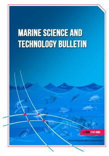
Mar. Sci. Tech. Bull. (2022) 11(4): 475-492
e–ISSN: 2147–9666
info@masteb.com

dergipark.org.tr/en/pub/masteb
www.masteb.com
DOI: 10.33714/masteb.1178141



Marine Science and Technology Bulletin

PRENSIP
https://prensip.gen.tr/

RESEARCH ARTICLE

Sustainability of Karacaören-I Dam Lake rainbow trout cage farming (Türkiye) in terms of cultural energy and carbon footprint expended on compound diet and transportation

Gürkan Diken[1,2*]

[1] *Isparta University of Applied Sciences, Faculty of Eğirdir Fisheries, Isparta 32260, Türkiye*
[2] *Isparta University of Applied Sciences, Fisheries Application, and Research Center (SURAM), Isparta 32260, Türkiye*

ARTICLE INFO

Article History:
Received: 21.09.2022
Received in revised form: 13.11.2022
Accepted: 16.11.2022
Available online: 22.12.2022

Keywords:
Carbon footprint
Cultural energy
Compound diet
Rainbow trout
Sustainability
Transportation

ABSTRACT

The purpose of this study was to assess the consumed compound diet and juvenile fish, harvested fish, and compound diet transport of Karacaören Dam Lake-I rainbow trout cage farming (KRTC) in terms of cultural energy (CE) and carbon footprint (CF) expended sustainability. Data was collected through face-to-face interviews with the farmers. Cultural energy and carbon footprint were calculated with the data obtained from the literature. The lowest and highest FCRs in KRTC were 0.91 and 1.18, the closest and farthest distances related to transportation were 387 and 427 km for aquafeed factories, 7 and 650 km for hatcheries, and 67 and 450 km for processing factories. Cultural energy and carbon footprint expended on consumed compound diet (CECD-Gcal and Mcal kg^{-1}, and CFCD-tonne CO$_2$*e* and kg CO$_2$*e* kg^{-1}) and cultural energy and carbon footprint expended on transportation analyzes (CET-Gcal and Mcal kg^{-1}, and CFT-tonne CO$_2$*e* and kg CO$_2$*e* kg^{-1}) were performed according to the literature of 20-40 g fish stocked in the beginning of November 2020 and 270-500 g harvested until early June 2021 in the basin. In the access of sustainability, the CE (Mcal kg^{-1}) and CF (CO$_2$*e* kg^{-1}) expended values in kg of the harvested fish were given. The average values of CE expended of 5 different aquafeed groups used in the basin were 3.65, 3.58, 3.41, 3.25, and 3.55 Mcal kg^{-1}, respectively and the average values of CF expended were 1.05, 1.03, 1.14, 1.40, and 1.10 kg CO$_2$*e* kg^{-1}, respectively. The average share of CE and CF in the compound diet was 86.59% and 86.61%, respectively. The KRTC sustainability criterion for compound diet and transportation values was 2.9260 CE:CF. It is recommended to develop a sustainability index of aquaculture systems and species-specific CE and CF expended values.

Please cite this paper as follows:

Diken, G. (2022). Sustainability of Karacaören-I Dam Lake rainbow trout cage farming (Türkiye) in terms of cultural energy and carbon footprint expended on compound diet and transportation. *Marine Science and Technology Bulletin*, *11*(4), 475-492. https://doi.org/10.33714/masteb.1178141

---

[*] Corresponding author
E-mail address: gurkandiken@isparta.edu.tr (G. Diken)

Introduction

The aquaculture studies of countries with a high share in world food production are a reference in the species-based evaluation of sustainability against global climate change. Freshwater aquaculture meets 77% of the world's edible aquaculture production, excluding aquatic plants. Freshwater aquaculture has provided 80% of the finned finfish production with external feed support since 2000 (Zhang et al., 2022). Türkiye is an innovative country with a strong sectorial direction in intensive finfish aquaculture on a world scale. Türkiye, which is the leading country among European and Mediterranean countries in portioned rainbow trout farming was the world leader until 2012, but after this year it left the world leadership to Iran. In 2019, 22.48% of the world rainbow trout production shares were provided by Iran and 13.43% by Türkiye (FAO, 2022). Rainbow trout farming in Türkiye's inland waters increased regularly from 42,572 tonnes in 2000 to 135,732 tonnes in 2021 (GDFA, 2022).

The length of the coastline is 8,333 km, with an area of 8,903 km^2 nearly 200 natural lakes, approximately 177,714 km of rivers, 342,377 hectares of dam lakes, 70,000 hectares of lagoon lakes, Türkiye has a total aquaculture production capacity of 25,577,200 hectares (Demir & Sevinç, 2020; Arslan & Oguzhan Yıldız, 2021). Karacaören-I Dam Lake, which is located within the borders of Isparta and Budur provinces of Türkiye's Lakes Region Basin, was built on the Aksu stream for irrigation, flood control, and electricity generation. The dam is 93.00 m high from the stream bed and has a normal water code of 270 m, and the reservoir volume and area at normal water level are 1234 hm^3 and 45.50 km^2, respectively (Becer Ozvarol & İkiz, 2009) (Figure 1).

In terms of the stability of the world and examining the extent of that stability, the true cost of resource consumption and environmental degradation will help us determine the energy value of the production system (Henriksson et al., 2010). In aquaculture, species, feeding habits, and aquaculture systems cause differences in energy use, making it difficult to establish basic rules for determining energy use efficiency (Pelletier et al., 2011). Along with the food systems, the fishery and aquaculture sector is also associated with the source of greenhouse gases that cause global climate change, which is dependent on the energy use of non-renewable fossil fuels (Pelletier et al., 2011; Muir, 2015; Boyd et al., 2019). However, the energy use of aquaculture in the fossil fuel-based global food system is around 1%. As a cross-sectoral approach, the energy efficiency of farmed fish, calculated as energy input per protein-energy output, is better than the production of livestock (Hargreaves et al., 2019). It is important to evaluate the resources and practices of the fisheries sector, to determine the sustainability of energy use and to determine resource dependence (Muir, 2015).

In the agrifood chain, our direct or indirect energy needs and the purpose of using it reveal whether it can meet food security and sustainably support development goals (FAO, 2012). Cultural energy (CE) and carbon footprint (CF) studies in aquaculture can be considered as a concept that offers important approaches to sustainability (Diken et al., 2021, 2022; Diken & Koknaroglu, 2022). The carbon footprint in food production is expressed as the total kg of CO_2*equivalent* (*e*) emitted per kg of an edible product obtained within the scope of all activities. The calculation is based on estimations of the emission amounts for each input during the product life cycle (Lutz, 2021). CE or embodied energy results of aquaculture are fossil-based non-renewable energy values that include calculations of energy values other than solar sources (Kurnia et al., 2019). Agrifood production, which currently relies heavily on fossil fuels, needs energy at every step to meet the growing demand for food. Improving access to energy, using energy more efficiently, and increasing the use of renewable energy sources will be beneficial to energy input and thus increase efficiency (FAO, 2012). A global-scale aquaculture feed factory is turning to low-emission feed production in its feed production planning without sacrificing quality and feed production to contribute to the sustainability of the aquaculture industry (Hatchery Feed & Management, 2021). At the same time, within the scope of reducing the CF values caused by the transport of the produced feed to the farm, private feed facility investments belonging to the farm have also been started (Hatchery International, 2021).

The energy expenditure share of feed in intensive cage farming was 79 and 78% for salmon and grouper/bass, respectively (Flos & Reig, 2017). CE and CF expended consumed compound diet share of Turkish rainbow trout cage farming was close to 80% and 75%, respectively (Diken et al., 2021, 2022). In this study, the status of sustainable aquaculture in Karacaören-I Dam Lake which is one of the important inland aquaculture areas of Türkiye was determined by calculating the CE and CF budget of compound diet, and compound diet and fish transportation of rainbow trout cage farming in Karacaören-I Dam Lake.

