REVIEWS IN Aquaculture

Reviews in Aquaculture, 1–18 doi: 10.1111/raq.12373

Infrastructure, management and energy efficiency in a hypothetical semi-intensive shrimp model farm in Brazil: a systematic review and meta-analysis

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Received 24 June 2019; accepted 10 July 2019.

Abstract

The goal of this study was to characterize the main operational processes adopted by a shrimp aquaculture pond system in Brazil and to account the flows of energy use. The characterization was carried out via application of the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRIMA) methodology. The accounting of the energy flows was made through the quantification of the energy coming from economically required resources. Based on the data and characteristics identified in Brazilian shrimp farms, a hypothetical farm consisting of four nursery tanks, nine ponds, feed, fertilizer and general deposits, a refectory, restrooms and dressing rooms, garage, and main and secondary access roads. In this hypothetical shrimp farm, the water pumping was performed by a 20 hp pump, and aeration was performed via 4 hp paddle-type aerators. A biphasic operating system and a semi-intensive production regime were adopted, with a initial stocking density of 43 shrimp m^{-2} and harvest occurring when the shrimp reached an average weight of 12 g. The cultivation cycle lasted 90 days and include the pond preparation and curing period. The final yield was estimated to be 3500 kg ha^{-1}. The total energy cost was calculated as 835.597 MJ. The most energy inputs were feed, fuels and lubricants and electricity. Shrimp production in ponds is a very intensive activity relative to the energy demand and that increasing energy efficiency is one of the essential conditions for the truly sustainable production of long-term Brazilian shrimp farming not only for environmental but also mainly for economic reasons.

Key words: description shrimp aquaculture in Brazil, energy flux, grow-out phase, PRISMA methodology, shrimp aquaculture, shrimp farm energy indicators.

Introduction

The production of marine shrimp in captivity is an activity of significant economic importance in several countries. In 2016, world production reached 7862 thousand tons, generating an estimated revenue of 36 billion dollars (FAO, 2018). Of this total, according to FAO (2016b), 53% (4156 thousand tons) were from the cultivation of *Litopenaeus vannamei*, popularly known as white-legged shrimp. Although most productive ventures are concentrated in Asian countries (Abrunhosa 2016; Fao, 2016a), Latin America is notable for its great potential for expansion, especially in Ecuador, Mexico and Brazil (Leadership 2013).

In addition to the economic issues directly involved in production and marketing, shrimp farms are usually assessed by the impacts (positive and negative) associated with social and environmental issues (Carvalho & Martins 2017).

According to Rocha (2015), the degree of organization of Brazilian shrimp farming is not parallel in other sectors of national aquaculture. Its production chain is structured in three main pillars: (i) breeding and larviculture units; (ii) shrimp farms; and (iii) processing plants (Natori *et al.*

2011; ABCC, 2013). All of these pillars are supported by a complex supply network involving products and services: equipment suppliers (for water quality measurement, pumps, motors, machinery and equipment such as feeders, compressors, aerators, generators, shrimp processing equipment, etc.); inputs (mainly feed, fertilizer, limestone, ice and several chemical products) and general services (project design, consulting, rural extension, specialized labour, market analysis and logistics) (Costa & Sampaio 2004). The result of this strong and well-structured productive chain is reflected in job creation, employment (estimated at 3.75 jobs per cultivated hectare in Brazil) and income (ABCC, 2017a,2017b).

In contrast, there are a number of potential negative impacts that are mainly associated with the operation of shrimp farms that need to be avoided and mitigated, such as the discharge of effluents, which can lead to eutrophication of the adjacent water environments (Ribeiro *et al.* 2016; Soo *et al.* 2016); the degradation of mangroves for the construction of farms ant its ancillary structures (Bayles *et al.* 2016; Pham & Yoshino 2016); the reduction in biodiversity (Hossain *et al.* 2013); and negative social impacts, such as conflicts with other users, especially with traditional communities (Dias *et al.* 2012; Pinto *et al.* 2015). In addition, the grow-out phase is considered to be one in which there is a higher energy and financial expenditure compared with the previous stage (larviculture) and the following phase (processing) (Larsson *et al.* 1994; Cao *et al.* 2011; Albertim- Santos *et al.* 2015).

