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Published in:
Animal

DOI:
10.1016/j.animal.2022.100602

First published: 08/08/2022

Document Version
Publisher's PDF, also known as Version of record

Link to publication

Citation for pulished version (APA):
Ocak Yetisgin, S., Morgan-Davies, C., & Onder, H. (2022). Comparison of farm-level greenhouse gas emissions in transhumance and semi-intensive sheep production systems in continental rangelands. *Animal*, *16*(8), [100602]. https://doi.org/10.1016/j.animal.2022.100602

Animal 16 (2022) 100602

Contents lists available at ScienceDirect

Animal
The international journal of animal biosciences

Comparison of farm-level greenhouse gas emissions in transhumance and semi-intensive sheep production systems in continental rangelands

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ARTICLE INFO

Article history:
Received 23 December 2021
Revised 4 July 2022
Accepted 4 July 2022

Keywords:
Carbon calculator
Carbon emission
Environmental impact
Methane emission
Small ruminant

ABSTRACT

Despite their predominance worldwide, few studies have been conducted to look at the impact of sheep production systems relying on transhumance practices in arid and continental conditions, on farm-level greenhouse gas (**GHG**) emissions. Using Turkey as an example, this paper examines on farm-level GHG emissions calculated for two contrasting sheep production systems under arid and continental climate conditions. Production and management data were obtained through face-to-face interviews carried out on 10 transhumance and 15 semi-intensive meat sheep farms in Turkey. A total of seven GHG emission estimates were then calculated for each farm with the Agricultural Resource Efficiency Calculator (**AgRECalc**©) tool; i) total Carbon Dioxide (**CO2**) from energy use (kg CO2e), ii) total Carbon Dioxide equivalent (**CO2e**) from methane (kg CO2e), iii) total CO_2e from nitrous oxide (kg CO_2e), iv) whole farm and enterprise CO_2e emissions (kg CO_2e), v) net emission from land use (kg CO_2e), vi) whole farm CO_2e emissions per kg of farm output (kg CO_2e/kg output), vii) product CO_2e emissions (meat): kg CO_2e / kg live weight, and viii) farm output (kg of sheep). Multivariate analyses (using R software) were carried out to compare both farm types and their respective carbon emissions. The total farm output per ewe was lower in the transhumance farms (7.4 kg/ewe) than in the semi-intensive farms (7.7 kg/ewe). The kg CO_2e per kg of output was also lower for the transhumance farms (46.2 kg CO_2e) than for the semi-intensive ones (56.5 kg CO_2e). This trend was similar for the amount of CO_2e per kg of live weight produced (20.8 kg and 25.4 kg for the transhumance and the semi-intensive farms, respectively). Despite overall net emissions from land use being greater on average for the transhumance farms, once measured per hectare, they were found to be lower than those for the semi-intensive farms. This study provides a reference point for different sheep production systems' GHG emission impact in continental rangelands in Turkey.

Implications

Although sheep production contributes significantly to Greenhouse Gas emissions, little is known of the impacts of sheep transhumance, despite its importance. Elements affecting greenhouse gas emissions in semi-intensive and transhumance sheep systems were identified with a carbon calculator. Transhumance systems had lower whole farm CO_2e emissions per kg of farm output, indicating that traditional sheep transhumance systems, crucial to the rural economy and social fabric, do not have a higher carbon footprint than semi-intensive ones; greenhouse gas emissions in these systems could be improved at individual farm level with holistic approaches to mitigation opportunities.

Introduction

There are 1 238 million sheep and 1 094 million goats in the world (Food and Agriculture Organization of the United Nations statistical databases (FAOSTAT), 2019), and three-quarters of them are found in dry-arid and temperate areas. They tend to play an important socio-economic role in the rural economy, cultural traditions, landscape, and biodiversity preservation (Marino et al., 2016). Sheep production in the world is also quite varied (Morris, 2017), leading to a growing interest in measuring the environmental impacts of such a variation, which spans practices such as intensive indoor production to very extensive and transhumance systems.

Transhumance is the seasonal migration of livestock and humans between summer and winter pastures, maximising resource exploitation through grazing (Ruiz and Ruiz, 1986) and practised in many parts of the world (Olea and Mateo-Tomas,

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https://doi.org/10.1016/j.animal.2022.100602
1751-7311/

2009; Chakrabarti, 2011; Chetri et al., 2011; Hevia et al., 2013; Namgay et al., 2013; Ocak, 2016; Vigan et al., 2017; Vagnoni and Franca, 2018). One of the characteristics that distinguish transhumance from other forms of animal husbandry is its long association with nature and efficient utilisation of natural resources. Many mountain areas in Europe where transhumant livestock spend most of the year have developed highly diverse ecosystems that play a significant role in conserving biodiversity (MacDonald et al., 2000). The ecological and production rationales are well documented across Europe and Mediterranean countries (Perez and Saez, 1990; Starrs, 2018), and recent works have revealed multiple ecosystem services associated with twenty-first century transhumance (Oteros-Rozas et al., 2014; Hevia et al., 2016; Ocak, 2016) One of the few countries in the Mediterranean region where transhumance is still widely practised is Turkey.

Turkey is the 8th biggest sheep producer in the world (FAOSTAT, 2018) and its livestock production is important, with 14.6 million ha grasslands, covering approximately 19 % of the total land area and accounting for about 37.7 % of the total utilised agricultural land (Turkish Statistical Institute (TUIK), 2019). Besides, livestock, in particular sheep production, plays a significant role in the Turkish national and rural economy, contributing to 22 % of the total agriculture value (TUIK, 2019). Different sheep production systems are present in Turkey, linked to breeding strategy and availability of grassland. However, the main sheep production system is extensive, dependent on transhumance, with a reliance on natural grasslands, stubble, and fallow pastures with a grazing period of 240-270d (Sayar et al., 2015).

The UNFCCC and the Kyoto Protocol were ratified by Turkey in 2004 and 2009, respectively, with a requirement to develop annual inventories on emissions and removals of Greenhouse Gas (**GHG**) not controlled by the Montreal Protocol, using the Intergovernmental Panel on Climate Change (**IPCC**) Guidelines. Thus, a National Greenhouse Gas Inventory of Turkey was set up in 2006. The agriculture sector includes emissions from the enteric fermentation, manure management, rice cultivation, agricultural soils, field burning of agricultural residues and urea application (Turkish Greenhouse Gas Inventor (TGHGI), 2021). According to the latest Turkish GHG inventory, agriculture was responsible for 63.9 Mt **CO_2e** (Carbon Dioxide equivalent) in 2018, a contribution of 15.2 % to national emissions (TUIK, 2021). Additionally, 32.06 kt CO_2 eq. of the annual Methane (**CH_4**) emission in Turkey, with the primary source being ruminant animals, has been attributed to enteric fermentation (FAOSTAT, 2018). Enteric fermentation is by far the largest source of agriculture GHG emissions in Turkey since the 1990s, leading to 49.4 % of all CH_4 emissions in 2019; manure management was 13 % and Nitrous Oxide (**N_2O**) emissions accounted for around 7.5 % of Turkey's GHG emissions (Supplementary Fig. 1, TUIK, 2021). Emissions from manure management, agricultural soils, and field burning of agricultural residues include N_2O gas, with Turkish agriculture as a sector producing 91.58 kt N_2O emissions (27.3 Mt CO_2 eq in 2018 (TGHGI, 2021)). These numbers are calculated at the national level using a variety of methods (Supplementary Table S1) and activity data sources (Supplementary Table S2). However, these numbers do not differentiate between the emissions from the different types of sheep production systems, including the more traditional transhumance-based ones. To lessen GHG emissions, Turkey proposes to reduce agricultural emissions through more resilient local breeds, implementation of advanced and environmentally friendly farming practices and by improving pasture management for livestock production. Transhumance systems could play a role in this, and, by targeting specific improvements of farming elements, carbon footprint can be lessened.

Various tools have been developed in different contexts to assist with the quantitative assessment of farm-level emissions that would facilitate the reduction of, or mitigate, the GHG impact of production systems (e.g. Cool Farm Tool by Hillier et al., 2011; the CALM tool by CLA, 2009). Although these tools employ different methodologies, most tend to use the IPCC (2006) guidelines as their standard (Sykes et al., 2017). One tool called **AgRECalc** – Agricultural Resource Efficiency Calculator (SRUC, 2014), developed by the consulting division of Scotland's Rural College, allows the quantification of farm-level emissions for a range of production types. It is an online tool, certified under the PAS2050:2011 specification for GHG life cycle assessment (BSI, 2011), that conforms to IPCC Tier I and Tier II calculations for all livestock types. This tool calculates whole farm emissions, emissions by enterprises and on a product-basis. It also captures forestry carbon sequestration and renewable energy production and has been mostly used to study beef systems at farm level (Sykes et al., 2017; Kamilaris et al., 2020).

