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The Water–Economy Nexus of Beef Produced from Different Cattle Breeds

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Abstract: The sustainable use of water, or any other natural resource for that matter, is not the only factor that should be considered in terms of sustainability, as social equity and economic prosperity are equally important. The objective of this study was to analyse different breeds of beef cattle, following the same production method, in terms of their water footprint and economic value addition for different links in the value chain. A bottom-up approach was applied to identify the breed with the best economic water consumption in terms of beef production. The results indicated that the total WF/kg carcass revealed notable differences between the various breeds. The Bonsmara had the smallest WF/kg carcass, while the Limousin had the largest. The WF/kg of beef for the different cuts (rib eye, topside, and flank) showed large variations between the breeds and between the different cuts of beef from the same breed. In terms of the economic water consumption, the Angus consumed between 4% and 25% less water per rand of economic value addition than the Bonsmara, Simmentaler, Simbra, Limousin, Afrikaner, and Brahman. When the economic water consumption of the individual value links was considered, it was found that Bonsmara had the best figures for cow–calf production, while the Limousin and Simmentaler were the best in terms of feedlot finishing and processing, respectively. These contradicting results showed the importance of a bottom-up approach to ensure that the fallacy of division does not occur and, secondly, that possible problem areas in the value chain are identified and addressed separately.

Keywords: water footprint; economic water consumption; cattle breeds; value chain analysis

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1. Introduction

Water footprint (WF) research initially set out to quantify water use and make recommendations regarding water use sustainability. The sustainable use of water, or any other natural resource for that matter, is, however, not the only factor that should be considered in the overall sustainability of businesses, sectors, or a country to preserve it for future generations. Elkington [1] coined the term "triple bottom line" (TBL), which refers to a sustainability framework that considers three parts, namely social, ecological, and financial. According to the TBL, a business will only be sustainable when it considers social equity (people), environmental stewardship (planet), and economic prosperity (profit).

The problem with improving more than one sustainability indicator is that these indicators are often negatively correlated. For example, although some research has shown that social sustainability practices directly reduce costs [2–4], Pullman, Maloni, and Carter [5] contradicted these findings. According to Pullman et al. [5], environmental efforts may reduce some costs, but these savings are negated by related cost increases or reduced income levels. The improvement of environmental stewardship in terms of the WF of a business should thus be done in such a manner that it does not ruin the economic prosperity of the business, and the water–economy nexus should therefore be considered. Ibidhi and Salem [6], who did a review of available literature on the WF of livestock production, echoed the statement above by stating that water use is often considered independently of other environmental and economic indicators and mentioned a need for combined indicators.

Previous studies that reported both water and economic impacts utilised either the economic water productivity (EWP) in monetary unit per volume [7–13] or the economic water consumption (EWC) in volume per monetary unit [14,15]. Both ways of reporting reveal the correlation between freshwater use and the economic impact of water use. Therefore, in principle, both reporting methods show the same thing in opposite directions. The question then remains: Which one of the two available reporting methods should be used?

It is impossible to discredit one method in favour of the other, as both are correct. The argument for and against the two reporting methods should be based on the applicability of the preferred method in terms of the specific research. However, WF research is always reported as the product/process water consumption per unit of output (m^3 or L WF/kg or tonne) and not as the product/process water productivity (kg or tonne/m^3 or L WF). It thus makes sense that the economic impact is reported in the same way as the water impact as the EWC in L or m^3 per one unit of monetary VA.

Another problem with the reported EWP or EWC of the previously mentioned authors is that almost all the studies estimated the economic contribution differently. Therefore, it is difficult to compare the results. For example, Aldaya et al. [8], Chouchane et al. [10], and Zoumides et al. [11], respectively, used the market price of the product, the value of the marginal product (VMP), and the gross value of the output as the economic contribution. Although all of these certainly can be seen as indicators of economic productivity, none of them genuinely grasps the total value added (VA) through the value chain as, for example, the value of by-products may not be included. Another problem is that some stages of production may have been omitted from the water use or WF estimation, and the estimated EWP may then be very high for the included production stages. None of these estimations can further be compared with one another as they all estimated the economic contribution differently.

Crafford et al. [7], Jordaan [9], and Owusu-Sekyere et al. [13] estimated EWP by expressing the VA per m^3 of water. Jordaan [9] and Owusu-Sekyere et al. [13] estimated the VA per m^3 of water for every step in the value chain. The problem with their approach was that the VA was calculated differently for primary agricultural production and processing. VA was considered the difference between the total revenue and the variable cost at the primary production level. In contrast, at the processing level, VA was regarded as the difference between the revenue of the processor and the price paid for the intermediate product, with no deduction of other costs. Crafford et al. [7] considered VA as the difference between proceeds from production and the cost of the intermediate products used for production.

The various estimations of the VA make it challenging to compare the different studies' results in terms of EWP. One also wonders which of the studies applied the correct procedure to estimate VA. The MacMillan Dictionary [16] defines VA as "the amount by which the value of a product increases as it goes through the different stages of being made and sold". Two critical factors stand out from the definition: The increase in the value of the product and the different stages of being made and sold (production stages). Therefore, from the beginning to the final stage of analysis, the increase in value of the product should be determined according to the various stages of production. A value chain analysis should thus be conducted to estimate the VA by each production stage.

Bockel and Tallec [17] stated that VA represents the value that the agent has added during the accounting period to the value of the inputs in the process of production or processing and defined it as:

$$\mathrm{VA} = \mathrm{Y} - \mathrm{II} \tag{1}$$

where Y is the value of the output and II is the value of the intermediate inputs used. VA is thus a measure of the creation of wealth, which is the contribution of the production process to the economy's growth.

