et al. (2016)
BCS Thin / Fat, %	**15.3 / 20.6**	**13.0 / 6.2**
Fecal soiling, %	**6.3**	**15.3**
Udder asymmetry, %	**27.6**	3.8
Dehorning defects, %	**8.2**	**12.7**
Dirty hind quarters, %	-	**32.7**
Abscesses, %	**11.2**	**26.2**
Head injuries (ears)	-	**35.5**
Overgrown claws	**23.0**	**55.5**
Knee calluses, %	-	**92.9**
Discharges Eye / Nose, %	**36.5 / 44.0**	0.9 / 5.7

No full coincidence needing research

Prioritization of welfare issues of dairy goats in Techcare project

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Welfare problems in dairy goats	Priority
Spain: Intensive	
Mastitis and milking management	**1**
Nutrition (low, high, bad) and offer (excess)	2
Shelter and facilities conditions	3
Greece: Semi-intensive	
Nutritive competition (agonistic behavior)	**1**
Shelter and bedding conditions	2
Mastitis and milking management	3
Norway: Mixed	
Mastitis and milking management	**1**
Parasitism (internal and external)	2
Agonistic social behavior	3

Prioritization of technologies for dairy goats in TechCare project

Integrating innovative TECHnologies along the value Chain to improve small ruminant welfARE management

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Weather station

Sensing technology for dairy goats	Priority
Spain: Intensive	
Weather station (internal-external)	**1**
Automatic milk meters (or bulk tank)	2
UHF-ID readers and accelerometers	3
Greece: Semi-intensive	
Weather station (internal-external)	**1**
Automatic milk meters (or bulk tank)	2
UHF-ID readers and accelerometers	3
Norway: Mixed	
GPS and accelerometers	**1**
Automatic milk meters (or bulk tank)	2
Infrared cameras (mastitis and health)	3

Prioritized technologies and welfare issues for producing early warning systems (EWS) for dairy goats in the TechCare project

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Technology	Welfare issue
Weather stations (internal-external)	Shelter and facilities conditions
Automatic milk meters (or bulk tank weight)	Mastitis and milking management, nutrition
GPS and accelerometers UHF-ID readers and accelerometers	Grazing, agonistic and nutritive behavior
Automatic weighing scales	Nutrition, health

Conclusions: 1/2

- **SR are a huge market** for sensor development and, currently, PLF implementation is poorly developed.
- Generalization of **e-ID** is a key for individual welfare assessment (e.g. EU).
- **Sensors** are input devices producing variable outputs (signals) according to the input quantity: Expected new developments for SR.
- Currently **prioritization of welfare problems** depends on **species**, **age** and production **system**.
- Very **few research** has been done **in dairy goats**.

Conclusions: 2/2

- **Wearable** sensors seems to be the ideal option for early alert/warning systems.
- **Non-wearable** may be the currently cost-efficient option for welfare assessment and early alert/warning systems.
- **Not all sensor device expectances are today warranted** and further applied research and innovation companies are highly needed.

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