The processes that occur during the grow-out phase of shrimp farming in Brazil are represented schematically in Figure 1. The process begins with the arrival of post-larvae (PL) to the farms. In most of the farms there is no direct transference to the ponds, but there is a transfer of PL to the nurseries tanks. That stage, has an average duration of 15 to 30 days, depending on the age of the PL acquired, frequent biometrics and the rigorous control of water quality are performed. In nurseries, the PL are fed with commercial dry feed and, in some cases, receive artemia for supplementation. Then, the PL are transferred to previously prepared (through the oxidation of residual organic matter, disinfection, soil correction and fertilization) ponds. The total period of the grow-out phase, which usually lasts for 3 to 4 months, depends on the region of the country where the enterprise is located; the season of year; the initial size of the PL; the nutritional and food management plan adopted; the monitoring water quality; biometrics and shrimp sanitation monitoring; as well as the renewal and replacement of lost volumes (through infiltration or evaporation) of water. In this phase, the effluent must be controlled, and the water can generally be reused, after passing through sedimentation and stabilization tanks, or discarded. At the end of the grow-out stage, the shrimp are harvested and sent to processing units. Some specimens may be used for the formation or renewal of breeding stocks.

An analysis of the energy indicators during the shrimp farming process in ponds can provide the elements for the optimization of the use of general resources and for the reduction of the negative impacts associated with the activity (Boyd *et al.* 2007). An indicator widely used for this purpose is energy accounting (EA) (Tyedmers 2004), which is based on a set of parameters for quantifying the energy flows of a given economic activity (Folke 1988). There are several parameters that can be evaluated in EA, such as efficiency (η), intensity (EI) (Troell *et al.* 2004), productivity (EP) (Hamedani *et al.* 2011) and energy balance (EB) (Ulbanere 1988).

Although the Brazilian shrimp farming scenario presents a horizon of expansion, it faces challenges regarding environmental, economic and social issues. Thus, the analysis of energy-use during cultivation can be considered an auxiliary tool for a more orderly and efficient development of the activity through the identification, and subsequent correction, of the main causes of inefficiency, idleness and energy waste. The objective of the present study was to characterize the use of infrastructure and the main operational processes adopted by a typical shrimp aquaculture pond system in Brazil and to account the flows of energy use by a shrimp model farm.

Materials and methods

Characterization of the structural, technical and operational data of the hypothetical farm

The analysis of the energy use in a typical Brazilian shrimp farm was carried out through the establishment of a hypothetical enterprise. The characterization of such a "conceptual farm" was made using data acquired through a systematic review of the literature and the application of the PRISMA methodology (Preferred Reporting Items for Systematic Reviews and Meta-Analyses). (Moher *et al.* 2009). Based on the results obtained in this review, the structural and operational characteristics of the hypothetical enterprise as well as the zootechnical parameters (technical data) associated with shrimp farming were predefined. The cultivation cycle lasted 90 days and include the pond preparation and curing period.

The bibliographic review was performed using restricted IP access from the Federal University of Paraná - UFPR, Brazil, on the following platforms and scientific databases: Web of Knowledge, Wiley Online Library, Web of Science, Science Direct, Springer, Portal of Newspapers CAPES, Scopus, Google search engine and Google Scholar. We searched for books, technical and scientific articles, case studies, theses and dissertations published through March 2018 that presented the terms listed in Table 1 in their titles, abstracts or keywords.