Rudenko et al. [15] stated that VA includes the contributions of the production factors. Although it corresponds to the income received by the owners of these factors, it is not just an element of income. VA also represents income distribution among the four fundamental economic agents: Households, financial institutions, government administration, and non-financial enterprises. Rudenko et al. [15] further explained that VA could also be estimated as the difference between the sale price of a given product and the total production costs incurred to produce the product.

The calculation of VA, as proposed by Bockel and Tallec [17] and Rudenko et al. [15], in terms of value chain analysis, certainly holds water. It also does not pose a problem when used in conjunction with direct water use [9], but when VA is linked to the concept of WF analysis, it presents a problem. Since the WF of a product or process also includes the indirect use of water, it consists of the water embedded in the production inputs used to produce the product. Therefore, when estimating the EWP or the EWC, the total WF of the product (including the WF of the production inputs) is used in conjunction with the VA of only the specific process or product. This results in an under- or overestimation of the EWP/EWC. For example, when the WF of feedlot-finished calves is estimated, the WF of the feed (which is a production input) is included in the total WF of the finished calves. Suppose the VA is calculated by subtracting the cost of the production inputs (feed). In that case, only the VA by the feedlot in the feeding process is considered the total VA, while the total WF includes the WF of the production inputs. To correctly estimate the EWP or EWC for the feedlot, the cost of the production inputs should either be included in the total VA of the feedlot (in the event where the WF of the production inputs is included in the total WF) or the WF of these production inputs should be excluded from the total WF (in the event where the cost of the production inputs is subtracted from the total VA).

The VA for each production stage should thus be taken as the total revenue from the produced products minus the cost of the intermediate production inputs of which the WF is not included in the WF of the specific production stage or product. At the same time, the definition is based on the assumption that the revenue is more than the cost of intermediate production inputs.

The WF of different beef value chain links (cow–calf production, feedlot, and slaughterhouse) for different breeds of cattle was calculated by Maré and Jordaan [18,19] and Maré, Jordaan, and Mekonnen [20]. The authors of the three mentioned studies based the research on the fact that the WF should differ between breeds as the reproduction rate, feed conversion rate, carcass size, and muscle to bone ratio differ. The breed with the lowest WF for each value chain link was identified by the authors mentioned above. The authors did valuable work to calculate the WF through a bottom-up approach. They refined the WF calculation of cow–calf production [20], tested the influence of different feedlot feeding periods on the WF [18], and calculated the WF of processing beef and proposed a value fraction allocation model to allocate the WF to different cuts of beef [19]. However, the mentioned research failed to report the total WF of beef for the whole value chain and did not consider the economic VA with the WF results.

This study investigates different breeds of beef cattle, following the same production method, regarding their WF and economic VA for different links in the value chain through a bottom-up approach to identify the breed with the best EWC figures in terms of beef production. Three links in the beef value chain, namely cow–calf production, feedlot finishing, and processing (slaughterhouse and cutting plant), will be used to calculate the WF and VA of each link to finally report on the EWC of the final products in the form of different beef cuts.

2. Materials and Methods

To calculate the EWC for beef, the total WF (TWF) of all the production steps is divided by the total VA (TVA) from all the production steps for each breed (B):

$$\text{EWCB} = \text{TWFB}/\text{TVAB} \tag{2}$$

Two distinct data sets for each of the three value chain links are thus needed: The WF and the VA. The WF results from Maré et al. [20], Maré and Jordaan [18], and Maré and Jordaan [19] will be used as the WF for cow–calf production, feedlot finishing, and processing, respectively, and are summarised in Table 1.

Table 1. WF of cow–calf production, feedlot finishing, and processing of beef.

	Afrikaner	Brahman	Angus	Bonsmara	Simbra	Simmentaler	Limousin
Cow–Calf Production							
Total WF/WCalf (m^3)	12,797.3	14,543.3	13,133.2	13,343.8	14,443.6	17,229.3	18,503.7
Green WF/WCalf (m^3)	12,746.0	14,485.0	13,078.2	13,287.5	14,385.1	17,159.9	18,429.9
Blue WF/WCalf (m^3)	36.3	41.3	38.3	39.0	41.3	49.1	52.4
Grey WF/WCalf (m^3)	14.9	17.0	16.8	17.3	17.2	20.3	21.3
Feedlot Finishing							
Total WF/FFCalf (m^3)	1035.7	1097.4	1821.9	1409.1	1681.8	2413.1	2146.9
Green WF/FFCalf (m^3)	947.2	1003.6	1666.4	1289.5	1538.1	2207.8	1963.9
Blue WF/FFCalf (m^3)	27.0	28.6	46.0	35.4	42.6	60.1	54.1
Grey WF/FFCalf (m^3)	61.5	65.2	109.5	84.2	101.0	145.2	128.9
Processing							
Total WF/SCU (m^3)	73.4	73.4	73.4	73.4	73.4	73.4	73.4
Green WF/SCU (m^3)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Blue WF/SCU(m^3)	0.087	0.087	0.087	0.087	0.087	0.087	0.087
Grey WF/SCU (m^3)	73.3	73.3	73.3	73.3	73.3	73.3	73.3

WCalf denotes weaned calf, FFCalf denotes feedlot finished calf, and SCU denotes slaughtered cattle unit. Source: Compiled from Maré and Jordaan [18], Maré et al. [20], and Maré and Jordaan [19].