Material and Methods

Rainbow Trout Cage Farming Management

This study is based on the data of 22 cage farms rearing rainbow trout in Karacaören-I Dam Lake within the borders of Isparta and Burdur provinces in Türkiye's Mediterranean Region Lakes Region (Figures 1, 2). Data was collected through

Table 1. Karacaören-I Dam Lake rainbow trout cage farming management*

Cage		**Juvenil initial**		**Harvested fish**		**Diet (kg)**									**Transportation (km)**		
Code	***Technical***	***AW (g)***	***Σ (kg)***	***AW (g)***	***Σ (kg)***	***Code***	***1.9 mm***	***3 mm***	***4 mm***	***4.5 mm***	***5 mm***	***6 mm***	***Σ***	***FCR***	***Aquafeed***	***Hatchery***	***Processing factory***
1	Offshore (8 pieces; ø=20 m, h=15 m)	23	31.050	300	400.950	A		28.000	52.000		108.000	161.188	349.188	1.18	315	7	100.5
						C		3.500	6.500		13.500	20.149	43.649		417		
						E	3.500	6.500		13.500		20.149	43.649		413		
						Σ	3.500	38.000	58.500	13.500	121.500	201.485	349.188				
2	Offshore (20 pieces; ø=12 m, h=6 m, and 15 pieces; ø=16 m, h=7 m)	40	16.560	500	205.000	A		7.000	55.000		68.000	75.000	205.000	1.09	380	7	380 75
3	Octagonal (15 pieces; l=4.6 m, 10.5 h=6 m)	20	2.560	270	33.250	A		2.000	6.000		10.000	14.000	32.000	1.04	380	9	380
4	Offshore	28	5.600	250	49.000	D		5.000	10.000		15.000	20.000	50.000	1.15	427	98	442
5	Square & octagonal (25 pieces; l=5 m, h=4 m & 3 pieces; l=6.4 m, h=6 m)	20	2.400	300	35.000	C		3.000	9.000		10.000	11.000	33.000	1.01	417	45	75
6	Offshore (10 pieces; ø=12 m, h=6 m)	25	4.125	300	48.000	B		4.250	8.500		16.000	19.500	48.250	1.10	315	7	120
7	Offshore (10 pieces; ø=12 m, h=6 m)	25	4.250	300	49.000	B		4.250	8.500		16.500	20.000	49.250	1.10	315	7	120
8	Offshore (12 pieces; ø=12 m, h=7 m)	25	4.000	300	45.000	B		4.000	8.000		15.000	18.000	45.000	1.10	315	7	120
9	Offshore (1 piece; ø=20 m, h=9 m)	23	4.510	253	49.092	A		3.200	7.200		15.200	20.600	46.200	1.18	315	7	100.5
						C		400	900		1.900	2.575	5.775		417		
						E	400	900		1.900		2.575	5.775		413		
						Σ	400	4.500	8.100	1.900	17.100	25.750	57.750				
10	Square & octagonal (10 pieces; l=5 m, h=4 m & 3 pieces; l=6.4 m, h=6 m)	20	1.700	300	25.050	C		2.000	6.500		7.000	8.000	23.500	1.01	417	45	75
11	Octagonal (4 pieces; l=6.4 m, h=6 m)	20	2.000	260	30.000	B		2.000	6.000		10.000	14.500	32.500	1.16	315	7	120
12	Offshore (24 pieces; ø=16 m, h=5 m)	25	10.000	320	120.000	E	40.000	60.000			20.000		120.000	1.09	408	230	72

Table 1 (continued)

Cage		Juvenil Initial		Harvested Fish		Diet (kg)									Transportation (km)		
Code	***Technical***	***AW (g)***	***Σ (kg)***	***AW (g)***	***Σ (kg)***	***Code***	***1.9 mm***	***3 mm***	***4 mm***	***4.5 mm***	***5 mm***	***6 mm***	***Σ***	***FCR***	***Aquafeed***	***Hatchery***	***Processing factory***
13	Offshore (25 pieces; ø=20 m, h=7 or 9 m)	20	30.000	350	500.000	D		20.000	120.000		200.000	160.000	500.000	1.06	401	40	67
14	Offshore (14 pieces; ø=20 m, h=9 m and 10 pieces; ø=24 m, h=9 m & 5 pieces; ø=30 m, h=9 m)	23	31.050	300	400.950	A		28.000	52.000		108.000	161.188	349.188		315		
						C		3.500	6.500		13.500	20.149	43.649	1.18	417	7	100.5
						E	3.500	6.500		13.500		20.149	43.649		413		
						Σ	3.500	38.000	58.500	13.500	121.500	201.485	436.485				
15	Offshore (20 pieces; ø=20 m, h=7 or 9 m)	20	36.000	330	450.000	D		20.000	80.000		150.000	200.000	450.000	1.09	401	40	67
16	Offshore (12 pieces; ø=16 m, h=6 m)	35	35.000	400	346.000	D		55.000	100.000		150.000	22.000	327.000	1.05	402	650	69
17	Offshore & octagonal (16 pieces; ø=16 m, h=6 m & 7 pieces; l=6.4 m, h=7 m)	20	12.000	330	170.000	D		5.000	20.000		100.000	45.000	170.000	1.08	401	40	450
18	Offshore (9 pieces; ø=12 m, h=5 m, and 5 pieces; ø=16 m, h=7 m)	27	9.600	300	75.388	A		2.400	38.000		24.100		64.500	0.98	391	58	166
19	Offshore (4 pieces; ø=16 m, h=6 m)	35	14.000	400	95.000	D		14.000	25.000		40.000	6.000	85.000	1.05	402	650	69
20	Offshore (5 pieces; ø=16 m, h=7)	20	2.000	400	25.000	D		4.000	8.000		6.000	7.000	25.000	1.09	401	40	68
21	Offshore (5 pieces; ø=16 m, h=7)	20	2.000	400	25.000	D		4.000	8.000		6.000	7.000	25.000	1.09	402	41	68
22	Octagonal (5 pieces; l=6.4 m, h=4 or 5 m)	20	2.000	258	25.000	B		1.000	5.000		5.000	10.000	21.000	0.91	315	7	76
TOTAL & Average			262.405		3,201.680		47.400	299.400	646.600	28.900	1,128.700	1,085.720	3,236.720	1.08	387.0	93.1	150.3

Note: *Total annual project capacities were 3,840 tonnes (Anonymous, 2021).

face-to-face interviews with the farmers. Rainbow trout juveniles stocked in Karacaören-I Dam Lake as 20-40 g in early November 2020 were harvested 270-500 g until early June 2021 with a mortality rate varying between 1-10% (Table 1). The cage farms used 5 different aquafeed groups (CD/A, CD/B, CD/C, CD/D, CD/E). A compound diet with 6 diameters of 1.9 mm (D1), 3 mm (D2), 4 mm (D3), 4.5 mm (D4), 5 mm (D5), and 6 mm (D6) was used in these 5 different aquafeed groups. The order of the lowest and highest chemical compositions of 5 different aquafeed groups were like that 44-51 CP (crude protein), 17-22 CF (crude fat), 6.1-10.6 CA (crude ash), 0.9-2.4 CF (crude fibre) for D1 and D2, 38.7-45 CP, 20-25.2 CF, 6.8-11 CA, 1.7-2.7 CF for D3 and D4, 44-45 CP, 20-21 CF, 8.6-11 CA, 1.7-2.4 CF for D5, and 37-45 CP, 20-25.3 CF, 9.5-11 CA, 0.9-2.8 CF for D6. The feed ingredients used in diets generally vary as fish meal, poultry meal, blood meal, krill meal, hydrolysed feather protein, fish oil, soybean oil, soybean meal, soybean concentrated, wheat, wheat flour/middlings, wheat gluten, corn gluten/protein, sunflower meal, sunflower cake, guar protein, yeast extract, vitamins, and minerals. Each diet has different feed ingredients content.

Cultural Energy (CE, Mcal kg^{-1}) and Carbon Footprint (CF, kg CO$_2$e kg^{-1}) Expended Analyses

The CE and CF values of the compound diets were determined by the method given by Diken & Koknaroglu (2022) and Diken et al. (2022) (Feedipedia, 2002; IAFFD, 2020).

Based on the chemical analysis of the compound diets and the feed ingredients content, the CE values of the compound diets (Mcal kg^{-1}) were determined by multiplying the unit values of feed ingredients (Mcal kg^{-1}) with the usage percent rate of the feed ingredients (Tables 2, 3). It was calculated by multiplying the total consumed compound diet amount (Table 1) by the unit values of the feeds (Tables 2, 3), and the cultural

Figure 1. Karacaören-I Dam Lake (Türkiye) (Google Earth, 2022)

Figure 2. Karacaören-I Dam Lake rainbow trout cage farms

energy expended on consumed compound diet (CECD) values are given in Table 4, and the carbon footprint expended on a consumed compound diet (CFCD) values are given in Table 5. CE and CF expended calculations for the transport of compound diet, juvenile and harvested fish (cultural energy expended on transportation-CET, carbon footprint expended on transportation-CFT) were calculated by multiplying the distance and amount given in Table 1 by the unit values in Tables 2 and 3, and the results are given in Tables 6 and 7. The sustainability management of KRTC according to CECD, CFCD, CET, and CFT is given in Table 8.

Results and Discussion

Karacaören Dam Lake-I Rainbow Trout Cage Farming

In the production period of 2020-2021, 22 Karacaören Dam Lake-I rainbow trout cage farms (KRTC) produced 83.31% of their total annual project capacity (Table 1; Figures 1, 2). While the annual project capacity of inland water species was 215,022 tonnes and the production of inland aquaculture species was 136,042, 135,732 tonnes of this amount was met from trout production (GDFA, 2022). KRTC is the basin where production is above the average of Türkiye.