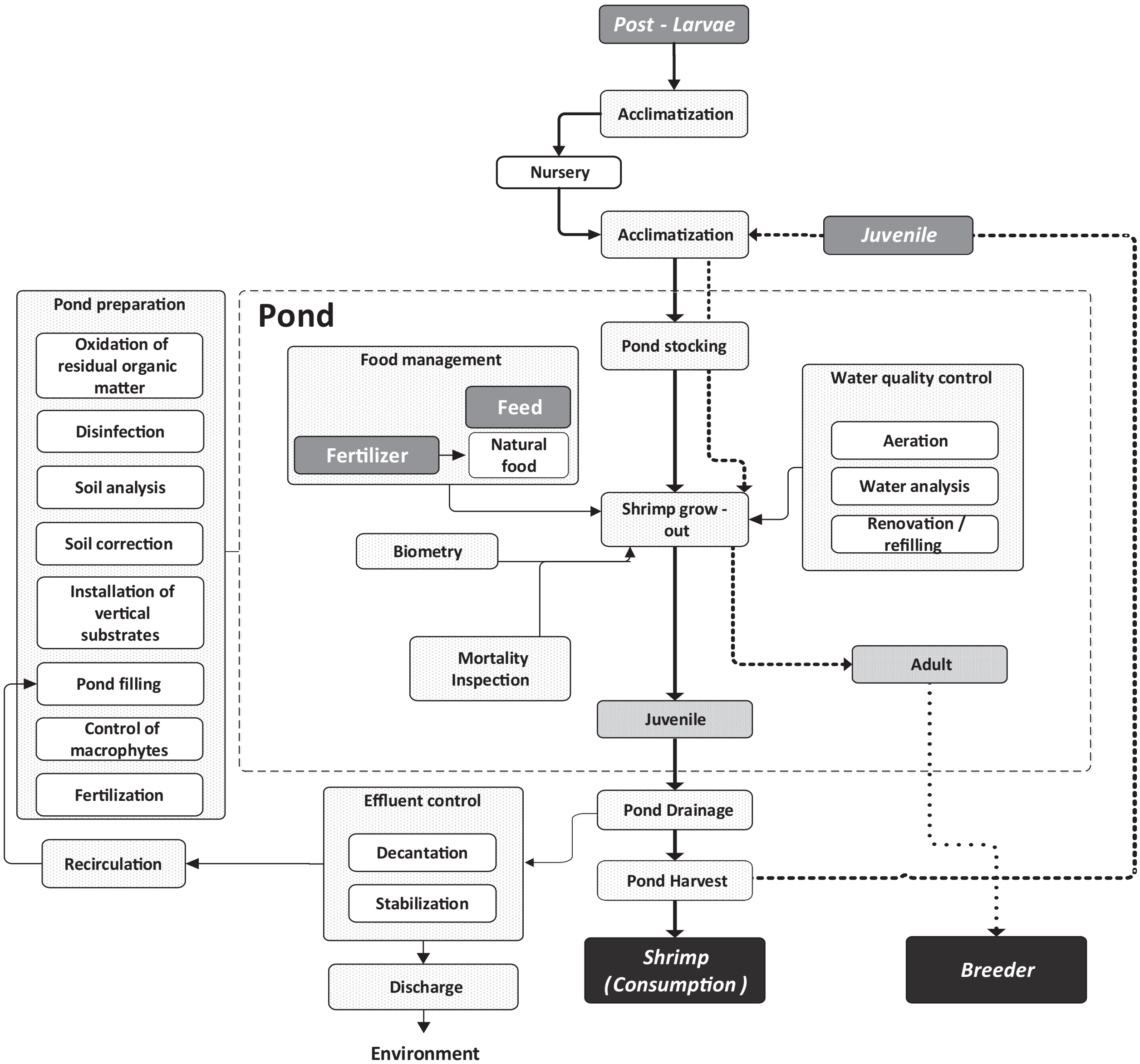

Figure 1 Flowchart representing the main routine processes, inputs and outputs of feedlots in the grow-out phase in a typical semi-intensive shrimp farm in Brazil (adapted from Cozer (2017)).(---) representation of the processes that take place inside the shrimp ponds; (→) sequences and stages of the grow-out phase; and (. . .) the most common aquacultured shrimp destinations. (▩) Input product; (■) Output product; (▩) Biological phase; (▢) Management

At the end of the search phase, 3030 documents were obtained. Of these, 357 documents were preselected according to their relevance to the theme of this study. After the elimination of duplicate documents and those that presented some evident bias, 265 documents were selected for presenting the concepts, results, fundamentals and qualitative and quantitative information on pond aquaculture shrimp in Brazil. After the full reading of the texts and the application of the selection criteria described in Figure 2, 52 documents (eight books, 25 scientific articles, nine technical articles and 10 case studies, including theses and dissertations) were selected to obtain the data and later characterize the hypothetical shrimp farm.

CAD DRAFTSIGHT® (SPo - Dassault Systèmes® USA - 2018) software was used for the construction of the sketch of the farm. The database obtained through the systematic review were grouped according to their classification during the cultivation process in (i) production and facilities infrastructure; (ii) operational parameters; (iii) equipment; and (iv) volumes and quantities of the inputs used. Thereafter, the various physical units were converted to energy units according to the methodology proposed by Pimentel (1980).