Maré et al. [20] calculated the WF of cow–calf production. They argued that the accepted methodology by Mekonnnen and Hoekstra [21,22] to calculate the WF of an animal over its lifetime is an underestimation of the WF of beef production. The problem with the WF over the lifetime of the animal is that the cow–calf producer has to keep an entire herd of cattle consisting of cows, young heifers, two-year-old heifers, and bulls, which all require water (feed, drinking, and service) to wean a certain number of marketable calves and culled cows. The WF of the entire herd should therefore be allocated to the weaned calves and culled cows according to the value factor of each [20] and the allocated WF for the weaned calves is used as the cow–calf WF in this study.

The WF calculation for a feedlot is more straightforward than for the cow–calf enterprise, but Maré and Jordaan [18] used two different economic scenarios for the calculation. The authors considered both a normal pre-determined feeding period (NPFP) where all breeds were fed for the same duration of time and a profit maximising feeding period (PMFP) where each breed was fed according to its growth performance until maximum profit was realised. The WF results for the PMFP are used in this study as, although the WF of this scenario was 1% higher than for the NPFP, the financial margin was 33% higher, thus reducing the WF per rand of margin by 24% [18].

Maré and Jordaan [19] calculated the WF for processing beef at the slaughterhouse and cutting plant and proposed a value fraction allocation model where the WF can be allocated according to individual cuts according to their value fraction. Both the processing WF calculated by the authors and the value fraction allocation model are utilised in this study. In terms of this study, the total WF of the value chain is allocated with the value fraction allocation model to the different cuts of beef.

The total WF of a slaughtered cattle unit (SCU) for a certain breed (WFB SCU) consists of the sum of the WFs of the weaned calf from the cow–calf production system (WFB WCalf) [20], the feedlot finished calf from the feedlot (WFB FFCalf) [18], and the processing at the slaughterhouse and cutting plant (WFB Processing) [19], and can be expressed as:

$$\text{WFB SCU} = \text{WFB WCalf} + \text{WFB FFCalf} + \text{WFB Processing} \tag{3}$$

To estimate the WF of beef, the WFB SCU should first be allocated according to the value factors (VFs) of the by-products and carcass, before the WF of the carcass is allocated to different cuts of beef according to the VF of each cut [19]. The WFB SCU was thus allocated according to the value fraction model of Maré and Jordaan [19], with the only difference being that WFProcessing was replaced with WFB SCU, and the total WF of the carcass (WFB C) is now estimated as:

$$\text{WFB C} = \text{WFB SCU} \times \text{VFB C} \tag{4}$$

The total WF of the breed TWFB is calculated by multiplying the WF of a cattle unit (CU) at slaughter (WFB SCU) for each of the breeds with the number of calves or CUs for that breed:

$$\text{TWFB} = \text{WFB SCU} \times \text{NB Calves or CU} \tag{5}$$

In terms of VA, it must be remembered that many products undergo various stages before they can be considered a final product. The final product of one producer/business can be an intermediate product or production input in the production process of another producer/business. For example, in the beef production chain, the primary producer of weaned calves uses different resources to produce the weaned calves as a final product. However, the weaned calf is considered by the feedlot as a production input to produce a final product in the form of feedlot finished calves. These finished calves are then considered a production input by the abattoir and deboning plant that produce final products of different meat cuts and by-products.

To determine the total value contributed to the economy and avoid any double counting, the VA must be accounted for at each production phase. Since the production of weaned calves is the first production step in the beef value chain, the VA is equal to the income from the weaned calves (VWCalves). Although the VA of the culled cows (VCulledCows) should also be calculated to divide the WF of the herd between the value fractions of the weaned calves (primary product) and culled cows (by-product), the VA of the culled cows is not included in the TVA as these animals do not move through the rest of the value chain.

The feedlot adds value to the value chain of beef production by increasing the weight of a weaned calf until it is ready to slaughter. Therefore, the VA by the feedlot is equal to the value at which the feedlot sells the feedlot finished calves (VFFCalves) minus the value at which the weaned calves were purchased (VWCalves), with no other deductions being made and the equation based on the assumption that the total revenue of the enterprise exceeds the total costs.

A slaughterhouse and cutting plant, in general, does not realise any profits on the carcass and cuts as it sells the cuts for more or less the same total value that was paid for the carcass. The total gross margin realised by the slaughterhouse and cutting plant thus stems almost solely from the by-products (head, offal, and hide) sold. The VA per SCU (VASCU) by the slaughterhouse and cutting plant to the economy is thus equal to the value of the by-products (VBP).

Since the VA by each link in the value chain is expressed differently, according to a live weaned calf, a feedlot finished calf, or slaughter unit, the easiest way to calculate the total VA by the different breeds (TVAB) is to multiply the VA of each link in the value chain with the total number of calves weaned from the cow–calf production system:

$$\text{TVAB} = \text{NB Calves or CU}(\text{VAB WCalf} + \text{VAB FFCalf} + \text{VAB Processing}) \tag{6}$$

where NB Calves or CU denotes the number of calves or CUs (depending on the value chain link) for the breed, and VAB WCalf/FFCalf/Processing is the VA per unit of the breed for every link in the value chain. The data used to calculate the VA for each value chain link are presented in Table 2.

Table 2. Value addition of the different breeds for each link in the value chain.