Table 2. Cultural energy values for input and output of compound diet and transportation of Karacaören-I Dam Lake rainbow trout cage farming

Items	**Unit**	**Mcal unit^{-1}**	**References**
CE expended on consumed compound diet			
Feed ingredients			
fish oil	kg	2.38	Chatvijitkul et al. (2017) & Davulis et al. (1977)
soybean oil	kg	2.24	Chatvijitkul et al. (2017) & Smith et al. (2007)
fish meal, anchovy	kg	4.45	Chatvijitkul et al. (2017) & Davulis et al. (1977)
krill meal	kg	17.95	Ecoinvent v3
blood meal	kg	5.45	Ecoinvent v3
poultry meal	kg	2.32	Chatvijitkul et al. (2017) & Davulis et al. (1977)
hydrolysed feather protein	kg	0.05	Ecoinvent v3
corn gluten/protein	kg	2.98	Chatvijitkul et al. (2017)
soybean meal	kg	0.93	Chatvijitkul et al. (2017) & Smith et al. (2007)
soybean concentrated	kg	5.43	Ecoinvent v3
sunflower meal	kg	0.68	Ecoinvent v3
sunflower cake*	kg	0.68	Ecoinvent v3
wheat	kg	0.95	Chatvijitkul et al. (2017) & Davulis et al. (1977)
wheat flour/middlings	kg	1.84	Chatvijitkul et al. (2017)
wheat gluten	kg	2.98	Chatvijitkul et al. (2017)
guar protein**	kg	0.93	Chatvijitkul et al. (2017)
yeast, extract	kg	28.32	Ecoinvent v3
vitamins	kg	0.09	Chatvijitkul et al. (2017)
minerals	kg	0.09	Chatvijitkul et al. (2017)
pellets production	kg	0.51	Hognes et al. (2011)

***CE expended* (Mcal kg^{-1})**

Aquafeed	***1.9mm***	***3mm***	***4mm***	***4.5mm***	***5mm***	***6mm***	***Mean ± SD***
A		3.76	3.61		3.61	3.61	3.65 ± 0.08
B		3.60	3.57		3.57	3.57	3.58 ± 0.01
C		3.38	3.29		3.29	3.67	3.41 ± 0.18
D		3.34	3.22		3.34	3.11	3.25 ± 0.11
E	5.40	2.78		3.23		2.77	3.55 ± 1.25

CE expended on transportation

Items	**Unit**	**Mcal unit^{-1}**	**References**
Truck	km.kg	0.00083	Pimentel (1980)

Note: CE = cultural energy. * Since sunflower meal and cake are derived from the same process, sunflower meal data is a very good approximation to sunflower cake data. ** Since guar is a typical Indian crop, the values of soybean meal have been used.

Table 3. Carbon footprint (kg CO_2e) values for input and output of compound diet and transportation of Karacaören-I Dam Lake rainbow trout cage farming

Items	Unit	kg CO_2e unit^{-1}	References
CF expended on consumed compound diet			
Feed ingredients			
fish oil	kg	0.99	Hognes et al. (2011)
soybean oil	kg	2.024	Schmidt (2015)
fish meal, anchovy	kg	0.99	Hognes et al. (2011)
krill meal	kg	5.4	Parker & Tyedmers (2012)
blood meal	kg	2.45	Ecoinvent v3
poultry meal	kg	3.14	Hognes et al. (2011)
hydrolysed feather protein	kg	0.0244	Ecoinvent v3
corn gluten/protein	kg	1.061	O'Brien et al. (2014)
soybean meal	kg	0.541	Moe et al. (2014)
soybean concentrated	kg	3.20	Hognes e al. (2011)
sunflower meal	kg	0.468	Ecoinvent v3
sunflower cake*	kg	0.468	Ecoinvent v3
wheat, Chile	kg	0.425	Vellinga et al. (2013)
wheat flour/middlings	kg	0.913	Ecoinvent v3
wheat gluten	kg	2.08	Hognes et al. (2011)
guar protein**	kg	0.164	Ecoinvent v3
yeast, extract	kg	5.91	Ecoinvent v3
vitamins	kg	1.62	Rotz et al. (2019)
minerals	kg	1.62	Rotz et al. (2019)
pellets production	kg	0.13	Hognes et al. (2011)

***CF expended* (kg CO_2e kg^{-1})**

Aquafeed	*1.9mm*	*3mm*	*4mm*	*4.5mm*	*5mm*	*6mm*	*Mean ± SD*
A		1.07	1.05		1.05	1.05	1.05 ± 0.01
B		1.03	1.03		1.03	1.03	1.03 ± 0.00
C		1.14	1.12		1.12	1.19	1.14 ± 0.03
D		1.41	1.39		1.40	1.38	1.40 ± 0.01
E	1.47	0.89		1.08		0.96	1.10 ± 0.26

CF expended on transportation

Items	Unit	kg CO_2e unit^{-1}	References
	km.tonnes	0.236, 0.468, 0.722	Robertson et al. (2015)

Note: CF = carbon foot print. *Since sunflower meal and cake are derived from the same process, sunflower meal data is a very good approximation to sunflower cake data. ** Since guar is a typical Indian crop, the values of Indian soybean meal have been used.

A total of 3,236,720 tonnes of compound diets were used from 5 different aquafeed factories in KRTC. The shortest distance between cage farms to aquafeed factories is 315 km, the longest distance is 427 km, and the average distance is 387 km (Table 1). KRTC FCR values were the lowest at 0.91, the highest at 1.18, and the average at 1.08. The companies numbered 1, 9, and 14 from the cage farms have used 3 different aquafeed factories (Table 1). Fifteen KRTC juvenile fish needs were met from hatcheries established on the Göksu Stream flowing into the Karacaören Dam Lake. While the average distance of the hatcheries to the KRTC basin is 93.1 km, the distance of the hatchery with the longest distance to the cage farm is 650 km (Table 1). The distance between the processing factories to the cage farms is 150.3 km on average, with the shortest at 67 km and the longest at 450 km. Cage farm 2 sent the harvested fish in half and half to 2 different processing factories (Table 1).

The management strategies were similar due to the kinship of the cage farms because some different cage farms were owned by the same person or company (Table 1).

Table 4. Cultural energy expended on consumed compound diet (CECD) of Karacaören-I Dam Lake rainbow trout cage farming

Code		**Total cultural energy expended on consumed compound diet (Gcal)**							🐟
Farm	***Aquafeed***	***1.9mm***	***3mm***	***4mm***	***4.5mm***	***5mm***	***6mm***	**Σ**	
1	A		105.29	187.54		389.51	581.34	1,263.69	3.4163
	C		11.83	21.41		44.46	73.85	151.55	0.3689
	E	18.89	18.10		43.62		55.85	136.45	0.4097
								Σ1,551.69	4.1949
2	A		26.32	198.36		245.25	270.50	740.43	3.9293
3	A		7.52	21.64		36.07	50.49	115.72	3.7706
4	D		16.70	31.20		49.40	73.30	171.59	3.9538
5	C		10.14	29.64		32.93	40.32	113.03	3.4673
6	B		15.30	30.39		57.20	69.71	172.59	3.9336
7	B		15.30	30.39		58.98	71.50	176.16	3.9366
8	B		14.40	28.60		53.62	64.35	160.96	3.9259
9	A		12.03	25.97		54.82	73.64	166.46	3.7338
	C		1.35	2.96		6.26	9.44	20.01	0.4024
	E	2.16	2.51		6.14		7.14	17.94	0.4489
								Σ204.41	4.5851
10	C		6.76	21.41		23.05	29.32	80.54	3.4494
11	B		7.20	21.45		35.75	51.83	116.23	4.1510
12	E	215.85	167.09		64.62			447.56	4.0687
13	D		66.78	386.35		668.96	497.77	1,619.85	3.4465
14	A		105.29	187.54		389.51	581.34	1,263.69	3.4163
	C		11.83	21.41		44.46	73.85	151.55	0.3689
	E	18.89	18.10		43.62		55.85	136.45	0.4097
								Σ1,551.69	4.1949
15	D		66.78	257.56		501.72	622.21	1,448.27	3.4982
16	D		183.65	321.96		501.72	68.44	1,075.76	3.4590
17	D		16.70	64.39		334.48	140.00	555.56	3.5162
18	A		8.01	122.34		80.61		210.97	3.2068
19	D		46.75	80.49		133.79	18.67	279.69	3.4530
20	D		13.36	25.76		20.07	21.78	80.96	3.5199
21	D		13.36	25.76		20.07	21.78	80.96	3.5199
22	B		3.60	17.87		17.87	35.75	75.09	3.2650
Σ/Average		255.78	992.03	2,163.37	157.99	3,800.56	3,659.99	11,029.72	3.7475

Note: 🐟 = CECD value per kg of rainbow trout aquaculture (Mcal).