Table 1 Terms and combinations, in Portuguese and English, used to obtain the bibliographic data for the characterization of the typical semi-intensive shrimp farm in Brazil

Portuguese	English
Dimensão e carcinicultura	Dimension and shrimp farming or shrimp cultivation and growth
Características e carcinicultura	Characteristics and shrimp farming or shrimp cultivation and growth
Perfil e carcinicultura	Profiling and shrimp farming or shrimp cultivation and growth
Estado da arte e carcinicultura	State of the art and shrimp farming or shrimp cultivation and growth
Cenário atual e carcinicultura	Current scenario and shrimp farming or shrimp cultivation and growth
Manejo alimentar e carcinicultura	Food management and shrimp farming or shrimp cultivation and growth
Manejo nutricional e carcinicultura	Nutritional management and shrimp farming or shrimp cultivation and growth
Manejo operacional e carcinicultura	Operational management and shrimp farming or shrimp cultivation and growth
Regime de produção e carcinicultura	Production and shrimp farming regime
Sistema de produção e carcinicultura	Production and shrimp farming system
Tamanho unidades produtivas e carcinicultura	Size of production units and shrimp farming or shrimp cultivation and growth
Densidade estocagem e carcinicultura	Stocking density and shrimp farming or shrimp cultivation and growth
Infraestrutura associada e carcinicultura	Associated infrastructure and shrimp farming or shrimp cultivation and growth
Instalações e carcinicultura	Installations and shrimp farming or shrimp cultivation and growth
Equipamentos e carcinicultura	Equipment and shrimp farming or shrimp cultivation and growth
Preparação de viveiros e carcinicultura	Preparation of nurseries and shrimp farming or shrimp cultivation and growth
Produtividade e carcinicultura	Productivity and shrimp farming or shrimp cultivation and growth

Energy Accounting

The quantification of the energy flows was carried out from an economic standpoint, that is, through the quantification of the energy from economic resources. Both the direct and indirect energy input data, as well as the energy output data are displayed in megajoules (MJ).

Direct energy input sources

The sources of direct energy input were labour, fuels and lubricants, electrical energy and general inputs (PL, feed, fertilizers and soil correctives) directly consumed in the shrimp production process. Labour, the energy consumed by the workers involved in shrimp production weighted according to the workload dedicated to this activity, was considered the energy coefficient of 1.76 MJ h^{-1} proposed by de Carvalho *et al.* (1974). The fuels and lubricants consisted of diesel and lubricating oils and greases. In this case, the energy coefficient used was 13 GJ ha^{-1}, which was attributed by Serra *et al.* (1979) and Larsson *et al.* (1994). For electricity, 1 KW h^{-1} was adopted as the equivalent of 3.6×10^6 J (Tipler & Mosca 2009). The average amount of energy used in shrimp farming was based on Boyd *et al.* (2007, 2017). For the inputs, the total energy value related to PL production was obtained through the energy coefficient of 70×18.78 J per individual established by Kurmaly *et al.* (1991). For the feed (90% dry matter), the energetic coefficient adopted was 3200 Kcal kg^{-1} (Varandas 2016). The conversion used was by Tipler and Mosca (2009), in which 1 cal = 4184 J. The total energy contained in the feed was estimated based on the following equation:

$$\mathrm{FE} = \mathrm{FC} \times \mathrm{FDM} \times \mathrm{FEC} \qquad (1)$$

Where FE: energy contained in the feed (Kcal); FC: feed consumption (kg); FDM: feed dry matter content (kg kg^{-1}); and FEC: feed energy coefficient (kcal kg^{-1}).

For the fertilizers and soil correctives, the values adopted were those recommended by Pellizzi (1992): N = 73 MJ kg^{-1}; P = 13 MJ kg^{-1}; K_2O = 9 MJ kg^{-1}; urea = 65 MJ kg^{-1}. The value of energy contained in limestone (0.2 MJ kg^{-1}) was based on the study of Macedônio and Picchioni (1985).

Indirect energy input sources

Indirect energy input sources are sources of energy derived from the use and maintenance of machinery, equipment, facilities and productive infrastructure. The energy costs related to the construction of the productive infrastructure (nurseries, ponds, canals, sheds, roads, power grid, etc.) or to the manufacturing and installation of equipment were not considered here since the objective of this work is to evaluate the energy used only in the operation of the shrimp farm.