In the literature, few studies have been conducted to look at the impact of different sheep production systems by assessing farm-level GHG emissions with tangible on-farm data. Studies in New Zealand (Ludemann et al., 2012), Australia (Alcock and Hegarty, 2011) and in the UK (Lambe et al., 2014) looked at genetic improvement for mitigating GHG emissions in sheep systems. In Australia (Colley et al., 2020) and in Spain (Ripoll-Bosch et al., 2013; Batalla et al., 2015), studies looked at the different levels of intensification in sheep meat systems and their impact on carbon footprint. Studies by Eldesouky et al. (2018) and Horrillo et al. (2020) looked at livestock systems, including meat sheep, in the more arid Mediterranean conditions of the Spanish dehesas. However, to our knowledge, no studies have been conducted comparing transhumance and semi-intensive systems, despite their importance.

This paper will therefore address these issues and aim to provide a reference point in terms of GHG emissions for transhumance and semi-intensive systems, using Turkey as an example, applying the AgRECalc© software. The following questions will be considered: 1) what is the effect of sheep transhumance on **CO_2** (Carbon Dioxide) emissions from energy use, methane and nitrous oxide in the grassland ecosystems; 2) what are the main GHG emitters/-variables in transhumance and semi-intensive sheep production systems and 3) which technical characteristics of farming elements are the main sources of GHG emissions in these production systems? These questions are pertinent as there is still an ongoing debate (Kamilaris et al., 2020) regarding the emission levels and GHG of systems of contrasting intensity.

Material and methods

Study site and field survey

The study site was located in Ergani, (lat 38°17′E, long 39° 44″K) Diyarbakır, in the region of South East Anatolia, Turkey. The climate of South East Anatolia is continental and characterised as semi-arid with high evaporation, winters are cold and rainy, and the pastures dry out very quickly at the beginning of June. This sub-climatic zone is in the "fertile crescent," at the heart of a series of civilisation centres that have intensively used the land for multiple millennia. Although perennial, warm-season grasses likely once covered the higher plains, it is now a sparse cover of mostly annual grasses (Koc et al., 2015). The most abundant vegetation species in these rangelands can be defined as; *Cynodon dactylon, Hordeum murinum, Medicago sativa and Amaranthus sp.* (Seydoşog̃lu, 2018). The pastures in the South East Anatolia lowlands are rangelands and are elevated 606 and 1 022 m above sea level. Mean annual precipitation is 500 mm of which approximately 80 % occurs from autumn to spring (Sayar et al., 2015). Being a continental climate, the temperature range is quite extreme, with a minimum temperature of – 4.8 °C in February and a maximum of + 40.7 °C in July (TSM, 2017).

As well as being severely disadvantaged, due to weather conditions and rural poverty, the South East Anatolia region has the 3rd largest sheep population (TUIK, 2021) in Turkey (14 %), after Central Anatolia (22 %) and East Anatolia (33 %), and is quite representative of the majority of Turkish extensive and semi-intensive systems.

Data for this study were gathered through a field survey, following principles outlined by Fowler (2009). Around 100 farmers were contacted through the Sheep and Goat Breeders' Association in the province. A total of 15 semi-intensive and 10 transhumance farms were retained in the dataset. They were farmers who agreed to take part and could provide the required data. Qualitative research methods (face-to-face questionnaire – Supplementary Table S3) were used to interview the 15 semi-intensive and 10 transhumance farmers from one town over a two-week period in 2018 by the same interviewer and collect the relevant data. Farmers were selected for having minimum representative flock numbers for the study area (100 and 500 head minimum for semi-intensive and transhumance flocks, respectively). The locations of the farms are shown in Fig. 1.

Data collection of farm management and Greenhouse gas emissions

Data on management practices were collected for both types of farms (Supplementary Table S3). All the farms were breeding local "Karakaş" sheep, known for being a hardy local breed. Flock nutrition is based on grazing (grassland and crop residues) with some supplementary feed provided during last trimester of pregnancy and early lactation. Table 1 presents the characteristics of the transhumance and semi-intensive farms in the sample. In the semi-intensive farms, sheep were kept for 5–6 months indoors depending on the weather conditions with barley and straw supplementation. Once the snow no longer lay on the communal grasslands, sheep were allowed to graze outside. Grazing starts usually in April until mid-June, and animals are also allowed to graze on crop/agricultural residues. In the transhumance farms, sheep were kept outside on the rangelands for the entire year and fed with supplementary feed only in the last trimester of gestation and early lactation period (February–March). The animals grazed on the rangelands during the day and were housed at night in temporary shelters (tents). The transhumance farmers were using trucks to transport the animals to the summer grazing areas (350–400 km). The GHG emissions from these farms were calculated using the AgRECalc© calculator, which determines on-farm emissions per unit of output. Input data for the calculator have been collected from the study flocks through the face-to-face questionnaire (Supplementary Table S3), with questions focusing on farm environment and animal performance. Data were collected during the interviews with the farmers, and covered; land and crops, grass and forage (area), livestock numbers, weights and fate (number sold, number dead), energy used, renewable energy produced, and waste produced.

Agricultural Resource Efficiency calculator model

The Agricultural Resource Efficiency Calculator (AgRECalc©) was developed as part of the Scottish Government's Farming for a Better Climate initiative by the consulting division of Scotland's Rural College (**SRUC**). It was developed in alignment with IPCC (2006) Tier I and II methodology and is PAS2050 certified (IPCC, 2006; Sykes et al., 2017). The model employed IPCC (2006) Tier II methodology to estimate emissions coming from livestock and manure management, while IPCC (2006) Tier I methodology is used to calculate N_2O emissions from fertiliser applications and crop residues (IPCC, 2006; Kamilaris et al., 2020). The model also considers embedded emissions from the production of fertilisers (Kamilaris et al., 2020), calculated using emission factors from Kool et al. (2012), while embedded emissions for imported feed and bedding are calculated according to Vellinga et al. (2013).

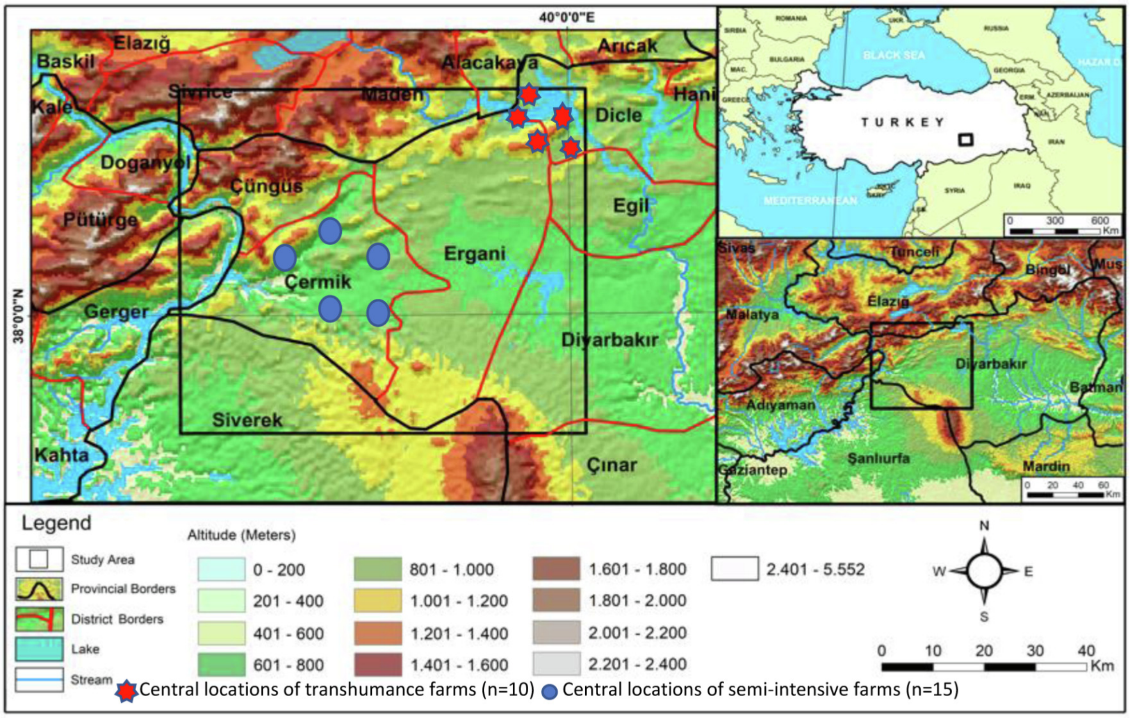


Fig. 1. Schematic representation of semi-intensive and transhumance sheep farms in the study area.

Table 1
Technical indicators and emissions of different sheep production systems (farm average for both systems, with range in brackets).