Breeds	Afrikaner	Brahman	Angus	Bonsmara	Simbra	Simmentaler	Limousin
Calves weaned	790	688	779	783	688	558	516
Cow–calf							
Weaning weight (kg)	210	232	227	250	231	222	242
Price	R29.00	R29.00	R29.00	R29.00	R29.00	R29.00	R29.00
VA (VWCalves)	R3,235,749	R3,113,548	R3,447,679	R3,816,955	R3,100,451	R2,414,569	R2,434,091
Feedlot							
Live weight kg	376	409	506	472	493	594	575
Dressing %	57%	59%	58%	58%	60.5%	62%	63%
Price/kg Carcass	R35.00	R35.00	R35.00	R35.00	R35.00	R35.00	R35.00
VFF Calves	R5,925,653	R5,812,111	R8,004,849	R7,498,244	R7,180,406	R7,193,485	R6,530,406
VA (VFF Calves–VWCalves)	R2,689,903	R2,698,563	R4,557,170	R3,681,289	R4,079,955	R4,778,917	R4,096,315
Processing							
By-product weight							
Head (kg)	10.95	12.37	13.79	14.87	13.11	16.44	15.00
Offal (kg)	43.10	48.70	54.29	58.55	51.60	64.73	59.04
Hide (kg)	32.62	36.86	41.08	44.30	39.05	48.98	44.68
By-product value							
Head @ R100/head	R100.00	R100.00	R100.00	R100.00	R100.00	R100.00	R100.00
Offal @ R9.35/kg	R402.98	R455.36	R507.60	R547.40	R482.48	R605.22	R552.02
Hide @ R15.50/kg	R505.54	R571.25	R636.79	R686.72	R605.28	R759.26	R692.51
VA (VBP)	R796,907	R775,365	R925,111	R1,044,565	R856,509	R816,839	R693,516

R denotes South African rand (ZAR). The USD/ZAR exchange rate at the time of data collection was USD 1.00 = ZAR 12.78.

The prices used in Table 2 to calculate the VA were the actual market prices at the time of the experiment. The feedlot, where the feeding experiment took place, paid the same price (R/kg) for weaned calves from the various breeds and thus did not differentiate between the breeds. Although it is common for beef prices to differ between breeds in some other countries, this principle does not apply in South Africa as the branding of beef according to breed is still an uncommon practice. Therefore, the carcass price (R/kg) was also the same for all the breeds. The carcass price only differs between different carcass classifications, but all carcasses were classified as A2.

3. Results

The results of the study are presented in two parts. The first part reports on the total WF of the different breeds, allocated to the individual cuts, while the second part reports on the EWC of producing beef from the various breeds.

3.1. The Water Footprint of Beef Produced from Different Cattle Breeds

The WFs of beef produced from different cattle breeds are presented in Table 3. The first section of Table 3 provides the WFs of an SCU for each of the seven breeds. Although it is clear that the total WF/SCU differs drastically between the breeds, there is no use comparing these figures as the relative weight of the products (carcass and by-products) derived from a CU of each breed differs. The total WF/SCU is thus only calculated and included in the table to base the rest of the product WFs on.

The second part of Table 3 provides the WFs of the by-products and carcasses of the different breeds. In terms of the by-products, the Bonsmara had the smallest WF/kg by-products at 13,539 L/kg, while the Limousin exhibited the largest WF/kg by-products at 18,756 L/kg. The differences in the WF/kg by-products for the different breeds were notably large, with the WF of the Angus, Simbra, and Simmentaler being, respectively, 16%, 18%, and 20% larger than that of the Bonsmara. In comparison, the Brahman and Afrikaner revealed differences of 29% and 30% compared to the Bonsmara. The Limousin's WF/kg by-products are 39% higher than that of the Bonsmara.

Table 3. The water footprint of beef produced from different cattle breeds.

Breeds	**Afrikaner**	**Brahman**	**Angus**	**Bonsmara**	**Simbra**	**Simmentaler**	**Limousin**
Total WF/CU (m^3)	13,906	15,714	15,029	14,826	16,199	19,716	20,724
Green WF/CU (m^3)	13,693	15,489	14,745	14,577	15,923	19,368	20,394
Blue WF/CU(m^3)	63	70	84	74	84	109	107
Grey WF/CU (m^3)	150	156	200	175	192	239	224
WF/kg by-products (BP)							
WBP (kg)	86.66	97.93	103.76	117.72	109.16	130.16	118.72
VFBP	0.110	0.109	0.108	0.108	0.108	0.107	0.107
Total WF/kg BP (L)	17,662	17,483	15,710	13,539	16,036	16,180	18,756
Green WF/kg BP (L)	17,391	17,232	15,413	13,311	15,763	15,894	18,457
Blue WF/kg BP (L)	81	78	88	68	83	90	96
Grey WF/kg BP (L)	190	173	209	160	190	196	202
WF/kg carcass (C)							
WC (kg)	232.97	263.25	278.93	316.46	293.45	349.89	319.13
VFC	0.890	0.891	0.892	0.892	0.892	0.893	0.893
Total WF/kg C (L)	53,122	53,189	48,035	41,814	49,236	50,330	57,962
Green WF/kg C (L)	52,307	52,426	47,128	41,111	48,398	49,441	57,039
Blue WF/kg C (L)	242	237	269	210	255	279	298
Grey WF/kg C (L)	572	526	638	493	582	610	625
WF/kg rib eye (RE)							
WRib eye (kg)	3.03	2.90	3.91	4.11	3.52	3.85	4.47
VFRib eye	0.042	0.036	0.045	0.042	0.039	0.036	0.045
Total WF/kg RE (L)	172,473	172,691	155,958	135,760	159,857	163,409	188,188
Green WF/kg RE (L)	169,828	170,213	153,012	133,477	157,137	160,523	185,190
Blue WF/kg RE (L)	787	769	875	682	829	906	968
Grey WF/kg RE (L)	1858	1709	2072	1601	1891	1980	2030
WF/kg topside (TS)							
WTopside (kg)	12.58	15.01	14.23	16.14	15.55	17.49	18.83
VFTopside	0.070	0.073	0.066	0.066	0.068	0.064	0.076
Total WF/kg TS (L)	68,437	68,524	61,884	53,870	63,431	64,841	74,673
Green WF/kg TS (L)	67,388	67,540	60,715	52,964	62,352	63,696	73,483
Blue WF/kg TS (L)	312	305	347	271	329	359	384
Grey WF/kg TS (L)	737	678	822	635	750	786	806
WF/kg flank (F)							
WFlank (kg)	10.25	12.11	12.55	12.97	11.15	12.25	11.81
VFFlank	0.043	0.045	0.044	0.040	0.037	0.034	0.036
Total WF/kg F (L)	51,673	51,738	46,725	40,674	47,893	48,957	56,381
Green WF/kg F (L)	50,881	50,996	45,842	39,990	47,078	48,093	55,483
Blue WF/kg F (L)	236	231	262	204	248	271	290
Grey WF/kg F (L)	557	512	621	480	567	593	608