Cultural Energy and Carbon Footprint Expended on Consumed Compound Diet

The average lowest and highest CE and CF expended values of the compound diets were calculated as 3.65 and 3.25 Mcal kg^{-1} and 1.03 and 1.40 kg CO$_2$*e* kg^{-1} (Tables 2, 3). This situation is related to the rate of use of feed ingredients depending on the chemical composition of the compound diets. It is similar to the difference in the embodied energy values of their feeds depending on the feed ingredients content reported by Chatvijitkul et al. (2017). The results were similar to the 3.40 Mcal kg^{-1} CE expended value of rainbow trout diets reported by Diken & Koknoroglu (2022), but higher than the 0.97 kg CO_2e kg^{-1} CF expended value reported by Diken et al. (2022). In addition, considering the report of Boissy et al. (2011), which states that depending on the diet content, the climate change effect (kg CO_2e) of a plant-based diet in trout feed is 6% lower than that of a fish meal-based standard diet, it can be concluded that the CF of diets can be improved in trout aquaculture. At the same time, it has been reported that the choice of different feed production systems and feed ingredients considering the distance effect should be evaluated in terms of environmental impact strategies to create the less global warming effect of aquaculture feeds (da Silva Pires et al., 2022). Although these approaches reveal the importance of plant-derived feed ingredients for the sustainability of trout diets, attention should be paid to the kg CO_2e $unit^{-1}$ values of feed ingredients given in Table 3 in compound diet rations.

Table 5. Carbon footprint expended on consumed compound diet (CFCD) of Karacaören-I Dam Lake rainbow trout cage farming

Code		**Total Carbon Footprint Expended on Consumed Compound Diet (tonne CO_2e)**							🐟
Farm	***Aquafeed***	***1.9mm***	***3mm***	***4mm***	***4.5mm***	***5mm***	***6mm***	**Σ**	
1	A		30.00	54.53		113.26	169.04	366.83	0.9917
	C		3.98	7.27		15.10	23.90	50.24	0.1358
	E	5.15	5.81		14.55		19.26	44.76	0.1210
								Σ 461.83	1.2485
2	A		7.50	57.68		71.31	78.65	215.14	1.1417
3	A		2.14	6.29		10.49	14.68	33.60	1.0949
4	D		7.04	13.86		21.07	27.63	69.60	1.6038
5	C		3.41	10.07		11.18	13.05	37.70	1.1566
6	B		4.37	8.75		16.47	20.08	49.67	1.1321
7	B		4.37	8.75		16.99	20.59	50.70	1.1330
8	B		4.12	8.24		15.44	18.53	46.33	1.1299
9	A		3.43	7.55		15.94	21.60	48.52	1.0884
	C		0.45	1.01		2.13	3.05	6.64	0.1489
	E	0.59	0.36		0.97		2.46	4.38	0.0982
								Σ 59.54	1.3355
10	C		2.27	7.27		7.83	9.49	26.86	1.1503
11	B		2.06	6.18		10.30	14.93	33.46	1.1950
12	E	58.81	53.65		21.56			134.02	1.2183
13	D		28.17	166.33		280.92	221.05	696.47	1.4819
14	A		30.00	54.53		113.26	169.04	366.83	0.9917
	C		3.98	7.27		15.10	23.90	50.24	0.1358
	E	5.15	5.81		14.55		19.26	44.76	0.1210
								Σ 461.83	1.2485
15	D		28.17	110.89		210.69	276.31	626.06	1.5122
16	D		77.47	138.61		210.69	30.39	457.17	1.4700
17	D		7.04	27.72		140.46	62.17	237.40	1.5025
18	A		2.57	39.85		25.27		67.70	1.0290
19	D		19.72	34.65		56.18	8.29	118.85	1.4672
20	D		5.63	11.09		8.43	9.67	34.82	1.5140
21	D		5.63	11.09		8.43	9.67	34.82	1.5140
22	B		1.03	5.15		5.15	10.30	21.62	0.9400
Σ /Average		69.69	350.19	804.63	51.63	1,402.09	1,296.98	3,975.21	1.2827

Note: 🐟 = CFCD value per kg of rainbow trout aquaculture (kg CO_2e)

Table 6. Cultural energy expended on transportation (CET) of Karacaören-I Dam Lake rainbow trout cage farming

Code		**Aquafeed**		**Hatchery**		**Processing Factory**		**Σ**
Farm	***Aquafeed***	***Σ Gcal***	🐟	***Σ Gcal CO_2e***	🐟	***Σ Gcal CO_2e***	🐟	🐟
1[a,b,c]	A	110.13	0.2977	0.58	0.0016	19.52	0.0528	
	C	15.11	0.0408	0.31	0.0008	29.20	0.0789	
	E	14.96	0.0404					
		Σ140.20	0.3790	Σ0.89	0.0024	Σ48.71	0.1317	0.5131
2[b,c]	A	64.66	0.3431	0.46	0.0025	36.59	0.1942	0.5781
				0.01	0.0001	7.22	0.0383	
				Σ0.48	0.0025	Σ43.81	0.2325	
3[b]	A	10.09	0.3289	0.07	0.0024			
			0.01	0.0005				
			Σ0.09	0.0029		13.72	0.4470	0.7788
4[b]	D	17.72	0.4083	2.03	0.0469			
				1.46	0.0337			
				Σ3.50	0.0806	27.51	0.6340	1.1229
5[b]	C	11.42	0.3504	0.07	0.0023			
			0.30	0.0092				
			Σ0.37	0.0115		2.71	0.0831	0.4449
6	B	12.61	0.2875	0.12	0.0026	5.78	0.1317	0.4218
7	B	12.88	0.2877	0.12	0.0026	5.78	0.1291	0.4194
8	B	11.77	0.2629	0.12	0.0028	5.78	0.1409	0.4066
9[a,c]	A	14.57	0.3268			1.50	0.0337	
	C	2.00	0.0054			4.17	0.0936	
	E	1.98	0.0444					
		Σ18.55	0.3767	0.15	0.0033	Σ5.67	0.1272	0.5071
10[b]	C	8.13	0.3483	0.07	0.0032			
				0.30	0.0128			
				Σ0.37	0.0160	1.81	0.0773	0.4416
11	B	8.50	0.3035	0.01	0.0004	4.33	0.1547	0.4586
12	E	40.64	0.3694	19.09	0.1735	8.67	0.0788	0.6217
13	D	166.42	0.3541	8.72	0.0185	38.93	0.0828	0.4554
14[a,b,c]	A	110.13	0.2977	0.58	0.0016	19.52	0.0528	
	C	15.11	0.0408	0.31	0.0008	29.20	0.0789	
	E	14.96	0.0404					
		Σ121.36	0.3790	Σ0.89	0.0024	Σ48.71	0.1317	0.5131
15	D	149.77	0.3618	10.46	0.0253	35.03	0.0846	0.4717
16	D	109.11	0.3508	194.22	0.6245	28.06	0.0902	1.0656
17	D	56.58	0.3581	3.49	0.0221	13.62	0.0862	0.4664
18	A	20.93	0.3182	3.85	0.0585	15.43	0.2346	0.6113
19	D	28.36	0.3501	75.53	0.9325	8.02	0.0990	1.3816
20	D	8.32	0.3618	0.58	0.0253	1.98	0.0859	0.4729
21	D	8.34	0.3627	0.60	0.0259	1.98	0.0859	0.4745
22	B	5.49	0.2387	0.06	0.0025	2.21	0.0960	0.3372
Σ/Average		1,050.70	0.3400	323.69	0.0927	368.24	0.1566	0.5893

Note: 🐟 = CET value per kg of rainbow trout aquaculture (Mcal). It includes calculations resulting from a = aquafeed factory distance difference and b,c = difference of vehicles used in transportation

Table 7. Carbon footprint expended on transportation (CFT) of Karacaören-I Dam Lake rainbow trout cage farming