Item	Transhumance (N = 10)	Semi-intensive (N = 15)
Technical characteristics of the farms		
Land use (ha)	612 (100–2 500)	109 (3–500)
Average flock number (head)	881 (550–1 200)	261 (120–800)
Number of sold animals (head)	305 (80–550)	97 (30–300)
Weigh at selling (kg)	45.6 (35–55)	46.9 (40–63)
Lambing rate (%)	1.3 (1.2–1.8)	1.2 (1.0–2.0)
Number of dead animals (head)	82 (40–150)	24 (5–90)
Time spent at grazing (%)	100 (100–100)	47 (7–80)
Time being housed (%)	20 (0–100)	21 (5–50)
Purchase feed quantity (t/year)	141.1 (75–220)	85.7 (31–280)
Grazing distance (km/year)	279.0 (120–400)	60.1 (2–300)
Water used (l/year)	2 146 (1 000–4 200)	700 (290–2 000)
Financial output* (000 £/year)	48.2 (27.5–65.5)	19.1 (6.0–45.0)
Stocking density (LU/ha)	1.4 (0.36–10)	2.4 (0.44–43)
Contribution of various emissions		
Energy source	Solar	Electricity
Fuel (l/year)	5 490 (2 200–15 000)	988 (0–2 500)
Plastic waste (kg/year)	145.1 (6–250)	102.3 (20–250)
Total CO_2 from energy use (kg CO_2e)	65 093 (37 135–95 103)	38 672 (16 635–114 793)
Total CO_2e from methane (kg CO_2e)	81 509 (37 135–150 595)	47 432 (19 702–146 970)
Total CO_2e from nitrous oxide (kg CO_2e/kg)	36 599 (14 899–56 926)	14 986 (6 011–48 124)
Net emission from land use (kg CO_2e)	251 607 (135 947–364 715)	101 088 (44 101–309 887)
Whole farm CO_2e emissions per kg of farm output (kg CO_2e/kg output)	46.2 (26.8–97.4)	56.5 (26–191)
Meat CO_2e emissions (kg CO_2e/kg live weight)	20.8 (12.1–43.8)	25.4 (12–86)
Farm output (kg/year)	6 476 (1 440–13 613)	1 996 (540–5 400)

Abbreviations: *= Euro-Turkish lira currency during data collection year-1 £=3.02€, LU: livestock unit; CO_2 = Carbon Dioxide; CO_2e = Carbon Dioxide equivalent.

The differences in the contrasting diets are accounted for in the model, as different feed emission factors are used in the coefficient calculations, with default values calculated using FeedPrint (2015). Emissions from electricity and fossil fuels are estimated using emission factors from DEFRA/DECC (2013) Conversion Factors for Company Reporting (Sykes et al., 2017). One of the shortcomings of the model is that the version used could not estimate the effects on soil carbon sequestration. As the model was initially developed for temperate climate (UK), the emission factor calculation used for manure management was changed (from using an annual temperature of 10 degrees to an annual temperature of 15–25 degrees), to cater for the Turkish conditions (G. Inman, pers. comm.).

The main inputs in the model:

- Land and crops, grass and forage (area, productivity, type and quantity of fertiliser applied, type of manure applied)
- Monthly livestock numbers (by type – i.e. ewes, rams, female replacements, lambs), weights (kg) of animals bought and sold, and fate (sold, dead)
- Quantity and type of feeds bought (kg), quantity of hay (kg) and of bedding (straw) used (kg).
- Energy used (e.g. litres of petrol, diesel used, kW electricity used, renewable energy produced, water (litres) consumed, and waste (kg plastic) produced).

Although the model can accommodate sheep, suckler cows, dairy cows, pigs and poultry, we only used the sheep enterprise element of the model.

The main outputs of the model (see Supplementary Table S4) are emissions calculated for the whole farm, per enterprise and per unit of saleable product (Bell et al., 2021), namely:

- Total CO_2 from energy use: Carbon dioxide (kg CO_2e) a) from direct emissions (from diesel, electricity, other fuels, renewables) and b) direct and indirect (embedded from purchased inputs – e.g. feed, fertiliser, lime, bedding, etc.)
- Total CO_2 from methane (kg CO_2e): a) enteric fermentation and b) manure management.
- Total CO_2 from nitrous oxide (kg CO_2e) from a) volatilisation, leaching and run-off (from inorganic fertiliser, imported organic manure, grazing management, manure management and organic manure) and b) from vegetation, stubbles and roots (crop N residues).
- Whole farm and enterprise CO_2e emissions (sum of energy use, methane and nitrous oxide)
- Whole farm CO_2e emissions per kg of farm output (kgCO_2e/kg output)
- Product CO2e emissions for meat (total kg CO_2e, kg CO_2e/kg live weight and kg CO_2e/kg dead weight).

Validation of methods used and statistical analysis

This study is based on a field survey to capture flock data from both transhumance and semi-intensive farms in the study site. The face-to-face interviews adhered to the approach described by Fowler (2009). The pro-forma questionnaire used (Supplementary Table S3) during the face-to-face interview was designed to gather the data necessary for the description of farm management practices and for AgRECalc©. Although the AgRECalc© calculator provides printable input sheets (https://www.agrecalc.com), the required data were included in the pro-forma questionnaire used during the face-to-face interview and were then later inputted into the calculator by the authors, in a similar approach to Morgan-Davies et al., 2021). Data were analysed in two sets: a) farm data (from the interviews) and b) GHG emission data (from the AgRECalc© calculator). Farm data information were related to land use (ha), average flock number (heads), number of sold animals (heads), weight at selling (kg), lambing percentage (%), number of dead animals per year (heads), time spent on grazing (%), time spent on shed (%), feed quantity (t), grazing distance (km), water used (t), fuel used (l), energy source (Solar/Main), plastic waste (kg). A total of seven GHG emission estimates were calculated with the AgRECalc tool, namely i) total CO_2 from energy use (kg CO_2e), ii) total CO_2e from methane (kg CO_2e),iii) total CO_2e from nitrous oxide (kg CO_2e), iv) whole farm and enterprise CO_2e emissions (kg CO_2e), v) net emission from land use (kg CO_2e), vi) whole farm CO_2e emissions per kg of farm output (kg CO_2e/kg output), vii) product CO_2e emissions (meat): kg CO_2e / kg live weight, and viii) farm output (kg of sheep). In order to analyse the effect of farm and GHG emission variables on the two different production systems, multivariate analysis techniques (principal component analyses (**PCAs**)) were used within the R software (R Development Core Team, 2005), to identify potential groupings within the farms or to identify the variables with the most effect (Riedel et al., 2007; Morgan-Davies et al., 2012). The following variables were included in the analysis: land use (ha), average flock number (head), number of sold animals (head), weight at selling (kg), lambing percentage (%), number of dead animals per year (head), time spent on grazing (%), time spent being housed (%), feed quantity (t), fuel (l), energy source (solar/mains), plastic waste (kg), grazing distance (km), water used (t), financial output (€), CO_2 from energy use (kg CO_2e), total CO_2e from methane (kg CO_2e), total CO_2e from nitrous oxide (kg CO_2e), net emissions from land use (kg CO_2e), whole farm CO_2e emissions per kg of output (kgCO_2e/kg output), Meat CO_2e emissions (kg CO_2e/kg live weight) and farm output (kg of sheep) were used as raw data for the PCA analyses (Supplementary Material S1). The obtained results were then clustered in biplots. Finally, to identify and quantify associations between the two sets (transhumance and semi-intensive flock) of variables, a canonical correlation (Härdle and Simar, 2015) was carried out on the whole dataset, using R (R Development Core Team, 2005), to identify which variables contribute to the most variance (Supplementary Material S2).

Results

Datasets were collected and analysed for 25 farms in total (10 transhumance and 15 semi-intensive farms). The primary products of all the farms were finished lamb and breeding stock. They were all meat sheep farms with different levels of intensification (Table 1). The farm characteristics, technical indicators and emissions of the two different production systems are presented in Table 1. The transhumance farms ranged in size from 100 to 2 500 ha, with an average flock size between 550 and 1 200 head, while the semi-intensive farms ranged in size from 3 to 500 ha, with an average flock size between 120 and 800 head. Stocking densities were lower in the transhumance farming systems compared to the semi-intensive ones. The lambing rates were slightly higher in transhumance flocks (1.3 %) while weights at selling were found relatively static (Table 1). The mean CO_2 from energy use, methane and nitrous oxide produced in transhumance farms were almost double to that of semi-intensive ones, although whole farm CO_2e emissions per kg of farm output and CO_2e emissions per kg of finished lamb were lower (Table 1).

Transhumance farms

For the transhumance farm data, the first five components in the PCA explained 94 % of the total variance. Grazing time was excluded from the model because all the flocks are grazing year-round. The first principal component (**PC1**) explains 43 % of the variance, with PC2 and PC3 explaining 24 % and 11 % of the variance, respectively. In total, PC1, PC2 and PC3 explain 79 % of the total variance. The variables contributing to the greatest amount of variance in PC1, PC2 and PC3 are presented in Table 2. Fig. 2 shows how the transhumance farms are distributed on the two main component axes, and which farms could be clustered together. For instance, average flock number, number of sold animals, feed quantity and water use data show a clear determinant for forming clusters. Three farms in the sample (TR-5, TR-9 and TR2) contributed strongly to the variation (22, 19 and 19 %, respectively). The PCA results on the transhumance farm emission variables (Table 2) show that the first 2 components explain 82 % of the total variation, with PC1 and PC2 contributing to 61 and 21 %, respectively. The variables contributing to the greatest amount of variance in PC1 and PC2 are presented in Table 2. The variables farm output and meat emissions are clear determinants for forming clusters (Fig. 3). Three farms in the sample (TR-9, TR-5 and TR-8) contributed strongly to the variation (35, 20 and 12 %, respectively).