The total WF/kg carcass also revealed large differences between the various breeds. The Bonsmara, as in the case with the by-products, had the smallest WF/kg carcass at 41,814 L/kg, while the Limousin had the largest at 57,962 L/kg. Although the order of the breeds remains relatively similar to the by-products, it is interesting to note that the WF/kg carcass of the Afrikaner was a bit lower than the Brahman's. At the same time, it was the other way around in the case of the by-products. The percentage difference in WF/kg carcass between the breeds also varied slightly from the differences between the breeds in terms of the by-products. The WF/kg carcass of the Limousin was 39% higher than that of the Bonsmara, while the Brahman, Afrikaner, Simmentaler, Simbra, and Angus had WFs/kg carcass of, respectively, 27%, 27%, 20%, 18%, and 15% more than the Bonsmara.

The fact that the ranking order and size of the differences in the various breeds' WFs of the by-products and carcasses differed in relation to the Bonsmara is quite interesting. The by-products and carcass WFs were allocated according to the VF of the carcass and by-products, with the same product prices (R/kg) used for all the breeds. The reason for different rankings when the WFs of the by-products and the carcasses are compared stems from the differences in the dressing percentage (weight of the carcass expressed as a percentage of the live animal weight) between the breeds. Using the Afrikaner and Brahman as an example, since they switched positions in the ranking, the influence of the dressing percentage is apparent. Concerning the by-products, the Afrikaner had a larger WF/kg than the Brahman, while it was the other way around in terms of the WF/kg carcass. The dressing percentage of the Afrikaner was 57.61%, while that of the Brahman was 61.36%. This results in the Afrikaner's VF of the by-products being higher than that of the Brahman, and a larger share of the WF is thus allocated to the by-products of the Afrikaner than in the case of the Brahman. However, it works the other way around in terms of the WF/kg carcass, and a smaller part of the Afrikaner's total WF is thus allocated to the carcass than in the case of the Brahman.

The third section of Table 3 provides the total WF/kg beef according to three different cuts of beef (rib eye, topside, and flank). Regarding the WF of beef, there are large variations between the breeds and between the different cuts of beef from the same breed. Comparing the WFs of the beef cuts among the breeds, the Bonsmara revealed the smallest WF/kg for all the cuts, while the Limousin had the largest WF/kg for all the cuts. The total beef cut WFs of the Bonsmara for rib eye, topside, and flank were 135,760 L/kg, 53,870 L/kg, and 40,674 L/kg. The beef cut WFs of the Limousin were on average 39% larger at 188,188 L/kg rib eye, 74,673 L/kg topside, and 56,381 L/kg flank.

The rest of the breeds had the same ranking in their beef WFs for each cut. Although the percentage difference of each breed to the Bonsmara differed slightly for various cuts, the differences were negligibly small. The average percentage differences in the WFs/kg beef of all three cuts for the various breeds to the Bonsmara were 15%, 18%, 20%, 27%, 27%, and 39%, respectively, higher for the Angus, Simbra, Simmentaler, Afrikaner, Brahman, and Limousin.

Although these substantial variations between the breeds point out the importance of breed selection when one aims to reduce the WF of beef consumption, the variation between the WFs of different beef cuts for the same breed is even more prominent. Since the WF of each beef cut is calculated according to the VF of the specific cut, rib eye, which is considered a high-value cut, is allocated a larger share of the WF than topside (medium-value cut) and flank (low-value cut). In terms of all the breeds, the WF/kg topside is equal to only 40% of the rib eye's WF/kg, while flank's WF/kg only comprises 30% of the WF/kg rib eye. The WF of the topside for Bonsmara beef is 81,890 L/kg smaller than that of rib eye, while the WF of the flank is 95,086 L/kg less than that of rib eye. The differences are even more prominent in the breeds with higher overall beef WFs/kg, with a kilogram of Limousin rib eye having 113,515 L/kg and 131,807 L/kg larger WFs than topside and flank, respectively.

3.2. The Water–Economy Nexus of Beef Produced from Different Cattle Breeds

The EWC of beef for the various breeds is presented in Table 4. The EWC was estimated based on the assumption that all the weaned calves moved through the entire value chain.

When the various breeds in Table 4 are compared on the total WF/herd over the whole value chain, it is interesting to see that the difference between the breed with the lowest total WF (Limousin) and the breed with the highest total WF (Angus) is only 10%. It thus may seem that the choice of breed only has a marginal impact on the WF of beef production. However, the WF/herd of the various breeds over the entire value chain is only a total consumptive indicator and is not linked to the production statistics of the breeds. Therefore, to compare the breeds with one another, a WF efficiency indicator should be used, such as the EWC, where the WF is expressed per unit of economic VA.

Table 4. The economic water consumption of beef produced from different cattle breeds.