The energy values necessary for the operation machines and equipment were estimated using the methodology developed by Doering (1980), which is based on energy depreciation, and by Fernandes and Souza (1982), who present some important energy coefficients in their work.

Output energy sources

The average productivity at the hypothetical farm, used to define the direct sources of energy output, was estimated at 3500 kg ha^{-1}, based on data from the Brazilian Association of Shrimp Breeders (ABCC, 2017a,2017b). It was also

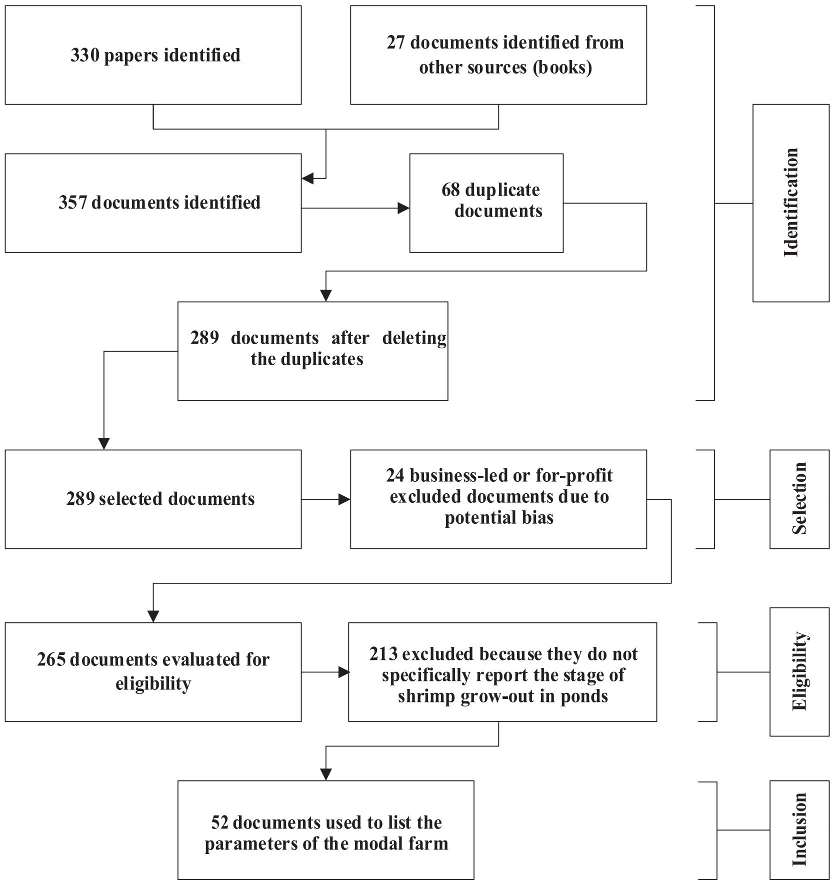

Figure 2 Flow diagram showing the four phases of the systematic review (PRISMA) conducted to identify the documents used as a base for the construction of the hypothetical semi-intensive model shrimp farm in Brazil.

considered that the dry matter content present in shrimp is 26% and that its energy coefficient is 4493 Kcal kg^{-1}, as suggested by Hu *et al.* (2008). The conversion suggested by Tipler and Mosca (2009) was also adopted, where 1 cal = 4184 J. Thus, the equation used to estimate the energy contained in the shrimp was:

$$EC = [N] \times [LW] \times [DM] \times [SEC] \quad (2)$$

Where EC: energy contained in shrimp (kcal kg^{-1}); LW: live animal weight (kg); N: number of animals; DM: shrimp dry matter content (kg kg^{-1}); and SEC: shrimp energy coefficient (kcal/kg).

Energy calculations

Energy efficiency (ŋ) was calculated based on equation 3, which was proposed by Quesada *et al.* (1986). Energy productivity (EP) was calculated based on equation 4, which was proposed by Rahman and Barmon (2012). Energy intensity (EI) was calculated based on equation 5, which was proposed by Troell *et al.* (2004). Energy Balance (EB) was calculated based on equation 6, which was proposed by Rahman and Barmon (2012):

$$\eta = \frac{\sum \text{DE output} + \text{IE output}}{\sum \text{DE input} + \text{IE output}} \quad (3)$$

$$\text{EP} = \frac{\sum(\text{DE output} + \text{IE output})(\text{kg/ha})}{\sum(\text{DE input} + \text{IE output})(\text{MJ/ha})} \quad (4)$$

$$\text{EI} = \frac{\sum(\text{DE output} + \text{IE output})(\text{MJ/ha})}{\sum(\text{DE input} + \text{IE input})(\text{kg/ha})} \quad (5)$$

$$\text{EB} = \frac{\sum(\text{DE output} + \text{IE output})(\text{MJ/ha})}{\sum(\text{DE input} + \text{IE input})(\text{kg/ha})} \quad (6)$$