Semi-intensive farms

For the semi-intensive farms, the first five components in the PCA analysis explained 89 % of the total variance, with the first two components PC1 and PC2 explaining 41 and 17 %, of the total variance, respectively. The contribution of the semi-intensive farm data variables to the components is shown in Table 3. The variables feed quantity, number of animals, number of sold and dead animals are clear determinants for forming clusters (Fig. 4). Three farms in the sample (SI-12, SE-8 and SI-14) contributed strongly to the variation (45, 17 and 8 %, respectively). The PCA results on the emissions from the semi-intensive farms show that the first two components explained 99 % of the total variance, with PC1 and PC2 explaining 68 % and 31 % of the variance, respectively. The contribution of the variables to the components is shown in Table 3. Fig. 5 shows clearly that three farms in the sample (SI-12, SI-4 and SI-14) contributed strongly to the variation (47 %, 26 % and 8 %, respectively).

Canonical correlation

The canonical correlation established which variables contributed to the most variance in the transhumance and semi-intensive farms. The canonical correlation coefficients among the

Table 2
Components (farm data and emission) for the transhumance sheep production system and their respective effects on the total variance.

Farm Data Component Matrix				Emission Component Matrix		
	Component				Component	
Variable	PC1	PC2	PC3	Variable	PC1	PC2
Number of sold animals (head)	0.961	0.233	0.035	Farm output (kg/year)	0.956	−0.021
Feed quantity (t/year)	0.943	0.279	−0.066	Net emission from land use (kgCO_2e)	0.912	0.357
Water used (l/year)	0.797	0.128	0.093	Total CO_2 from nitrous oxide (kgCO_2e)	0.907	0.231
Average flock number (head)	0.755	0.505	−0.29	Meat CO_2e emissions (CO_2e/kg live weight)	−0.76	0.628
Weight at selling (kg)	0.744	−0.52	0.059	Total CO_2e from methane (kg CO_2e)	−0.494	−0.106
				CO_2 from energy use (kg CO_2e)	0.556	0.699

Abbreviations: PC = principal component; CO_2 = Carbon Dioxide; CO_2e = Carbon Dioxide equivalent.

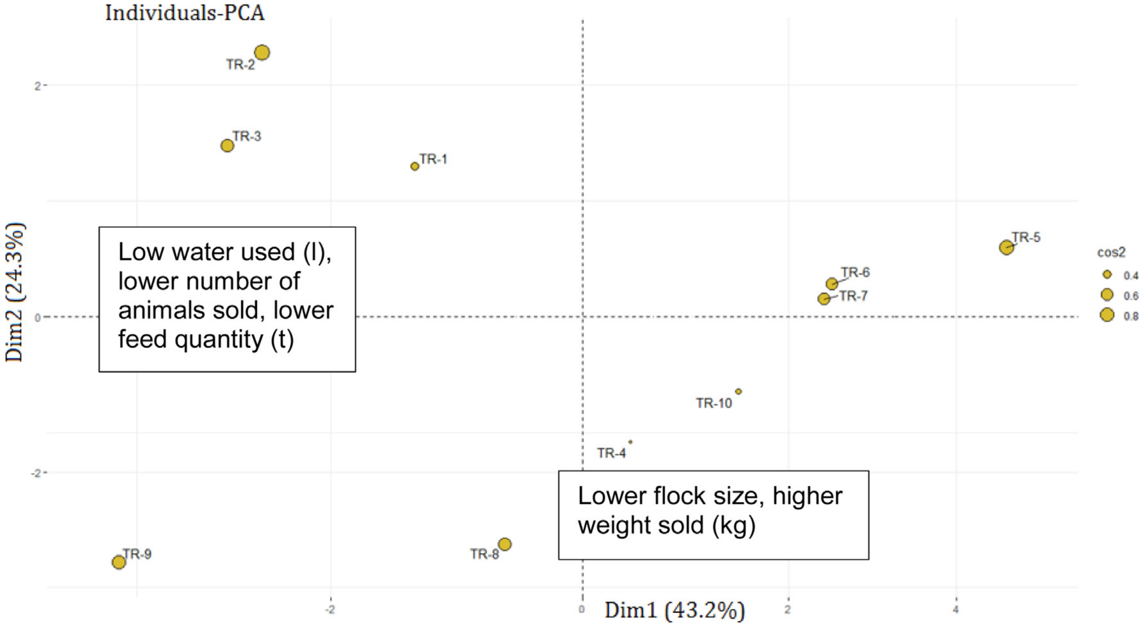


Fig. 2. Distribution of the transhumance sheep farms on the two main component axes for farm data. Abbreviations: PCAs = principal component analyses; Dim1 = dimension 1; Dim2 = dimension 2; TR1 = transhumance farm 1; TR2 = transhumance farm 2 etc.; Cos2 = the importance of a principal component for a given observation.

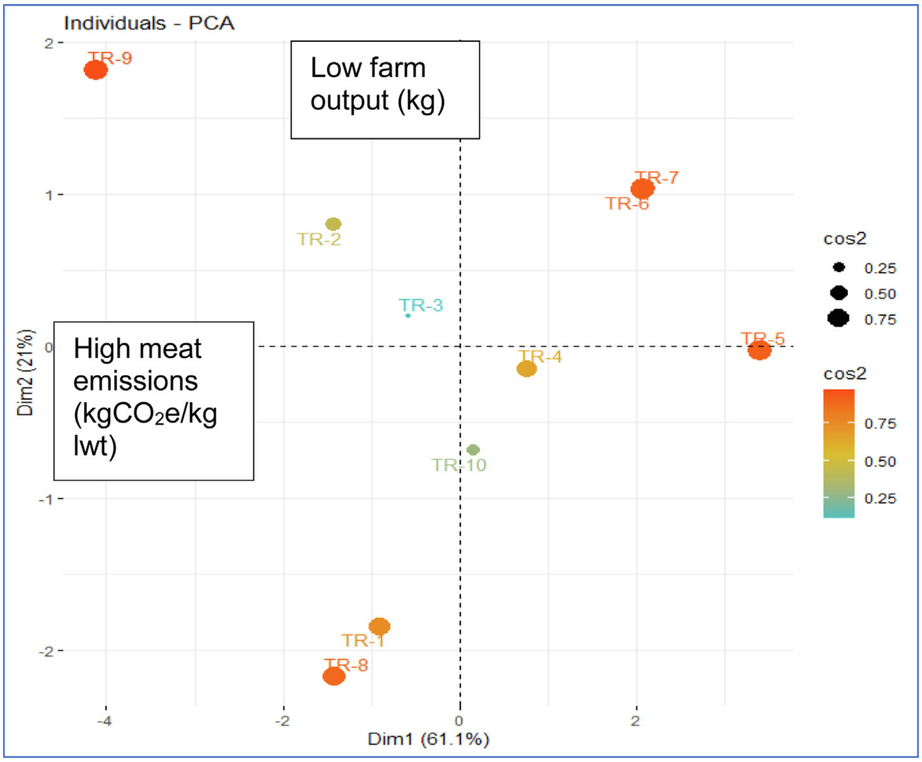


Fig. 3. Distribution of the farms on the two main component axes relating to farm emissions for the transhumance sheep farms. Abbreviations: PCAs = principal component analyses; Dim1 = dimension 1; Dim2 = dimension 2; TR1 = transhumance farm 1; TR2 = transhumance farm 2 etc.; Cos2 = the importance of a principal component for a given observation; lwt = live weight.

effective variable sets for both farming systems are shown in Fig. 6. In the transhumance systems, land use and net emission from land use are correlated. Likewise, the whole farm emissions per kg of output are correlated to the flock size, the number of animals sold, and the time spent being housed. On the other hand, in the semi-intensive systems, there is a correlation between both the amount of CO_2 from energy use and amount of CO_2e from methane, and the flock size, the number of animals sold, time being housed, but also the feed quantity. The total farm output (kg of meat produced) is also correlated with the land use area. Interestingly, for both sys-

Table 3
Components (farm data and emission) for the semi-intensive sheep production system and their respective effects on the total variance.