Code		**Aquafeed**		**Hatchery**		**Processing Factory**		**Σ**
Farm	***Aquafeed***	***Σ tonne CO_2e***	🐟	***Σ tonne CO_2e***	🐟	***Σ tonne CO_2e***	🐟	🐟
1[a,b,c]	A	31.32	0.0847	0.17	0.0004	5.55	0.0150	
	C	4.30	0.0116	0.09	0.0002	8.30	0.0224	
	E	4.25	0.0115					
		Σ39.87	0.1078	Σ0.25	0.0007	Σ13.85	0.0374	0.1459
2[b,c]	A	18.38	0.0976	0.13	0.0007	20.63	0.1095	
				0.01	0.0001	4.07	0.0216	
				Σ0.14	0.0008	Σ24.70	0.1311	0.2294
3[b]	A	3.53	0.1151	0.04	0.0014			
				0.01	0.0004			
				Σ0.06	0.0018	7.74	0.2521	0.3689
4[b]	D	5.04	0.1161	0.58	0.0133			
				0.42	0.0096			
				Σ0.99	0.0229	7.82	0.1803	0.3193
5[b]	C	3.97	0.1219	0.06	0.0020			
				0.17	0.0052			
				Σ0.23	0.0072	1.53	0.0468	0.1759
6	B	3.59	0.0818	0.03	0.0008	3.26	0.0742	0.1567
7	B	3.66	0.0818	0.03	0.0007	3.26	0.0728	0.1553
8	B	3.35	0.0816	0.03	0.0008	3.26	0.0794	0.1618
9[a,c]	A	4.14	0.0929	0.04	0.0009	0.43	0.0096	
	C	1.74	0.0127			1.19	0.0266	
	E	1.72	0.0126					
		Σ7.60	0.1183			Σ1.61	0.0362	0.1554
10[b]	C	2.31	0.0990	0.06	0.0028			
				0.17	0.0072			
				Σ0.23	0.0100	1.02	0.0436	0.1526
11	B	2.96	0.1059	0.01	0.0004	2.44	0.0872	0.1935
12	E	11.55	0.1050	5.43	0.0493	21.23	0.1930	0.3474
13	D	47.32	0.1007	2.48	0.0053	7.75	0.0165	0.1224
14[a,b,c]	A	31.32	0.0847	0.17	0.0004	5.55	0.0150	
	C	4.30	0.0116	0.09	0.0002	8.30	0.0224	
	E	4.25	0.0115					
		Σ39.87	0.1078	Σ0.25	0.0007	Σ13.85	0.0374	0.1459
15	D	42.59	0.1029	2.97	0.0072	9.96	0.0241	0.1341
16	D	31.02	0.0998	55.22	0.1776	7.98	0.0257	0.3030
17	D	16.09	0.1018	0.09	0.0063	3.87	0.0245	0.1326
18	A	5.95	0.0905	1.10	0.0166	4.20	0.0667	0.1738
19	D	8.06	0.0996	21.48	0.2651	2.28	0.0281	0.3928
20	D	2.37	0.1029	0.17	0.0072	0.56	0.0244	0.1345
21	D	2.37	0.1031	0.17	0.0074	0.56	0.0244	0.1349
22	B	1.56	0.0679	0.03	0.0014	1.92	0.0835	0.1528
Σ/Average		304.94	0.1004	92.35	0.0269	149.37	0.0723	0.1995

Note: 🐟 = CFT expended per kg of rainbow trout aquaculture (kg CO_2e). It includes calculations resulting from a = aquafeed factory distance difference and b,c = difference of vehicles used in transportation

Table 8. Total cultural energy and carbon footprint expended values in Karacaören-I Dam Lake rainbow trout cage farming sustainability management

Cage Farm	**Compound Diet**		**Transportation**								**TOTAL**		**Compound Diet (%)**		
			Aquafeed		***Hatchery***		***Processing factory***		***Σ***						
	CE 🐟	***CF*** 🐟	***CE*** 🐟	***CF*** 🐟	***CE*** 🐟	***CF*** 🐟	***CE*** 🐟	***CF*** 🐟	***CE*** 🐟	***CF*** 🐟	***CE*** 🐟	***CF*** 🐟	***CE*** 🐟	***CF*** 🐟	**CE:CF**
1	4.1949	1.2485	0.3790	0.1078	0.0024	0.0007	0.1317	0.0374	0.5131	0.1459	4.7080	1.3944	89.10	89.54	3.3763
2	3.9293	1.1417	0.3431	0.0976	0.0025	0.0008	0.2325	0.1311	0.5781	0.2294	4.5074	1.3711	87.17	83.27	3.2874
3	3.7706	1.0949	0.3289	0.1151	0.0029	0.0018	0.4470	0.2521	0.7788	0.3689	4.5494	14639	82.88	74.80	3.1078
4	3.9538	1.6038	0.4083	0.1161	0.0806	0.0229	0.6340	0.1803	1.1229	0.3193	5.0766	1.9231	77.88	83.40	2.6399
5	3.4673	1.1566	0.3504	0.1219	0.0115	0.0072	0.0831	0.0468	0.4449	0.1759	3.9121	1.3325	88.63	86.80	2.9360
6	3.9336	1.1321	0.2875	0.0818	0.0026	0.0008	0.1317	0.0742	0.4218	0.1567	4.3554	1.2889	90.31	87.84	3.3792
7	3.9366	1.1330	0.2877	0.0818	0.0026	0.0007	0.1291	0.0728	0.4194	0.1553	4.3560	1.2884	90.37	87.94	3.3810
8	3.9259	1.1299	0.2629	0.0816	0.0028	0.0008	0.1409	0.0794	0.4066	0.1618	4.3326	1.2918	90.61	87.47	3.3540
9	4.5851	1.3355	0.3767	0.1183	0.0033	0.0009	0.1272	0.0362	0.5071	0.1554	5.0923	1.4909	90.04	89.58	3.4155
10	3.4494	1.1503	0.3483	0.0990	0.0160	0.0100	0.0773	0.0436	0.4416	0.1526	3.8910	1.3029	88.65	88.29	2.9864
11	4.1510	1.1950	0.3035	0.1059	0.0004	0.0004	0.1547	0.0872	0.4586	0.1935	4.6097	1.3884	90.05	86.07	3.3200
12	4.0687	1.2183	0.3694	0.1050	0.1735	0.0493	0.0788	0.1930	0.6217	0.3474	4.6905	1.5657	86.74	77.81	2.9957
13	3.4465	1.4819	0.3541	0.1007	0.0185	0.0053	0.0828	0.0165	0.4554	0.1224	3.9019	1.6043	88.33	92.37	2.4322
14	4.1949	1.2485	0.3790	0.1078	0.0024	0.0007	0.1317	0.0374	0.5131	0.1459	4.7080	1.3944	89.10	89.54	3.3763
15	3.4982	1.5122	0.3618	0.1029	0.0253	0.0072	0.0846	0.0241	0.4717	0.1341	3.9699	1.6463	88.12	91.85	2.4114
16	3.4590	1.4700	0.3508	0.0998	0.6245	0.1776	0.0902	0.0257	1.0656	0.3030	4.5246	1.7730	76.45	82.91	2.5520
17	3.5162	1.5025	0.3581	0.1018	0.0221	0.0063	0.0862	0.0245	0.4664	0.1326	3.9826	1.6351	88.29	91.89	2.4357
18	3.2068	1.0290	0.3182	0.0905	0.0585	0.0166	0.2346	0.667	0.6113	0.1738	3.8180	1.2028	83.99	85.55	3.1743
19	3.4530	1.4672	0.3501	0.0996	0.9325	0.2651	0.0990	0.0281	1.3816	0.3928	4.8346	1.8601	71.42	78.88	2.5991
20	3.5199	1.5140	0.3618	0.1029	0.0253	0.0072	0.0859	0.0244	0.4729	0.1345	3.9929	1.6485	88.16	91.84	2.4222
21	3.5199	1.5140	0.3627	0.1031	0.0259	0.0074	0.0859	0.0244	0.4745	0.1349	3.9944	1.6489	88.12	91.82	2.4225
22	3.2650	0.9400	0.2387	0.0679	0.0025	0.0014	0.0960	0.0835	0.3372	0.1528	3.6022	1.0928	90.64	86.02	3.2964
Ave.	3.7475	1.2827	0.3400	0.1004	0.0927	0.0269	0.1566	0.0723	0.5893	0.1995	4.3368	1.4822	86.59	86.61	2.9682

Note: 🐟 = Mcal or kg CO_2e expended corresponding per kg of rainbow trout aquaculture. Ave. = Average

The CD/A-4mm, 5mm, and 6mm diets with the same chemical compositions had lower CE and CF expended values compared to the CD/A-3mm diet (Tables 2, 3). This situation was due to the rate of use of fish meals, the high crude protein value of the A-3mm diet, and the low crude fibre. While the crude fibre ratios of the B diets were the same, the CE expended value was high due to the high crude protein value of the B-3mm diet (Table 2). Crude protein and crude fat total values were similar at a rate of 64% in CD/B-3mm and 65% in other B diets, respectively. While the CE value of the fish meal was higher than fish oil, the CF values were similar (Tables, 3, 4). Because of this situation, while the CE expended value of the CD/B-3mm diet was high, the CF values of all B diets were similar. The difference in the crude fibre values of the C diets affected the CE and CF expended values of the diets. The CE and CF expended values of the 6mm diet with the lowest crude fibre values were higher than the other C diets (Tables 2, 3). The crude fibre and crude protein ratios of D diets affected the CE and CF expended value. The 6mm diet with a high crude fibre value was the diet with low CE and CF expended value (Tables 2, 3). Compared to the CD/D-6mm diet, the 4 mm diet, which had a high crude protein value and a low crude fibre value had the lowest CE and CF expended values after this diet. The difference in feed ingredients used in the E diets affected the CE and CF expended values of the diets (Tables 2, 3). At the same time, the increase in the crude fibre ratio and the decrease in the crude protein ratio affected these values. The limiting effect of the crude fibre value of the diet formulations on the feed ingredient utilization rate primarily affected the CE and CF expended values of the diets. In addition, the feed ingredient differences of the same diet groups also affected the CE and CF expended values of the diets (Tables 2, 3).