Where DE: direct energy estimation; IE: indirect energy estimation; E (D or I - direct or indirect) output: energy output in the production process in the form of the final product (shrimp); and E (D or I - direct or indirect) input: estimation of the energy (direct or indirect) consumed in the productive process.

By definition, η consists of the ratio between the amount of energy used in an activity and the energy that is made available (Patterson 1996). Its value, according to Raugei *et al.* (2012), can be obtained through the quotient of the division between the amount of energy coming out of the process in the form of product (in this case, shrimp) and the estimation of the amount of energy consumed in the process (in this case, in the form of feed, PL, labour, fuel and lubricants, fertilizers and correctives, electricity and other inputs). The EP parameter represents the amount of product (shrimp) obtained per unit of energy consumed during the production process and can be expressed in kg MJ^{-1} (Hamedani *et al.* 2011). The EI parameter, expressed in MJ kg^{-1}, can be defined as the energy inputs required to supply a given quantity of a product or service of interest (Troell *et al.* 2004). The EB parameter, expressed in MJ ha^{-1}, is defined as an instrument to account for the energy produced and consumed in a given production system (Ulbanere 1988). These indicators were developed as tools for accounting for the energy produced and consumed in a given system, and the factors of production and intermediate consumption are translated into energy or equivalent units (Lamoureux *et al.* 2006). Using these parameters, it is possible to calculate and compare the energy indicators involved in the production process (Doering 1980; Bueno & Campos 2000; Pierson & Hlavacs 2015).

The production process of shrimp farming in semi-intensive ponds in Brazil

The stages and processes as well as the average values related to the dimensions of the facilities and productive infrastructure that characterize most of the shrimp farms operating in semi-intensive ponds in Brazil are presented in Table 2.

Brazil has a total of approximately 1300 farms dedicated to shrimp cultivation in semi-intensive ponds. Together, they sum to a total area of approximately 20 hectares and have an average productivity of 3500 kg ha^{-1}. Approximately 98% of these farms are concentrated on the northeast coast, with an emphasis on the states of Ceará, Rio Grande do Norte, Bahia and Pernambuco.

Small farms (with a maximum of 10 ha of ponds) account for approximately 74% of the total, while 23% are greater than 10 ha and less than or equal to 50 ha, and only 3% are considered large enterprises (with a total area greater than 50 ha). The activity, which is labour-intensive, generates the equivalent of 1.89 direct jobs and 1.86 indirect jobs per hectare. The survey also showed that 65% of the farms use aerators. The use of nursery tanks is still adopted by the minority (35%) of producers. In general, the producers do not verticalize their productions and acquire PL from specialized laboratories located mainly in the states of Ceará, Rio Grande do Norte and Piauí.

The feed for the grow-out phase has an average equivalent price of R$ 1.70, which represents the highest operating cost and is produced by specialized companies. The feeding method used by 96% of the producers involves the use of trays. Almost 79% of Brazilian producers perform regular monitoring of the hydrobiological variables in their shrimp ponds. Of these, 66% measured the oxygen concentration, 57% measured the pH, 60% measured the salinity, 58% measured the temperature and less than 30% monitored the ammonia, nitrate, nitrite, transparencies, BOD, COD or chlorophyll-*a* concentrations.