Farm Data Component Matrix			Emission Component Matrix		
	Component			Component	
Variable	PC1	PC2	Variable	PC1	PC2
Feed quantity(t/year)	0.931	0.011	Net emission from land use(kgCO_2e)	0.999	0.005
Average flock number(head)	0.915	0.077	Total CO_2 from nitrous oxide(kgCO_2e)	0.997	0.049
Water used (l/year)	0.847	−0.014	Total CO_2e from methane (kg CO_2e)	0.995	0.047
Number of sold animals (head)	0.773	−0.457	Total CO_2 from energy use (kg CO_2e)	0.981	−0.072
Number of dead animals (head)	0.661	0.558	Farm output (kg/year)	0.866	−0.461
			Meat CO_2e emissions (kg CO_2e/kg live weight)	0.188	0.981

Abbreviations: PC = principal component; CO_2 = Carbon Dioxide; CO_2e = Carbon Dioxide equivalent;

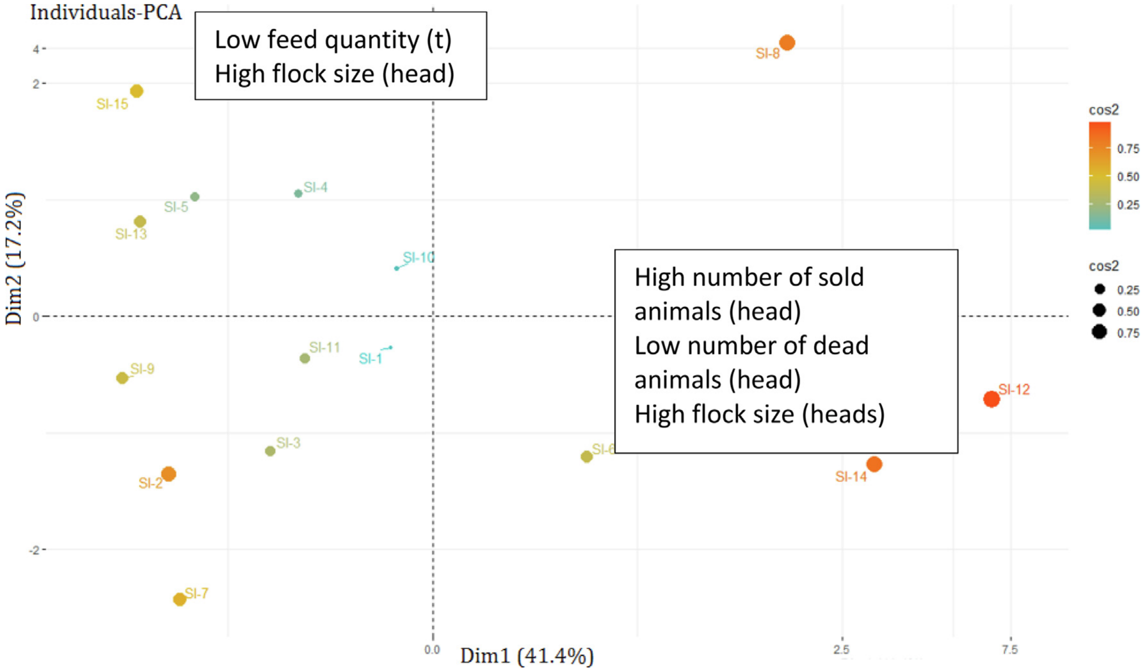


Fig. 4. Distribution of the farms on the coordinate axes for semi-intensive sheep farms. Abbreviations: PCAs = principal component analyses; Dim1 = dimension 1; Dim2 = dimension 2; SI1 = semi-intensive farm 1; SI2 = semi-intensive farm 2, etc.; Cos2 = the importance of a principal component for a given observation.

tems, the grazing distance was correlated to the whole farm CO_2e emission per kg of output, and the emissions from meat production. The water use was also correlated to the farm output, the net emissions from land use and the amount of CO_2e from nitrous oxide.

Discussion

The international scientific community has been studying the impact of livestock production on global warming and GHG emissions for many years. However, when considering sheep production, the diversity of systems and intensity levels makes it complex to pinpoint which element is responsible for the majority of GHG emissions. Feeding regime intensity can be one way to approach this complexity, hence this study's focus on extensive and semi-intensive grazing systems predominant in Turkey.

This paper presented an estimation of the carbon footprint, using the AgRECalc© carbon calculator, for two different common types of farming systems in arid and continental areas, using Turkey as an example.

The transhumance farms in the sample (Table 1) were larger than the semi-intensive farms, both in terms of land use and flock size. The grazing distance was also longer (approx. 10 km/day for transhumance and 1–2 km/day for semi-intensive farms), as expected from the nature of these sheep production systems. The amount of feed purchased per ewe was also higher in the transhumance farms than in the semi-intensive ones, due to the poor-quality grazed vegetation in the transhumance system. Average flock size was found to be almost four times higher in transhumance farms.

In general, variability in farm emissions between farms can be attributed to differences in local conditions such as farming system, breeds, and management strategies. In our study, transhumance farms had significantly lower whole farm CO_2 emissions per kg of farm output (kg CO_2e/kg output) and meat CO_2 emissions (kg CO_2e/kg live weight). Fibre degradation in the rumen is one of the main reasons for CH_4 emission, so the quality and type of feed are important (Sabia et al., 2020). For instance, Sabia et al. (2020) highlighted in dairy sheep systems the trade-offs between low energy inputs (low feed purchased) and meadow hay production (trade-offs between the enteric emissions and sequestration of carbon in pasture), and between enteric fermentation and level of outputs. In the model, CH_4 emissions are calculated from enteric fermentation due to diet, and from manure management. Both semi-intensive and transhumance systems had similar diets (rough grazing pasture and barley or concentrates – with emission factors based on FeedPrint, 2015) but with different levels (the transhumance system relied less on concentrates compared to the semi-