Rainbow trout farming with different compound diets in KRTC 1, 9, and 14 fish farms increased the cultural energy expended on consumed compound diet (CECD) and carbon footprint expended on consumed compound diet (CFCD) values per kg of rainbow trout aquaculture (Tables 4, 5). Although the FCR values of these farms were similar, the CECD and CFCD values increased to raise per kg of rainbow trout aquaculture due to the low amount of harvested fish from farm 9. While the CECD value of farm 22 using a B diet with low FCR values was low per kg of rainbow trout aquaculture, the high FCR value of farm 11 using the same diet increased this value (Tables 1, 4). The CECD value increased depending on the FCR value of the D compound diet with a low CE expended value (Table 1, 4). The increase in FCR values of farms 15, 16, and 17 using the D compound diet increased the CECD value per kg of rainbow trout aquaculture. Farms 13 and 19 using the D compound diet had a low CECD per kg of rainbow trout aquaculture.

The reason why the CECD value of farm 10 using compound diet C was similar to farms 13 and 19 per kg of rainbow trout aquaculture was due to the low FCR (Tables 1, 4). Farm 22 in the basin had a low CFCD value per kg of rainbow trout aquaculture (Tables 1, 5). The most important factor in this value was that although the CF expended value of compound diet B was low, the amount of diet consumed due to FCR was low (Table 1).

Farms 13 and 19 with low FCR had a low CECD per kg of rainbow trout aquaculture, but a high CFCD (Tables 1, 4, 5). This is due to the CF value of compound diet. As the FCRs of the farms using the same compound diets increased, the CECD and CFCD values of the compound diets consumed per kg of rainbow trout aquaculture increased (Tables 1, 4, 5). The CECD value per kg of rainbow trout aquaculture in the basin was high in farm 4, depending on the high value in the FCR (Tables 1, 5). FCR was the most influential factor over CECD and CFCD value per kg of rainbow trout aquaculture. In general, 5 and 6 mm compound diets from the grow-out diets of farms increased the CECD and CFCD values, and depending on these values, it increased the Mcal and kg CO_2e values per kg of rainbow trout aquaculture (Tables 1, 4, 5).

Depending on the nutritional habits of the cultivated species, the diversity of feed ingredients used in compound diets and the formulation differences affected the CE and CF expended values (Tables 1, 2, 3). In aquaculture, the feed had a high energy input of 53-86% (Pelletier et al., 2011; Diken & Koknaroglu, 2022). This rate was similar to broiler and layer hen production. The reason for this was the use of high-quality feed ingredients in the feed of chickens and laying hens (Koknaroglu & Atilgan, 2007; Akunal & Koknaroglu, 2021). The reason for the high CE expended values of carnivorous species such as rainbow trout was due to the need for feed ingredients (fish meal, fish oil, corn and wheat gluten, soybean concentrated, etc.) of animal origin and/or higher protein value in their diets. The CE expended values of diets belonging to carnivorous species such as rainbow trout were high due to feed ingredients with low CE expended value from other ruminant livestock (sheep) (Demircan & Koknaroglu, 2007; Demircan, 2008; Koknaroglu, 2008, 2010; Cinar & Koknaroğlu, 2019; Koknaroglu & Hoffman, 2019). According to Chatvijitkul et al. (2017), and Diken & Konaroglu (2022), the CE expended value of rainbow trout compound diets was between 2.93-3.40 Mcal kg^{-1}. In this study, the CE expended an average value of compound diets between 3.25-3.65 Mcal kg^{-1} (Table 3). The CE expended values for hybrid catfish, tilapia, pangasius, Atlantic salmon, whiteleg shrimp, back tiger shrimp from other aquatic species were reported as 1.17, 1.39, 1.27, 2.98, 2.17, 2.54 Mcal kg^{-1}, respectively (Chatvijitkul et al., 2017). The percentage of crude protein in European seabass compound diets was between 3.61-4.21 Mcal kg^{-1}, due to its relatively high value related to the rainbow trout diet (Diken et al., *unpublished*). The CE value of one kg of concentrated feed for beef cattle and dairy cattle was 1.13 Mcal kg^{-1} (Demircan, 2008; Koknaroglu, 2008) and 1.30 Mcal kg^{-1}, respectively.

Considering the 77.78% and 77.88% cultural energy and 72.60% carbon footprint values of the consumed compound diet, excluding the transportation values of rainbow trout cage farming (Diken et al., 2021, 2022; Diken & Koknaroglu, 2022), also in this study, the high rates of CE and CFP expended values of compound diet and consumed compound diet due to FCR support the result of feed-induced CE and CF budget increase. Flos & Reig (2017) reported that the feed had an energy share of 79% in intensive salmon cage cultivation. The CECD expended rate of earthen pond European seabass farming was calculated as 28.06% (Diken et al., *unpublished*). Together with these reports, the results of the current study revealed that CE and CF expended values based on feed should be considered as sustainability criteria in trout farming (Tables 5, 6).

In addition to a fish meal with high protein values, high emissions due to land use, such as soybean production, had affected salmonid feed emissions (MacLeod et al., 2020). Ziegler et al. (2021), reported that 85% of the total CF in salmon production was made up of feed. Similarly, the cage had a high share in rainbow trout farming compared to feed, and fish and feed transportation (Tables 4, 5, 6, 7, 8). The result of the study showed that the use of FCR and high-emission feed ingredients increased the CF expended value, supporting the finding that FCR increase in salmon fish farming and feed inputs with intense emissions caused an increase in emissions in production (Ziegler et al., 2021) (Tables 1, 3, 5). This and similar approaches enable us to understand the statements that CO_2e was reported to be used on feed labels as an indicator of the sustainability of the private aquaculture sector (Hatchery Feed & Management, 2021).

Cultural Energy and Carbon Footprint of Transportation

The compound diet transportation of cage farms 6, 7, 8, and 22 closest to the aquafeed factory in KRTC were the farms with low CET and CFT values per kg of rainbow trout aquaculture (Tables 1, 6, 7). Among these farms, farm 22, which had low transport distances, has the lowest CET and CFT values per kg of rainbow trout aquaculture (Tables 1, 6, 7). Farm 4 was the farthest from the aquafeed factory and processing factory (Table 1). CET was high per kg of rainbow trout aquaculture due to distance (Table 6). However, the CEF value for transportation per kg of rainbow trout aquaculture was not high (Table 7).

Farm 11 had the lowest CET and CFT values per kg of rainbow trout aquaculture in the basin, due to the low-capacity rainbow trout farming, the low need for juvenile fish, and the supply of juvenile fish from the close-range hatchery on the Göksu Stream located in the same basin (Tables 1, 6, 7). Since cage farms 1 and 14, which had the highest rainbow trout aquaculture in the basin, meet the need for juvenile fish from the hatcheries in the same basin, and the distance to the processing factory was below the average values of the basin, the CE and CF expended values of transportation were low (Table 1, 6, 7). Since cage farms 16 and 19 meet their juvenile fish needs from the same hatchery at the farthest distance, and the need for juvenile fish was high, the CET and CFT expended values were high (Tables 1, 6, 7). Cage farms 1, 2, 3, 6, 7, 8, 9, 11, 14, and 22, which provide juvenile fish needs from hatcheries on Göksu Stream, were farms with low CET and CFT values per kg of rainbow trout aquaculture (Tables 1, 6, 7).

CET and CFT of harvested fish per kg of rainbow trout aquaculture due to the proximity of farm 13 with the highest production to the processing factory were low (Tables 1, 6, 7). The CFT value of the harvested fish was high per kg of rainbow trout aquaculture since farm 22 transports the harvested fish with a low-capacity vehicle (Table 7).

If the distance of a farm to the aquafeed factory, hatchery, and processing factory in KRTC was below the average of the basin, the CET and CFT values per kg of rainbow trout aquaculture were low (Tables 1, 6, 7). The average values of 0.5893 Mcal kg^{-1} CET and 0.1995 kg CO_2e CFT per kg of rainbow trout aquaculture of farms 1, 14, and 15, which had the highest production in the basin, were below the basin average values (Tables 1, 6, 7). These results support the statement that the transport distance reported by Diken et al. (2021, 2022), affected the value of CE and CF expended transportation in trout farming. It has also been reported that CE expended transportation will increase by 2.22-3.08% in the simulation of the fact that the need for feed and juvenile fish in earthen pond European sea bass farming was provided from farther region enterprises (Diken et al., *unpublished*). Similarly, in the rainbow trout cage farming simulation study by Diken (2021), it was reported that the CE expended transportation value of the farms that met the compound diet requirement from longer distances, where the FCR ratios did not change, increased significantly. A private firm reported that they were planning to establish a feed facility on a salmon farm to reduce the carbon footprint of feed-related transportation (Hatchery International, 2021). As a result, it was reported that the transportation distance compared to the feed had a lower share of CE and CF expended but had an effect that should be taken into account in rainbow trout farming (Diken et al., 2021, Diken & Koknaroglu, 2022, Diken, *unpublished*).