Breeds	**Afrikaner**	**Brahman**	**Angus**	**Bonsmara**	**Simbra**	**Simmentaler**	**Limousin**
No. of calves	790	688	779	783	688	558	516
Total WF (m^3/herd)	10,988,486	10,814,879	11,705,332	11,608,492	11,149,646	10,996,831	10,689,574
Green WF (m^3/herd)	10,819,971	10,659,667	11,484,186	11,413,302	10,959,957	10,802,639	10,519,279
Blue WF (m^3/herd)	50,140	48,184	65,659	58,325	57,806	60,966	54,984
Grey WF (m^3/herd)	118,375	107,028	155,486	136,866	131,883	133,227	115,312
Total VA (R/herd)	R6,722,560	R6,587,476	R8,929,961	R8,542,810	R8,036,915	R8,010,324	R7,223,922
Cow–calf (R/herd)	R3,235,749	R3,113,548	R3,447,679	R3,816,955	R3,100,451	R2,414,569	R2,434,091
Feedlot (R/herd)	R2,689,903	R2,698,563	R4,557,170	R3,681,289	R4,079,955	R4,778,917	R4,096,315
Abattoir (R/herd)	R796,907	R775,365	R925,111	R1,044,565	R856,509	R816,839	R693,516
Total EWC (L/R)	1634.57	1641.73	1310.79	1358.86	1387.30	1372.83	1479.75
Green EWC (L/R)	1609.50	1618.17	1286.03	1336.01	1363.70	1348.59	1456.17
Blue EWC (L/R)	7.46	7.31	7.35	6.83	7.19	7.61	7.61
Grey EWC (L/R)	17.61	16.25	17.41	16.02	16.41	16.63	15.96

A comparison of the breeds in terms of total VA per herd revealed that the Brahman adds the least value at ZAR 6.59 million, while the Angus adds the most at ZAR 8.93 million (36% more than the Brahman). The Afrikaner, Limousin, Simmentaler, Simbra, and Bonsmara add 10%, 22%, 22%, and 30% more value throughout the value chain than the Brahman. However, it must be kept in mind that the total amount of product (beef) produced and the amount of production input used to produce this product also vary between the breeds. Since we are interested in the productivity with which water is used, the VA by each breed should thus be expressed in terms of the water needed if one wants to compare the breeds.

It is interesting to see that the ranking order of the EWC of the different breeds differs from both the ranking order of the total WF of the herds and the ranking of the total VA of the herds. In terms of the EWC, the Angus had the lowest EWC at 1311 L/R, while the Brahman had the highest consumption at 1642 L/R. The Angus consumed 4%, 5%, and 6% less water per rand of economic VA than the Bonsmara, Simmentaler, and Simbra, respectively. On the other hand, the Limousin consumed 13% more water per rand of economic VA than the Angus, while both the Afrikaner and Brahman consumed 25% more.

4. Discussion

The objective of this study was to analyse different breeds of beef cattle, following the same production method, regarding their WF and economic VA for different links in the value chain through a bottom-up approach to identify the breed with the best EWC figures in terms of beef production.

Three different cuts of beef were used to calculate the WF/kg of each cut according to the VF of each cut. The cut of beef with the smallest WF was Bonsmara flank, with a total WF of 40,674 L/kg, while the cut of beef with the largest WF was Limousin rib eye at 188,188 L/kg. The estimated beef WFs of this study are huge, even for the cut and breed with the lowest WF, compared with other studies. Since previous research did not distinguish between different breeds or cuts of beef, for comparison purposes, the average WFs of all three cuts over all the breeds were used as the beef WF/kg for this study.

Table 5 provides a comparison between the results of this study and the results of some previous studies that estimated the WF/kg of beef. It is clear from Table 5 that the total WF of beef from this study is much larger than the results of Mekonnen and Hoekstra [23] for both South Africa and the rest of the world.

Table 5. Comparison of results with other literature.

	This Study	**Mekonnen and Hoekstra [23]**	**Mekonnen and Hoekstra [23]**	**Palhares et al. [24]**	**Harding et al. [25]**
Location	Free State, SA	South Africa	Global	Brazil	South Africa
Production system	Mixed	Weighted average	Weighted Average	Industrial	Mixed
Value chain links	Production to processing	Production	Production	Feedlot only	Production to processing
Approach	Bottom-up	Top-down	Top-down	Bottom-up	Top-down
Product	Boneless beef	Boneless beef	Boneless beef	Boneless beef	Carcass
Total WF (L/kg)	92,764	17,387	15,415		
Green WF (L/kg)	91,232	17,050	14,414	5039	
Blue WF (L/kg)	470	226	550	769	437
Grey WF (L/kg)	1061	111	451		

Before any comparison with previous research can take place, one should keep in mind that the methodology applied in this study is new with a much wider scope than that of previous studies. In this study, the yearly WF of the total cattle herd was divided through the yearly offtake (weaned calves and culled cows) in terms of cow–calf production, while the other studies calculated the WF over the lifetime or production phase of a specific animal. The question is thus rather how the differentiated methodology influences the WF of beef when compared to previous studies.

When one compares the estimated blue WF of the different studies, the results from this study are much in line with the results of others. While the blue WF of 470 L/kg of boneless beef in this study is larger than the weighted average for South Africa by Mekonnen and Hoekstra [23], it is smaller than the global weighted average by the same authors. The blue WF of this study is also smaller than the blue WF average of beef produced in Brazilian feedlots [24], while it is only 33 L/kg larger than the blue WF that Harding et al. [25] estimated for beef produced in South Africa.