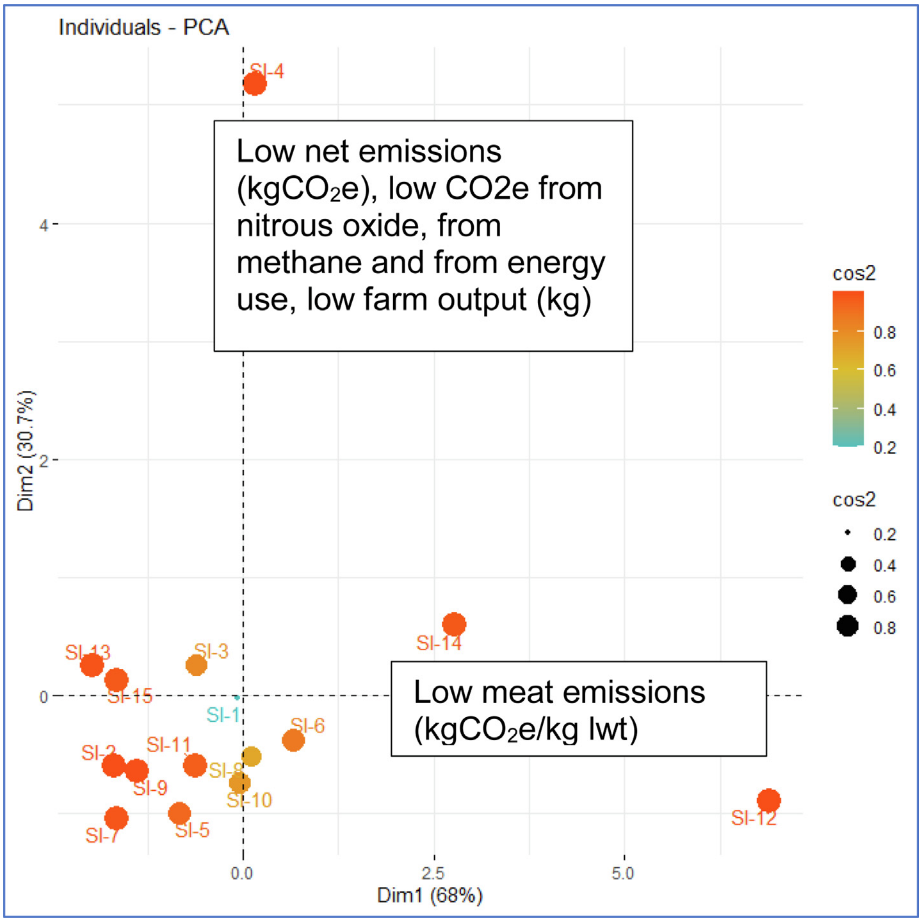


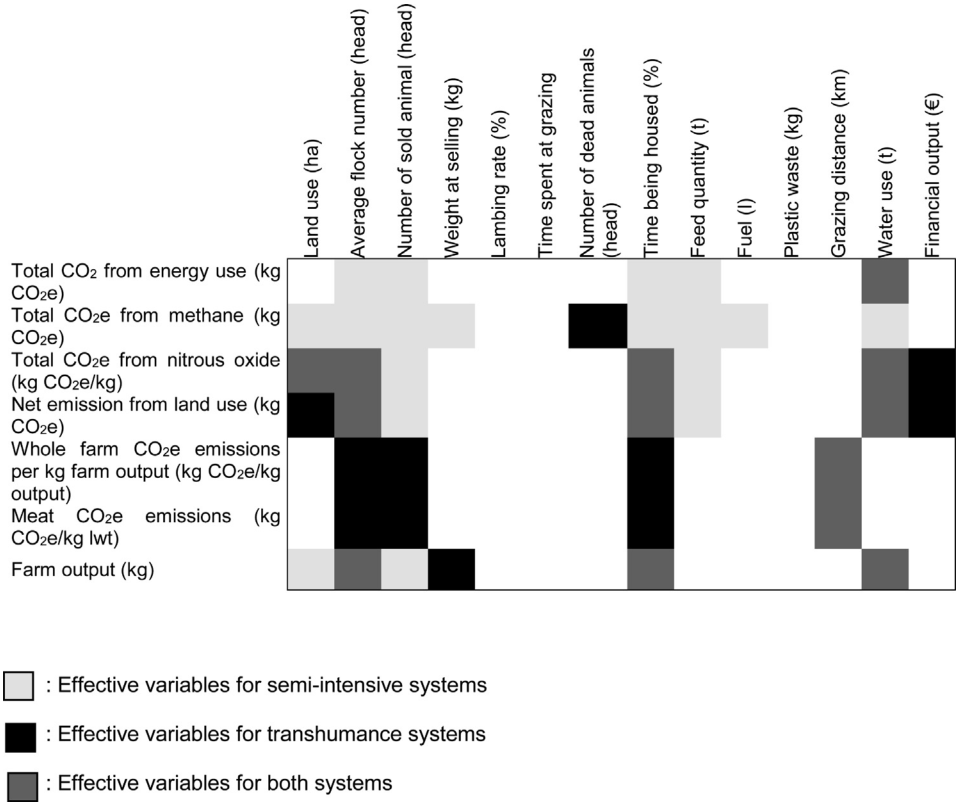
Fig. 5. Distribution of the semi-intensive sheep farms on the coordinate axes for emissions. PCAs = principal component analyses; Dim1 = dimension 1; Dim2 = dimension 2; SI1 = semi-intensive farm 1; SI2 = semi-intensive farm 2, etc.; Cos2 = the importance of a principal component for a given observation; lwt = live weight.

intensive one). This could explain why the transhumance had lower overall emissions per kg of output.

Although some research shows that extensive systems have a greater environmental impact than intensive and semi-intensive systems (Zervas and Tsiplakou, 2012; Kamilaris et al., 2020), in line with other livestock emission studies that found shorter finishing periods can reduce emissions (Casey and Holden, 2006; Cardoso et al., 2016), our results found a lower emission per kg of output produced in transhumance systems. Indeed, the total farm output per ewe was also slightly lower in the transhumance farms (kg/ewe) than in the semi-intensive farms (8 kg/ewe). However, in terms of carbon emissions, the kg CO$_2$e per kg of output was lower for the transhumance farms (46 kg CO$_2$e) than for the semi-intensive ones (57 kg CO$_2$e). This trend is the same when looking at the amount of CO$_2$e per kg of live weight produced (21 kg and 25 kg for the transhumance and the semi-intensive farms, respectively). These levels of carbon emissions per kg of output are similar to those found in other sheep studies. Ripoll-Bosch et al. (2013) in Mediterranean conditions found values between 24 and 26 kg CO$_2$e/kg lamb live weight for pasture-based and mixed grazing sheep systems, respectively. Likewise, a recent study by Morgan-Davies et al. (2021) found values for extensive sheep systems in Northern Europe to be between 16 and 23 kg CO$_2$e/kg live weight, depending on the breeding management system, using AgRECalc©.

Another study by Kamilaris et al. (2020) compared the environmental impact of a range of beef finishing systems as well as the trade-offs generated between mitigating emissions on temperate grassland-based beef systems in Scotland using a bio-economic simulation model (Grange Scottish Beef Model) and the AgRECalc tool. They found that beef production systems with low carbon footprint entail trade-offs between farm profitability and global environmental issues (Kamilaris et al, 2020). Likewise, Cederberg et al. (2009) also identified a greater carbon footprint with CH$_4$ (60–70 % of total CH$_4$) in extensive pasture-based beef systems than in more-intensive grain-based feeding systems.

The difference in emission levels between the transhumance farms and semi-intensive farms in this sample seems to be due to the amount and type of inputs. Indeed, the amount of CO$_2$ from energy use was lower per animal in the transhumance farms, despite their higher reliance on seasonal transport (and thus fuel consumption). This is probably due to their lesser reliance on bought-in feeds and fertilisers. Jones et al. (2014), in their study of lowland, upland and hill sheep farms in the UK, also concluded that concentrates used were one of the most influential variables on carbon footprint in these systems. Interestingly, their amount of CO$_2$e from methane per animal, which is mostly due to enteric fermentation, was also lower than the semi-intensive farms. In AgRECalc©, the calculations of enteric fermentation rely on energy maintenance for the ewes, which in turn vary partly based on animal weight (IPCC, 2006; SRUC, 2014). Although the same local breed is used, size and type (e.g. ram, ewes, lamb) of animals between the two systems can explain partly this difference, as mentioned earlier. Although the total net emission from land use was higher on average for the transhumance farms than for the semi-intensive ones, when calculated on a per hectare basis, the transhumance farms on average had lower emissions than the semi-intensive ones. These results echo findings by Vigan et al. (2017) in the southwestern France, where transhumance systems



	Land use (ha)	Average flock number (head)	Number of sold animal (head)	Weight at selling (kg)	Lambing rate (%)	Time spent at grazing	Number of dead animals (head)	Time being housed (%)	Feed quantity (t)	Fuel (l)	Plastic waste (kg)	Grazing distance (km)	Water use (t)	Financial output (€)
Total CO_2 from energy use (kg CO_2e)		░	░					░	░				▓	
Total CO_2e from methane (kg CO_2e)	░	░	░	░			■	░	░	░			░	
Total CO_2e from nitrous oxide (kg CO_2e/kg)	▓	▓	░					▓	░				▓	■
Net emission from land use (kg CO_2e)	■	▓	░					▓	░				▓	■
Whole farm CO_2e emissions per kg farm output (kg CO_2e/kg output)		■	■					■				▓		
Meat CO_2e emissions (kg CO_2e/kg lwt)		■	■					■				▓		
Farm output (kg)	░	▓	░	■				▓					▓	

░ : Effective variables for semi-intensive systems

■ : Effective variables for transhumance systems

▓ : Effective variables for both systems

Fig. 6. Canonical correlation coefficients for transhumance and semi-intensive sheep farms. CO_2 = Carbon Dioxide; CO_2e = Carbon Dioxide equivalent; lwt = live weight.

were shown to cause low carbon emissions, compared to more sedentary systems.

The transhumance farms were, however, not homogenous, and varied according to their flock size, weight and number of animals sold, as well as the water used (Fig. 2). When looking at their carbon footprint, the transhumance farms also vary according to their amount of CO_2e per kg of meat produced, and their total farm output (Fig. 3).

However, there was some degree of uncertainty in the AgRECalc© tool, as the inputs rely on information on pasture type (land and crop), which in this case, was qualified as 'rough grazing' in the model. That qualification is very wide and may not have reflected entirely the type of transhumance pastures used by the farmers in the sample. Likewise, the energy use was difficult to ascertain in the farms studied, as most of them did not have an electricity meter due to the transient nature of their systems. Additionally, urine deposition while grazing can be a large source of N_2O (López-Aizpún et al., 2020), and Lush et al. (2018) highlighted the uncertainties regarding the estimates of direct N_2O emission levels from urine deposited by livestock, particularly from sheep and extensively grazed systems. AgRECalc does not distinguish between urine and dung deposition and between different sheep systems, which may add another level of uncertainty to the results. Sukhoveeva (2021), in their study using various farms as a case study with four most common carbon calculators, found that AgRECalc did not allow record keeping of features in livestock grazing. Additionally, the AgRECalc© version used in the study did not estimate soil carbon sequestration, a major shortcoming. However, the latest AgRECalc© version now provides a soil carbon sequestration module, and it might be interesting to rerun the data with this new feature (SRUC, 2020).

Nonetheless, the model, although developed for northern Europe conditions, had the capability to be adapted for hotter and more continental conditions, by manipulating some of the coefficients (for instance, the manure management emission factor calculation). Likewise, Sukhoveeva (2021) recognised AgRECalc© as one of the best tools in terms of convenience of use, the possibility of representing the results as GHG flows, record keeping of different aspects, and the range of coverage of technological features in livestock raising. This is promising in terms of real applicability of the model in different contexts.

The canonical analysis also shows that other variables such as financial output are related to CO_2e from nitrous oxide and net emissions. Both analyses identified these variables are important when looking at the overall carbon footprint and should perhaps be prioritised when assessing sheep system emissions. Similarly, the semi-intensive farms in the sample also varied, but, interestingly, it was the amount of feed purchased and the number of dead animals that were strong variables to differentiate them (Fig. 4). This was confirmed through the canonical correlation analysis which showed similar effects. Likewise, in terms of carbon emissions, the amount of net emissions from land use, the emissions from methane, nitrous oxide and energy use (Fig. 5) were all variables explaining the variations between these semi-intensive farms. This shows that any approach to quantify carbon emissions of sheep systems needs to focus on different variables for the different systems. Vigan et al. (2017) also emphasised this need to include specificity of animal grazing in rangelands when evaluating sheep production carbon footprint.