Climate change is effective in the growth and food security of the aquaculture sector (Cubillo et al., 2021). It was reported that Norwegian salmon aquaculture in open cages had a lower CF value than RAS cultivation in the United States, but the CF value of imported Norwegian salmon offered for consumption in the USA increased due to transportation involving the transportation of Norwegian salmon to the USA (Liu et al., 2016). These reports draw attention to the CF value associated with transportation in aquaculture and support this report in terms of sustainability in the current study. These evaluations revealed that the CF global-scale approach to the sustainability of aquaculture, production should be handled on a national and local basis. There was a relationship between CF analysis and energy calculations (Flos & Reig, 2017) and Ziegler et al. (2021), who reported that cage salmon farming had a total CF feed share of 85% due to differences in aquaculture production systems. Similarly, it was reported that 90% of the CF of different aquaculture systems in India was from feed (Adhikari et al., 2013). These results are considered an important criterion to be considered in the sustainability of feed and feed-based studies in aquaculture. In the results of the evaluation of KRTC management in Table 8, it had been determined that the compound diet budget had an important place in the sustainability of rainbow trout farming, according to the average values of 86.59% CECD and 86.61% CFCD per kg of rainbow trout aquaculture. The 1.2-2.7 kg CO_2e value per kg live-weight gain of Atlantic salmon farming presented in the Pelletier & Tyedmers (2007), report is similar to the feed and transportation values of the study (Table, 8). It was important for CET sustainability that the hatcheries, where cage farms provide juvenile fish, were very close to Karacaören-I Dam Lake. In addition, when the report of Korkut et al. (2007), was examined, it could be stated that the distances of Türkiye aquafeed factories to the basin were below the Türkiye average, which is important in CET sustainability. Considering that the estimated distance of the Aegean aquafeed factory evaluated in the study in another dam lake where intensive production was made in Türkiye was around 3.5 times, the average distance of the Karacaören-I Dam Lake Basin, the cage farm compound diet transportation value of the other basin with the same production capacity would be calculated 3.5 times more.

Troel et al. (2004) reported that the increase in capacity had a positive effect on the energy used for unit production. Similarly, Demircan & Koknaroglu (2007) reported that the increase in farm size had a positive effect on energy use efficiency. According to these evaluations and the results of the study, production should be made according to the project capacity in terms of sustainability in KKTC. The 2.9682 CE:CF KRTC sustainability value of the catchment compound diet and transportation given in Table 8 should be taken into account in future studies.

Conclusion

One of the most important factors affecting the CE and CF expended values of rainbow trout farming was the CE and CF expended value and FCR of the compound diet, depending on the feed ingredients and usage rates. Depending on the FCR, with the value of CE and CF expended from the compound diet, transportation can be considered as a sustainability criterion in terms of production and food safety of rainbow trout farming. KRTC was in a sustainable position in terms of its distance from the aquafeed factory, hatchery, and processing facility. KRTC was in a sustainable position in terms of its distance from the aquafeed factory, hatcheries, and processing facilities. Aquaculture facilities need to produce according to their annual project production capacity in terms of reducing the CE and CF expended sustainability values per kg of rainbow trout aquaculture. In terms of aquaculture systems and aquaculture types, it is recommended to develop the sustainability index of the aquaculture species (species-specific) and aquaculture system (system-specific) CE and CF expended values.

Acknowledgments

The author would like to thank Dr. Hayati Koknaroglu, Dr. Hüseyin Sevgili, Dr. Joël Aubin, and Dr. Jacopo Bacenetti for their help during the study, and Fisheries Technician İsmail Can for fieldwork support.

Compliance With Ethical Standards

Conflict of Interest

The author declares that there is no conflict of interest.

Ethical Approval

For this type of study, formal consent is not required.

Funding

There was no funding for the research.

References

Adhikari, S., Lal, R., & Sahu, B. C. (2013). Carbon footprint of aquaculture in eastern India. *Journal of Water and Climate Change*, *4*(4), 410-421. https://doi.org/10.2166/wcc.2013.028

Akunal, T., & Koknaroglu, H. (2021). Commercial native laying hybrids developed in Turkey are comparable to foreign hybrids in terms of performance and cultural energy use efficiency. *Animal Science Papers and Reports*, *39*(2), 169-177.

Anonymous. (2021). Isparta Directorate of Provincial Agriculture and Forestry, Republic of Türkiye Ministry of Agriculture and Forestry.

Arslan, G., & Oguzhan Yildiz, P. (2021). *Türkiye su ürünleri sektörüne genel bakış* [An overview to fisheries sector in Turkey]. *Menba Kastamonu Üniversitesi Su Ürünleri Fakültesi Dergisi*, *7*(1), 46-57.

Becer Ozvarol, Z. A., & İkiz, R. (2009). Mortality ratio and stock analysis of vimba (*Vimba vimba tenella* (Nordmann,1840)) population in Karacaoren I Dam Lake (Burdur Turkey). *Journal of Applied Biological Sciences*, *3*(2), 143-147.

Boissy, J., Aubin, J., Drissi, A., van der Werf, H. M. G., Bell, G. J., & Kaushik, S. J. (2011). Environmental impacts of plant-based salmonid diets at feed and farm scales. *Aquaculture*, *321*(1), 61-70. https://doi.org/10.1016/j.aquaculture.2011.08.033

Boyd, C. E., McNevin, A. A., & Tucker, C. S. (2019). Resource use and the environment. In Lucas, J. S., Southgate, P. C., & Tucker, C. S. (Eds.), *Aquaculture Farming Aquatic Animals and Plants* (pp. 93–112). John Wiley & Sons Ltd.

Chatvijitkul, S., Boyd, C. E., Davis, D. A., & McNevin, A. A. (2017). Embodied resources in fish and shrimp feeds. *Journal of the World Aquaculture Society*, *48*(1), 7–19. https://doi.org/10.1111/jwas.12360

Cınar, İ., & Koknaroglu, H. (2019). *Süt sığırcılığında ırkın sürdürülebilirlik üzerine etkisi* [Examination of effect of breed on sustainability of dairy cattle production]. *SDU Journal of the Faculty of Agriculture/SDÜ Ziraat Fakültesi Dergisi*, *14*(2), 143–155.

Cubillo, A. M., Ferreira, J. G., Lencart-Silva, J., Taylor, N. G. H., Kennerley, A., Guilder, J., Kay, S., & Kamermans, P. (2021). Direct effects of climate change on productivity of European aquaculture. *Aquaculture International*, *29*(4), 1561-1590. https://doi.org/10.1007/s10499-021-00694-6

da Silva Pires, P. G., Andretta, I., Mendéz, M. S. C., Kipper, M., de Menezes Lovatto, N., & Loureiro, B. B. (2022). Life cycle impact of industrial aquaculture systems. In C. M. Galanakis (Ed.), *Sustainable Fish Production and Processing* (pp. 141-172). Academic Press.

Davulis, J. P., Frick, G. E., & New Hampshire Agricultural Experiment Station (1977). Potential for energy conservation in feeding livestock and poultry in the United States, *Station Bulletin, no. 506. New Hampshire Agricultural Experiment Station Bulletin 467.* https://scholars.unh.edu/agbulletin/467

Demir, U. A., & Sevinç, E. (2020). Marketing and economics of aquaculture in Turkey. In Çoban, D., Demircan, M. D., & Tosun, D. D. (Eds.), *Marine Aquaculture in Turkey: Advancements and Management* (pp. 416–430). Turkish Marine Research Foundation (TUDAV).

Demircan, V. (2008). The effect of initial fattening weight on sustainability of beef cattle production in feedlots. *Spanish Journal of Agricultural Research*, *6*(1), 17-24. https://doi.org/10.5424/sjar/2008061-290

Demircan, V., & Koknaroglu, H. (2007). Effect of farm size on sustainability of beef cattle production. *Journal of Sustainable Agriculture*, *31*(1), 75–87. https://doi.org/10.1300/J064v31n01_08

Diken, G. (2021). Burdur ili gökkuşağı alabalığı kafes yetiştiriciliğinin proje kapasitesine göre yem tüketimi ile taşımacılığının kültürel enerji ve karbon ayak izi tahmini. *21. Ulusal Su Ürünleri Sempozyumu. Atatürk Üniversitesi Su Ürünleri Fakültesi,* Erzurum, Türkiye, pp. 76–91.

Diken, G., & Koknaroglu, H. (2022). Projected annual production capacity affects sustainability of rainbow trout (*Oncorhynchus mykiss* Walbaum, 1792) reared in concrete ponds in terms of energy use efficiency. *Aquaculture*, *551*, 737958. https://doi.org/10.1016/j.aquaculture.2022.737958

Diken, G., Koknaroglu, H., & Bahrioğlu, E. (*unpuslihed*). Cultural energy use and energy use efficiency of European seabass (*Dicentrarchus labrax* Linnaeus, 1758) reared in earthen ponds up to portion size.

Diken, G., Köknaroğlu, H., & Can, İ. (2021). Cultural energy use and energy use efficiency of a small-scale rainbow trout (*Oncorhynchus mykiss* Walbaum, 1792) cage farm in the inland waters of Turkey: A case study from Karacaören-I Dam Lake. *Aquaculture Studies*, *21*(1), 31–39. https://doi.org/10.4194/2618-6381-v21_1_04

Diken, G., Koknaroglu, H., & İsmail, C. (2022). Small-scale rainbow trout cage farm in the inland waters of Turkey is sustainable in terms of carbon footprint (kg CO_2e). *Acta Aquatica Turcica*, *18*(1), 131-145. https://doi.org/10.22392/actaquatr.1103100

FAO. (2012). Energy-smart food at FAO: An overview. *Environment and Natural Resources Management Working Paper No. 53.* Food and Agriculture Organization of the United Nations. Rome, Italy.