The grey WF of a kilogram of boneless beef in this study is considerably higher than Mekonnen and Hoekstra's [23] for South Africa and the rest of the world, while the other two studies [24,25] did not estimate the grey WF. The large difference in the grey WF between this study and the study conducted by Mekonnen and Hoekstra [23] can be ascribed to the fact that they used a top-down approach to estimate the WF and worked only with production data (meat production and feed consumption). On the contrary, in this study, a bottom-up approach was used. The beef processing (slaughter and deboning) was included [19] and contributed the largest part of the estimated grey WF footprint.

Since the blue WF of this study relates well to the results from other studies, and even though the grey WF is more than double that of Mekonnen and Hoekstra [23], the difference in the total WF is still very large compared to previous research. Therefore, closer attention should be paid to the green WF. The green WF of this study is basically five times larger than the estimated South African WF calculated by Mekonnen and Hoekstra [23]. The reason for the large differences may be ascribed to the fact that Mekonnen and Hoekstra [23] estimated the consumption of natural grazing from the amount of beef produced by applying estimated feed conversion ratios (FCRs) in a top-down approach. In the case of this research, a more accurate analysis was conducted through a bottom-up approach, where the evapotranspiration (ET) of the required natural grazing was estimated with satellite imagery [20]. The green WF from the natural grazing in this study may also be larger since the total feed requirement of the herd was used by Maré et al. [20] to express the WF of the offtake (weaned calves and culled cows) according to the VF of each, instead of using the feed requirements for the animals that were slaughtered only.

The inclusion of the green WF of natural grazing in the total WF of an animal product remains open for debate. Although it was included in this study to provide a complete view on the WF of beef, it must, on the other hand, be kept in mind that even in the case where no farm animals grazed on the available natural grazing, the green WF of this grazing would have remained the same. If the green WF of the natural grazing is subtracted from the WF calculations, the average total WF of all the breeds and cuts reduces from 92,764 L/kg to 9892 L/kg, while the green WF decreases from 91,232 L/kg to 8361 L/kg.

Even though the green WF of beef in this study increases the total WF of beef to levels much higher than other previous studies, the blue and grey WFs relate well to prior studies when the differences in the calculation frameworks are considered. The estimated WF results of this study can thus be used as the WF of beef produced from a cow–calf production system and finished in a feedlot according to the optimal growth curve of each breed before being processed.

When one considers the EWC results of the study, it may be concluded and recommended that all the cattle in the Edenville region of the Free State province in South Africa should be replaced with Angus cattle, as their EWC is the lowest and the economic VA from the consumed water will be maximised. It may further be recommended to consumers that they should only consume low-value beef cuts to decrease their personal WFs. The question, however, is if these conclusions and recommendations are as simple as that?

The Angus may be the breed of choice in terms of EWC for beef production over the whole value chain (Table 4), but when the individual links of the value chain are considered, the picture changes. The EWC of the different value chain links is presented in Table 6. In terms of primary cow–calf production, the EWC of the Bonsmara was the smallest, while the Limousin was the breed of choice for the feedlot. The Simmentaler, on the other hand, had the lowest EWC in terms of processing.

Table 6. Economic water consumption of the different breeds and value chain links.

	Afrikaner	**Brahman**	**Angus**	**Bonsmara**	**Simbra**	**Simmentaler**	**Limousin**
Cow–Calf EWC							
WFVA (Litre/R)	3125	3215	2967	2737	3206	3980	3921
Green WFVA (Litre/R)	3113	3202	2955	2726	3194	3964	3906
Blue WFVA (Litre/R)	8.90	9.10	8.60	8.00	9.20	11.30	11.10
Grey WFVA (Litre/R)	3.60	3.70	3.80	3.50	3.80	4.70	4.50
Feedlot EWC							
WFVA (L/R)	304	280	311	300	284	282	270
Green WFVA (L/R)	278	256	285	274	259	258	247
Blue WFVA (L/R)	7.94	7.30	7.86	7.53	7.19	7.02	6.81
Grey WFVA (L/R)	18.07	16.63	18.71	17.91	17.05	16.95	16.23
Processing EWC							
WFVA (L/R)	72.81	65.18	59.01	55.04	61.82	50.14	54.61
Blue WFVA (L/R)	0.09	0.08	0.07	0.07	0.07	0.06	0.06
Grey WFVA (L/R)	72.72	65.10	58.94	54.98	61.75	50.08	54.55

The results from the various value chain links and the results from the total value chain for beef seem to contradict one another because, in terms of EWC, the Angus was not the breed of choice for any one of the individual links, but it is for the entire value chain. The reason for this may be in the different approaches to estimate the best breed in terms of each value chain link by Maré and Jordaan [18], Maré et al. [20], and Maré and Jordaan [19], and in terms of the whole value chain. In terms of the various value chain links, each link was analysed separately, and the breed that minimises the WF in terms of a year's operations was identified [18–20]. In addition, in this study the original number of weaned calves from the cow–calf enterprise [20] was taken through the value chain to compare the breeds in terms of the whole value chain.

The contradiction between the results of the various value chain links and the value chain as a whole, however, also proves that the reporting of WF, VA, and EWC results is not as simple as a weighted total average for a country, region, or production system. For example, when one compares the WF of different products, or the same product from different production systems, calculated with a top-down approach, it is easy to become a victim of the fallacy of division. This fallacy asserts that what is true for the whole must be true for any piece of the whole as well [26]. In the event where the EWC of the breeds, for the same region and production system, was estimated through a top-down approach, the conclusion that the Angus should be the breed of choice would have been accepted. The assumption would have been that the Angus would be the best breed for all the links in the value chain. However, the results of the different value chain links showed that one would have been guilty of the fallacy of division by making such an assumption. The principle may also be true for previously published WF results for different products and production systems on a country or regional level. One may believe, for example, that since the WF of lamb is lower than the WF of beef for a particular country and production system, the production and consumption of lamb rather than beef in the specific country will reduce the overall WF of the country. However, this may not be true if different regions, the type and availability of natural grazing, and the water stress levels are considered. The same can be said for the consumption of lower valued beef cuts to reduce one's personal WF. Although one's personal consumptive WF will be reduced, it will not affect the WF of beef in general as the rest of the carcass, including the higher-value products with higher WFs, will also be consumed in the market.