Conclusion

This study identified certain farming elements or characteristics that can explain the main sources of carbon emission in two sheep production systems. The question remains as to how this could be taken forward in terms of policy or management advice. Aguilera et al. (2020) looked at adaptation to climate change for Mediterranean agriculture, including transhumance systems and stressed the need to tailor public policy strategies to each specific local situation. The agricultural policies in Turkey encourage livestock production to become carbon neutral. Indeed, both the state and key agricultural organisations have announced plans and commitments to achieve carbon neutrality. In particular, the Eleventh Development Plan (Anon, 2019) covering the period of 2019–2023 is keen to develop an efficient agricultural sector that is environmentally, socially and economically sustainable.

Small ruminants are prevalent in most Mediterranean countries, mostly in natural grazing and semi-intensive systems, and there is no disagreement among scholars that they may contribute significantly to GHG emissions and climate change. The present research is essential to better understand these contributions. From what has been reported so far, although extensive grazing systems seem more environmentally friendly, scientific findings indicate that ruminant grazing-based systems have a higher impact on GHG emissions per unit of product. Differences in total farm output (kg), net CO_2 from land use ($kgCO_2e$), and total CO_2e from nitrous oxide ($kgCO_2e$) can explain the existing differences in environmental impact on transhumance systems, whereas net CO_2 from land use ($kgCO_2e$), total CO_2e from nitrous oxide ($kgCO_2e$), and total CO_2e from methane (kg CO_2e) were determinants for semi-intensive systems. While in AgRECalc©, the total CO_2e from nitrous oxide is calculated from the excreta (both from mineral fertiliser and animal deposition; Supplementary Table S4), no fertilisers were applied on any of the farms. So, the differences observed are due to the excreta (animal grazing) and time spent grazing or spent inside. Surprisingly, the transhumance system appeared to produce fewer emissions overall than the semi-intensive system, therefore maintaining transhumance is critical for these challenged areas. Focusing on certain aspects of these systems (the ones that seem to drive the emissions and the variations) is perhaps the way of the future, to ensure tailored solutions are adapted to the farming systems and thus enable better acceptance by farmers. Although further validation is required, with wider samples of farms and diverse sheep production systems over a longer period, this study still brings useful insights as to how carbon emissions are related to different production systems, and to diverse interconnected components in these systems, a topic that could be part of a more holistic approach to mitigation opportunities, in line with broader system analyses.

To conclude, this study is the first to use the AgRECalc approach to examine the effect of transhumance and semi-intensive systems in a Mediterranean country and might be used to investigate other production systems in comparable bioregions.

Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.animal.2022.100602.

Ethics approval

Not applicable.

Data and model availability statement

None of the data was deposited in an official repository. Data that support those study findings are available upon request.

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Sezen Ocak Yetişgin: Investigation, conceptualization, resources, data collection, writing-original draft. **Claire Morgan-Davies:** investigation, methodology, resources, writing – review & editing. **Hasan Önder:** formal analysis

Declaration of interest

None.

Acknowledgements

We gratefully acknowledge SAC Consulting and G. Inman for their advice and access to the SAC AgRECalc software and their permission to use any screenshots of the calculator. We also thank all the farmers who accepted to take part in this project.

Financial support statement

This research was financially supported by Ondokuz Mayıs University, Turkey with grant number PYO.ZRT.1901.21.001. SRUC's input to this manuscript was funded by the Global Food Security's 'Resilience of the UK Food System Program', which has support from BBSRC, the Economic and Social Research Council, the Natural Environment Research Council and the Scottish Government.

References

Aguilera, E., Diaz-Gaona, C., Garcia-Laureano, R., Reyez-Palomo, C., Guzman, G.I., Ortolani, L., Sánchez-Rodríguez, M., Rodríguez-Estévez, R., 2020. Agroecology for adaptation to climate change and resource depletion in the Mediterranean region. A review. Agricultural Systems 181, 102809.

Alcock, D.J., Hegarty, R.S., 2011. Potential effects of animal management and genetic improvement on enteric methane emissions, emissions intensity and productivity of sheep enterprises at Cowra, Australia. Animal Feed Science and Technology 166–167, 749–760.

Anonymous, 2019. Eleventh development plan. Retrieved on 21 December 2021 from https://www.sbb.gov.tr/wp-content/uploads/2021/12/Eleventh_Development_Plan_2019-2023.pdf.

Batalla, I., Knudsen, M.T., Mogensen, L., del Hierro, O., Pinto, M., Hermansen, J.E., 2015. Carbon footprint of milk from sheep farming systems in Northern Spain including soil carbon sequestration in grasslands. Journal of Cleaner Production 104, 121–129.

Bell, J., Beaton, C.B., McDowell, M.M., Hill, G.J., Stout, D.S., Sellars, A.S., Thomson, S.G., Spencer, M., Moxey, A.P., 2021. Suckler Beef Climate Change Group - Farm Carbon Case Studies Retrieved on 22 February 2022 from The Scottish Government https://www.gov.scot/binaries/content/documents/govscot/publications/independent-report/2021/01/suckler-beef-climate-scheme-final-report-2/documents/low-carbon-beef-case-study/low-carbon-beef-case-study/govscot%3Adocument/low-carbon-beef-case-study.pdf.

BSI, 2011. PAS 2050:2011 Specification for the Assessment of the Life Cycle Greenhouse Gas Emissions of Goods and Services Retrieved on 19 June 2017 from. British Standards Institute.

Cardoso, A.S., Berndt, A., Leytem, A., Alves, B.J.R., de Carvalho, I. das N.O., de Barros Soares, L.H., Urquiaga, S., Boddey, R.M., 2016. Impact of the intensification of beef production in Brazil on greenhouse gas emissions and land use. Agricultural Systems 143, 86–96. https://doi.org/10.1016/J.AGSY.2015.12.007.

Casey, J.W., Holden, N.M., 2006. Quantification of GHG emissions from sucker-beef production in Ireland. Agricultural Systems 90, 79e98. https://doi.org/10.1016/J.AGSY.2005.11.008.

Cederberg, C., Sonesson, U., Henriksson, M., Sund, V., Davis, J., 2009. Greenhouse Gas Emissions from Swedish Production of Meat, Milk and Eggs: 1990 and 2005. Swedish Institute for Food and Biotechnology, Gothenburg, Sweden.

Chakrabarti, A., 2011. Transhumance, Livelihood and Sustainable Development and Conflict between Formal institution and Communal Governance: An Evaluative Note on East Himalayan State of Sikkim, India. International Proceedings of Economics Development and Research 5, V1-2-V1-7.

Chetri, D.K., Karki, D.B.N., Sah, R., 2011. Transhumance effect on husbandry practices and physiological attributes of chauri (yak-catle) in Rasuwa district. Our Nature 9, 128–137. https://doi.org/10.3126/on.v9i1.5747.

CLA 2009. CALM Carbon Calculator. Country Land and Business Association. Retrieved on 14 October 2014 from http://www.calm.cla.org.uk/index.php?section¼further_reading.

Colley, T.A., Olsen, S.I., Birkved, M., Hauschild, M.Z., 2020. Delta Life Cycle Assessment of Regenerative Agriculture in a Sheep Farming System. Integrated Environmental Assessment and Management 16, 282–290.

DEFRA/DECC, 2013. Greenhouse gas reporting - Conversion factors 2011 - GOV.UK [WWW Document]. Retrieved on 10 April 2022 from https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2011.

Eldesouky, A., Mesias, F.J., Elghannam, A., Escribano, M., 2018. Can extensification compensate livestock greenhouse gas emissions? A study of the carbon footprint in Spanish agroforestry systems. Journal of Cleaner Production 200, 28–38.

FAOSTAT (Food and Agriculture Organization of the United Nations statistical databases) 2018. Homepage. Retrieved on 21 December 2021 from https://www.fao.org/faostat/en/#data/QCL.

FAOSTAT (Food and Agriculture Organization of the United Nations statistical databases) 2019. Homepage. Retrieved on 21 December 2021 from http://www.fao.org/faostat/en/#data/GE.

FeedPrint, 2015. A Tool Quantifying Greenhouse Gas Emissions of Feed Production and Utilization. Wageningen University and Research, Lelystad, Netherlands.

Fowler, 2009. Survey Research Methods, vol 1, 4th Edition. Sage Publications Inc., Thousands Oaks, CA, USA.

Härdle, W.K., Simar, L., 2015. Canonical Correlation Analysis. In Applied Multivariate Statistical Analysis. Springer, Berlin, Heidelberg, Germany https://doi.org/10.1007/978-3-662-45171-7_16.

Hevia, V., Bosch, J., Azcarate, F.M., Fernandez, E., Rodrigo, A., Barril-Graells, H., Gonzalez, J.A., 2016. Bee diversity and abundance in a livestock drove road and its impact on pollination and seed set in adjacent sunflower fields. Agriculture Ecosystems & Environment 232, 336–344. https://doi.org/10.1016/j.agee.2016.08.02.

Hevia, V., Azcarate, F.M., Oteros-Rozas, E., Gonzalez, J.A., 2013. Exploring the role of transhumance drove roads on the conservation of ant diversity in Mediterranean agroecosystems. Biodiversity and Conservation 22, 2567–2581.

Hillier, J., Walter, C., Malin, D., Garcia-Suarez, T., Milai-Canals, L., Smith, P., 2011. A farm-focused calculator for emissions from crop and livestock production. Environmental Modeling and Software 26, 1070e1078. https://doi.org/10.1016/j.envsoft.2011.03.014.