FAO. (2022). Food and Agriculture Organization of the United Nations Fisheries and Aquaculture Department Fishery Statistical Collections Global Aquaculture Production 2022. (FAO.). Retrieved on March 4, 2022 from https://www.fao.org/fishery/statistics-query/en/aquaculture/aquaculture_quantity

Feedipedia. (2022) Feedipedia: An on-line encyclopedia of animal feeds. Retrieved on May 12, 2022 from https://www.feedipedia.org/node/11698

Flos, R., & Reig, L. (2017). Improving energy efficiency in fisheries and aquaculture. *Aquaculture Europe, 42*(2), 29-34.

GDFA. (2022). Su Ürünleri İstatistikleri Ankara 2022. Retrieved on August 31, 2022 from https://www.tarimorman.gov.tr/BSGM/Belgeler/Icerikler/Su%20%C3%9Cr%C3%BCnleri%20Veri%20ve%20D%C3%B6k%C3%BCmanlar%C4%B1/Bsgm-istatistik.pdf

Google Earth. (2022). Karacören-I Dam Lake. Retrieved on May 5, 2022 from https://earth.google.com/web/search/Karaca%c3%b6ren+Baraj+G%c3%b6l%c3%bc/@37.39345781,30.89022138,502.76893175a,29838.56105953d,35y,-0h,0t,0r/data=CigiJgokCduwxQKPDEVAEUQGrduMiEBAGbDmZd0qpEdAIcgUiCR8ITVA

Hargreaves, J., Brummett, R., & Tucker, C. S. (2019). The future of aquaculture. In Lucas, J. S., Southgate, P. C., & Tucker, C. S. (Eds.), *Aquaculture Farming Aquatic Animals and Plants* (pp. 617–636). John Wiley & Sons Ltd.

Hatchery Feed & Management. (2021). Supplier's News December 2, 2021 "Aller Aqua starts labeling carbon emission equivalents on its feeds". Retrieved on December 14, 2021 from https://hatcheryfm.com/hfm-article/1678/Aller-Aqua-starts-labeling-carbon-emission-equivalents-on-its-feeds/

Hatchery International. (2021). News & Views November 18, 2021 "Skretting and Atlantic Sapphire partner on local feed supply venture." Retrieved on December 08, 2021 https://www.hatcheryinternational.com/skretting-and-atlantic-sapphire-partner-on-local-feed-supply-venture/

Henriksson, P., Little, D. C., Troell, M. & Kleijn, R. (2010). Energy efficiency of aquaculture. Global Aquaculture Advocate, 1-6. Retrieved on August 31, 2022 from https://www.globalseafood.org/advocate/energy-efficiency-aquaculture/

Hognes, E. S., Ziegler, F., & Sund, V. (2011). *Carbon footprint and area use of farmed Norwegian salmon.* SINTEF Fisheries and Aquaculture Report: A22673. Trondheim, Norway.

IAFFD. (2020). Feed ingredient composition database. International Aquaculture Feed Formulation Database (IAFD). Retrieved on April 25, 2022 https://www.iaffd.com/feed.html?v=4.3

Koknaroglu, H. (2008). Effect of concentrate level on sustainability of beef cattle production. *Journal of Sustainable Agriculture, 32*, 123-136. https://doi.org/10.1080/10440040802121452

Koknaroglu, H. (2010). Cultural energy analyses of dairy cattle receiving different concentrate levels. *Energy Conversion and Management, 51*, 955-958. https://doi.org/10.1016/j.enconman.2009.11.035

Koknaroglu, H., & Atılgan, A. (2007). Effect of season on broiler performance and sustainability of broiler production. *Journal of Sustainable Agriculture, 31*, 113-124. https://doi.org/10.1300/J064v31n02_08

Koknaroglu, H., & Hoffman, M. P. (2019). Season affects energy input/output ratio in beef cattle production. *Journal of Animal Behaviour and Biometeorology, 7*, 149-154. https://doi.org/10.31893/2318-1265jabb.v7n4p149-154

Korkut, A. Y., Kop, A., Saygi, H., Göktepe, Ç., Yedek, Y., & Kalkan, T. (2017). General evaluation of fish feed production in Turkey. *Turkish Journal of Fisheries and Aquatic Sciences, 17*(1), 223-229. https://doi.org/10.4194/1303-2712-v17_1_25

Kurnia, R., Soewardi, K., Setyobudiandi, I., & Dharmawan, A. H. (2019). Small scale capture fisheries sustainability analysis using emergy (embodied energy) approach. In *IOP Conference Series: Earth and Environmental Science* (Vol. 278, No. 1, p. 012067). IOP Publishing.

Liu, Y., Rosten, T. W., Henriksen, K. L., Hognes, E. S., Summerfelt, S. T., & Vinci, B. J. (2016). Comparative economic performance and carbon footprint of two farming models for producing Atlantic salmon (*Salmo salar*): Land-based closed containment system in freshwater and open net pen in seawater. *Aquacultural Engineering, 71*, 1-12. https://doi.org/10.1016/j.aquaeng.2016.01.001

Lutz, C. G. (2021). Assessing the carbon footprint of aquaculture. Retrieved on April 25, 2021 from https://thefishsite.com/articles/assessing-the-carbon-footprint-of-aquaculture

MacLeod, M. J., Hasan, M. R., Robb, D. H. F., & Mamun-Ur-Rashid, M. (2020). Quantifying greenhouse gas emissions from global aquaculture. *Scientific Reports, 10*(1), 11679. https://doi.org/10.1038/s41598-020-68231-8

Moe, A., Koehler-Munro, K., Bryan, R., Goddard, T., & Kryzanowksi, L. (2014, October). Multi-criteria decision analysis of feed formulation for laying hens. *Proceedings of the 9th International Conference on Life Cycle Assessment in the Agri-Food Sector,* USA, pp. 8-10.

Muir, J. F. (2015). Fuel and energy use in the fisheries sector – approaches, inventories and strategic implications. Rome, Italy. FAO Fisheries and Aquaculture Circular No. 1080. 94p.

O'Brien, D., Capper, J. L., Garnsworthy, P. C., Grainger, C., & Shalloo, L. (2014). A case study of the carbon footprint of milk from high-performing confinement and grass-based dairy farms. *Journal of Dairy Science*, *97*(3), 1835-1851. https://doi.org/10.3168/jds.2013-7174

Parker, R. W., & Tyedmers, P. H. (2012). Life cycle environmental impacts of three products derived from wild-caught Antarctic krill (*Euphausia superba*). *Environmental Science & Technology*, *46*(9), 4958-4965.

Pelletier, N., & Tyedmers, P. H. (2007). Feeding farmed salmon: Is organic better? *Aquaculture*, *272*, 399-416. https://doi.org/10.1016/j.aquaculture.2007.06.024

Pelletier, N., Audsley, E., Brodt, S., Garnett, T., Henriksson, P., Kendall, A., Kramer, K. J., Murphy, D., Nemecek, T. & Troell, M. (2011). Energy intensity of agriculture and food systems. *Annual Review of Environment and Resources*, *36*(1), 223–246. https://doi.org/10.1146/annurev-environ-081710-161014

Pimentel, D. (1980). Handbook of energy utilization in agriculture. CRC Press.

Rotz, C. A., Asem-Hiablie, S., Place, S. E., & Thoma, G. (2019). Environmental footprints of beef cattle production in the United States. *Agricultural Systems*, *169*, 1-3. https://doi.org/10.3168/jds.2009-2162

Schmidt, J. H. (2015). Life cycle assessment of five vegetable oils. *Journal of Cleaner Production*, *87*, 130-138.

Smith, E. G., Janzen, H. H., & Newlands, N. K. (2007). Energy balances of biodiesel production from soybean and canola in Canada. *Canadian Journal of Plant Science*, *87*(4), 793–801.

Troell, M., Tyedmers, P., Kautsky, N., & Rönnbäck, P. (2004). Aquaculture and energy use. *Encyclopedia of Energy*, *1*, 97-108.

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, No. 674*. Lelystad, UK.

Zhang, W., Belton, B., Edwards, P., Henriksson, P. J., Little, D. C., Newton, R., & Troell, M. (2022). Aquaculture will continue to depend more on land than sea. *Nature*, *603*, E2-E4. https://doi.org/10.1038/s41586-021-04331-3

Ziegler, F., Winther, U., Hognes, E. S., Emanuelsson, A., Sund, V., & Ellingsen, H. (2021). Greenhouse gas emissions of Norwegian seafoods: From comprehensive to simplified assessment. *Journal of Industrial Ecology*, 1-12. https://doi.org/10.1111/jiec.13150