5. Conclusions

The WF approach had previously been applied in numerous studies to estimate the green, blue, and grey WFs of products, processes, businesses, and countries, to name a few. In some previous studies, there were also attempts to combine the WF with an economic indicator to provide a more comprehensive picture of both the ecological and economic scenarios in question. Even though all the previous studies conducted on these aspects certainly deserve their place in research, there were certain gaps in the knowledge. For example, in the past, very little attention was paid to value chain analysis (VCA) through a bottom-up approach in combination with WF to provide a WF for each link in the value chain. There was also no consensus on which economic indicator to use in conjunction with WF research, which factors should be included in this economic indicator, and if it should be used to estimate EWC or EWP. Another gap in current knowledge is that the consumer cannot make informed decisions regarding WFs when purchasing products as information on the WF of the specific product under consideration often does not exist.

Based on the results of this study, it can be concluded that the approach that was followed assisted in addressing many of the current gaps in the knowledge and can be applied to other regions, products, or production systems. The applied bottom-up approach for calculating the WF and economic VA enables one to address each of the value chain links on their own. This is a critical aspect as the various value chain links are not always situated in the same region, and the WF results can then be paired with the water availability of the specific region to conduct a sustainability analysis. The individual results further enable one to identify the particular link with problems if it is found that the total WF is too large.

The estimated EWC brings the aspects of ecological stewardship and economic prosperity together. Although this indicator does not necessarily indicate the sustainability of the production process, it does show whether the consumed freshwater contributes to the economy and how much.

The calculation framework to determine the WF of various cuts of beef according to the VF of each supply type provides much-needed information that can be applied to inform consumers about the WF of their food choices. Even though the purchasing of cuts with a lower WF will not assist in reducing the WF of beef, since the WF of the carcass remains the same, it can be used to make consumers more aware of their personal WFs. This may lead to a scenario where consumers insist on knowing the WF of the products they consume, which may help keep products of which the water use is not sustainable off the shelves.

There were, however, also some limitations to the study. First, since WF research is still a relatively young research field, the total scope of water that should be included in the WF of a product or process should be defined better. This study did widen the sources of water which should be included in the WF of beef, but is it enough and where should one stop? Secondly, since livestock research with feeding experiments is very expensive, the research was only done for one production system and a relatively small production region. The research should be expanded to other systems and regions as well. Thirdly, since this is the first time the specific methodology was applied, it was difficult to compare it with previous results to really judge the accuracy of the research.

To improve the EWC of beef production, it is recommended that primary cow–calf producers evaluate the reproduction performance of the breed which they are farming. Suppose the reproduction performance, and thus the associated EWC, is not on par with the results of this study. In that case, they should either improve the reproduction performance through management and selection practices or switch to a breed with better overall production statistics. It is further recommended that feedlot owners consider precision feeding practices to address the variability in terms of the growth curve of different breeds by introducing different feeding periods and possibly other feed rations to optimise each breed's feedlot growth performance, thereby improving the EWC of the feedlot. Although it was proven that it is ecologically and economically more beneficial for the abattoir and deboning plant to process CUs from larger breeds, it is practically impossible. To improve the EWC of processing beef, it is recommended that the abattoir reduce its grey WF through the pre-treatment of wastewater, enhancing the effluent quality.

Water remains a scarce resource that should be protected and managed by government policies. The problem with current water management in South Africa is the fact that there is basically no, or very little, control over the use of groundwater (from boreholes) in agriculture. Since this water use is not regulated through pricing or other policies, the landowners can use as much groundwater as they like for agricultural production purposes. Since the WF includes groundwater in the blue WF, limitations on the WF of a particular product through policy formulation can assist. The formulation of any policy should, however, be based on solid research that supports the policy. Although all WF research may undoubtedly contribute to future policy formulation, it is recommended that no policy regarding the WF of products should be formulated unless detailed information regarding the WFs of the different value chain links is available. It is recommended that policymakers apply the results of this study to start developing WF benchmarks for the various value chain links in the beef production value chain. The WF benchmark ranges can then be used to formulate tax incentives for farmers, feedlots, and processors whose WFs are within the ranges or tax burdens for those whose WF is higher than the set ranges.

It is recommended that future research estimate the WF, VA, and EWC of any product separately for each link in the value chain through a bottom-up approach. The detailed information from the different value chain links will firstly ensure that the fallacy of division does not occur and, secondly, that possible problem areas in the value chain will be identified and be addressed separately. It is also recommended that when the water–economy nexus of products or processes is analysed in WF research, the EWC should be used rather than the EWP. Moreover, it is recommended that the economic indicator for EWC should be the economic VA, which is equal to the total revenue of a specific value chain link minus the cost of the production factors, of which the WF is not estimated and thus does not form part of the total WF. The WFs of primary, secondary, and by-products allocated according to the VF of each do help break down the total WF. Still, the consumption of the lower-value products with smaller WFs, instead of the high-value products with larger WFs, does not improve the total overall WF. Based on this fact, it is proposed that future research considers other approaches to divide the WF among primary, secondary, and by-products, or that the same WF is used for all product variations. Lastly, in terms of future research, it is recommended that more attention should be paid to methods that will reduce the WF of products.

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