Horrillo, A., Gaspar, P., Escribano, M., 2020. Organic farming as a strategy to reduce carbon footprint in Dehesa agro-ecosystems: a case study comparing different livestock products. Animals 10, 162.

IPCC 2006. IPCC Guidelines for National Greenhouse Gas Inventories. IGES, Japan. Retrieved on 20/12/2021 from http://www.ipcc-nggip.iges.or.jp/public/2006gl/.

Jones, A.K., Jones, D.L., Cross, P., 2014. The carbon footprint of lamb: Sources of variation and opportunities for mitigation. Agricultural Systems 123, 97–107.

Kamilaris, C., Dewhurst, R.J., Sykes, A.J., Alexander, P., 2020. Modelling alternative management scenarios of economic and environmental sustainability of beef finishing systems. Journal of Cleaner Production 253, 119888.

Koc, A., Schacht, W.H., Erkovan, I., 2015. The History and Current Direction of Rangeland Management in Turkey. Rangelands 37, 39–46.

Kool, A., Marinussen, M., Blonk, H., 2012. LCI data for the calculation tool Feedprint for greenhouse gas emissions of feed production and utilization. Wageningen University and Research Centre, Gouda, Netherlands.

Lambe, N.R., Wall, E., Ludemann, C.I., Bünger, L., Conington, J., 2014. Genetic improvement of hill sheep – Impacts on profitability and greenhouse gas emission. Small Ruminant Research 120, 27–34.

López-Aizpún, M., Horrocks, A.C., Charteris, A.F., Marsden, K.A., Ciganda, V.S., Evans, J.R., Chadwick, D.R., Cárdenas, L.M., 2020. Meta-analysis of global livestock urine-derived nitrous oxide emissions from agricultural soils. Global change biology 26, 2002–2013.

Ludemann, C.I., Byrne, T.J., Sise, J.A., Amer, P.R., 2012. Selection indices offer potential for New Zealand sheep farmers to reduce greenhouse gas emissions per unit of product. International Journal of Agricultural Management 1, 29–40.

Lush, L., Wilson, R.P., Holton, M.D., Hopkins, P., Marsden, K.A., Chadwick, D.R., King, A.J., 2018. Classification of sheep urination events using accelerometers to aid improved measurements of livestock contributions to nitrous oxide emissions. Computers and electronics in agriculture 150, 170–177.

MacDonald, D., Crabtree, J.R., Wiesinger, G., Dax, T., Stamou, N., Fleury, P., Gutierrez Lazpita, J., Gibon, A., 2000. Agricultural abandonment in mountain areas of Europe: Environmental consequences and policy response. Journal of Environmental Management 59, 47–69.

Marino, R., Atzori, A.S., D'Andrea, M., Iovane, G., Trabalza-Marinucci, M., Rinaldi, L., 2016. Climate change: Production performance, health issues, greenhouse gas emissions and mitigation strategies in sheep and goat farming. Small Ruminant Research 135, 50–59.

Morgan-Davies, C., Waterhouse, A., Wilson, R., 2012. Characterization of farmers' responses to policy reforms in Scottish hill farming areas. Small Ruminant Research 102, 96–107.

Morgan-Davies, C., Kyle, J., Boman, I.A., Wishart, H., McLaren, A., Fair, S., Creighton, P., 2021. A comparison of farm labour, profitability, and carbon footprint of different management strategies in Northern European grassland sheep systems. Agricultural Systems 191, 103155.

Morris, S.T., 2017. Overview of sheep production systems. In: Ferguson, D.M., Lee, C., Fisher, A. (Eds.), Advances in Sheep Welfare. Woodhead Publishing Series in Food Science, Technology and Nutrition, Kidlington, UK, pp. 19–33.

Namgay, K., Millar, J., Black, R., Samdup, T., 2013. Transhumant agro-pastoralism in Bhutan: Exploring contemporary practices and socio-cultural traditions. Pastoralism: Research, Policy and Practice 3, 13.

Ocak, S., 2016. Transhumance in Central Anatolia: A resilient interdependence between biological and cultural diversity. Journal of Agricultural Environmental Ethics 29, 439–453. https://doi.org/10.1007/s10806-016-9613-z.

Olea, P.P., Mateo-Tomas, P., 2009. The role of traditional farming practices in ecosystem conservation: the case of transhumance and vultures. Biological Conservation 142, 1844–1853.

Oteros-Rozas, E., Martin-Lopez, B., Gonzalez, J.A., Plieninger, T., Lopez, C.A., Montes, C., 2014. Socio-cultural valuation of ecosystem services in a transhumance social-ecological network. Regional Environmental Change 14, 1269–1289. https://doi.org/10.1007/s10113-013-0571-y.

Perez, M.R., Saez, A.V., 1990. Transhumance with cows as a rational land-use option in the Gredos Mountains (central Spain). Human Ecology 18, 187–202.

R Development Core Team, 2005. R: a language and environment for statistical computing [www.R-project.org]. R Foundation for Statistical Computing, Vienna, Austria.

Riedel, J.L., Casasús, I., Bernués, A., 2007. Sheep farming intensification and utilization of natural resources in a Mediterranean pastoral agro-ecosystem. Livestock Science 111, 153–163.

Ripoll-Bosch, R., de Boer, I.J.M., Bernues, A., Vellinga, T.V., 2013. Accounting for multi-functionality of sheep farming in the carbon footprint of lamb: A comparison of three contrasting Mediterranean systems. Agricultural Systems 116, 60–68.

Ruiz, M., Ruiz, J.P., 1986. Ecological history of transhumance in Spain. Biological Conservation 37, 73–86.

Sabia, E., Gauly, M., Napolitano, F., Serrapicac, F., Cifuni, G.F., Claps, S., 2020. Dairy sheep carbon footprint and ReCiPe end-point study. Small Ruminant Research 185, 106085.

Sayar, M.S., Han, Y.H., Başbag, M., Gül, I., 2015. Rangeland improvement and management studies in the South-eastern Anatolia region of Turkey. Pakistan Journal of Agricultural Science 52, 9–18.

Seydoşoğlu, S., 2018. Vegetation characteristics, rangeland status and health determination of some natural rangelands. Turkish Journal of Forestry 19, 368–373.

Sruc, 2014. AgRE Calc Retrieved on 21.06.2021 from www.sruc.ac.uk/info/120355/carbon_and_climate/1333/agricultural_resource_efficiency_calculator_agre_calc, .

Sruc, 2020. New soil sequestration module to reduce carbon footprint Retrieved on 24.05.2022 from https://www.sruc.ac.uk/all-news/new-soil-sequestration-module-to-reduce-carbon-footprint/, .

Starrs, P.F., 2018. Transhumance as Antidote for Modern Sedentary Stock Raising. Rangeland Ecology and Management 71, 592–602.

Sukhoveeva, O.E., 2021. Carbon Calculators as a Tool for Assessing Greenhouse Gas Emissions from Livestock. Doklady Earth Sciences 497, 266–271. https://doi.org/10.1134/S1028334X21030119.

Sykes, A.J., Topp, C.F.E., Wilson, R.M., Reid, G., Rees, R.M., 2017. A comparison of farm-level greenhouse gas calculators in their application on beef production systems. Journal of Cleaner Production 164, 398–409.

TGHGI, 2021.Turkish Greenhouse Gas Inventor. National Inventory Report for submission under the United Nations Framework Convention on Climate Change. Retrieved on 18.04.2022 from https://unfccc.int/documents/271544.

TSM, 2017. Turkish State Meteorological Service. Retrieved on 18.09.2021 from https://www.mgm.gov.tr/eng/forecast-cities.aspx?m=DIYARBAKIR.

TUIK, 2019. Turkish Statistical Institute. Retrieved on 20 May 2021 from http://www.turkstat.gov.tr/UstMenu.do?metod=temelist.

TUIK, 2021. Turkish Statistical Institute. Retrieved on 21 December 2021 from https://data.tuik.gov.tr/Bulten/Index?p=37196&dil=2.

Vagnoni, E., Franca, A., 2018. Transition among different production systems in a Sardinian dairy sheep farm: Environmental implications. Small Ruminant Research 159, 62–68.

Vellinga, T.V., Blonk, H., Marinussen, M., Van Zeist, W.J., Starmans, D.A.J., 2013. Methodology used in feedprint: a tool quantifying greenhouse gas emissions of feed production and utilization. Wageningen University and Research, Lelystad, Netherlands.

Vigan, A., Lasseur, J., Benoit, M., Mouillot, F., Eugene, M., Mansard, L., Vigne, V., Lecomte, P., Dutilly, C., 2017. Evaluating livestock mobility as a strategy for climate change mitigation: Combining models to address the specificities of pastoral system. Agriculture, Ecosystems and Environment 242, 89–101.

Zervas, G., Tsiplakou, E., 2012. An assessment of GHG emissions from small ruminants in comparison with GHG emissions from large ruminants and monogastric livestock. Atmospheric Environment 49, 13–23.