Table 2 Stages of the productive process, description, dimensions and quantities involved in the productive infrastructure of a typical shrimp farm in Brazil

Phase	Description	Source	Specification	Quantity
Nursery	Nursery tanks	Silva (2017a)	55 to 80 m^3	4 to 8 un
Grow-out	Total pond area	ABCC (2017a,b)	Up to 10 ha	–
	Individual pond area	ABCC (2017a,b)	10000 to 80000 m^2 per pond	–
	Supply channel	Silva (2017a)	–	1
	Reservoir	Silva (2017a)	–	1
	Drainage channel	Silva (2017a)	–	1
	Sedimentation pond	Silva (2017a)	–	1
	Feed storage	ABCC (2017a,b)	–	1
	Deposit of fertilizers and agricultural correctives	ABCC (2017a,b)	–	1
	Laboratory	ABCC (2017a,b)	–	1
	Administration	ABCC (2017a,b)	–	1
	Garage	ABCC (2017a,b)	–	1
	Repair shop	ABCC (2017a,b)	–	1
	Men's and women's restrooms and locker rooms	ABCC (2017a,b)	–	1
	Refectory	ABCC (2017a,b)	–	1
	Secondary feed deposits	ABCC (2017a,b)	–	–
	Main and secondary access roads	ABCC (2017a,b)	–	–

Table 3 Description and specification of the parameters usually applied in the management of a typical Brazilian semi-intensive shrimp farm

Phase	Description	Specification	Source
Nursery	Cost of PL	4.18 US$/thousand	Rocha (2015); Aquatec (2017); Labsul (2017); Potiporã (2017)
	Urea	206 g/55 m^3	ABCC (2010); Ostrensky and Silva (2017a)
	Triple superphosphate	10 g/55 m^3	ABCC (2010); Ostrensky and Silva (2017a)
	Na_2SiO_3	100 g/55 m^3	ABCC (2010); Ostrensky and Silva (2017a)
	$CaCO_3$	4 kg/55 m^3	ABCC (2010); Ostrensky and Silva (2017a)
	Vitamin B complex	20 ml/55 m^3	ABCC (2010); Ostrensky and Silva (2017a)
	Aeration	hoses with a diffuser per m^2	Boyd *et al*. (2007, 2010)
	PL initial weight	0.02 g	Villalón (1991); Ostrensky and Silva (2017a)
	Stocking density	30 PL L^{-1}	ABCC (2010); Albertim- Santos *et al*. (2015); Silva and Ostrensky (2017)
	Water renewal	10%/day	Ostrensky and Barbieri-Júnior (2002); Ostrensky and Silva (2017a)
	Feeding	4 a 6×/day	Prysthon da Silva and Mendes (2006); Araújo Lourenço *et al*. (2009); Silva (2015)
	Crude protein in feed	40%	Carvalho (2016)
	Final survival	>90%	Villalón (1991); Moura (2013)
	PL final weight	1 g	Villalón (1991); Moura (2013)
	Phase duration	14–30 day	Moura (2013); Silva and Ostrensky (2017)
Nursery/Grow-out	Salinity acclimatization	1 ppt/20 min	ABCC (2010)
	pH acclimatization	0.5 un h^{-1}	ABCC (2010)
	Temperature pH acclimatization	1° C/15 min	ABCC (2010)
	Temperature measurement	Twice a day	ABCC (2010); Boyd *et al*. (2010)
	Salinity measurement	Daily	ABCC (2010); Boyd *et al*. (2010)
	Dissolved oxygen measurement	Twice a day	ABCC (2010); Boyd *et al*. (2010)
	pH measurement	Twice a day	ABCC (2010); Boyd *et al*. (2010)
	Alkalinity measurement	Weekly	ABCC (2010); Boyd *et al*. (2010)
	Ammonia measurement	Twice a week	ABCC (2010); Boyd *et al*. (2010)
	Nitrite measurement	Twice a week	ABCC (2010); Boyd *et al*. (2010)
	Transparency measurement	Daily	ABCC (2010); Boyd *et al*. (2010)
	Reduction in the nursery water level	70%	ABCC (2010); Ostrensky and Silva (2017a)
Grow-out	Transport density	Up to 800 PL L^{-1}	Moraes (2004); ABCC 2010
	$CaCO_3$	3580 kg ha^{-1}	Ostrensky (2017b)
	Urea	9 kg ha^{-1}	Ostrensky (2017b)
	Triple superphosphate	900 g ha^{-1}	Ostrensky (2017b)
	Aeration	2 a 6 HP ha^{-1}	Boyd (1998); Silva (2017b)
	Initial PL age	PL_{20}	Joventino and Mayorga (2009); Silva and Ostrensky (2017)
	Initial storage density	30 a 50 shrimp per m^2	Belettini (2014); Albertim- Santos *et al*. (2015); Silva (2016)
	Water renewal	4 a 7%/day	Peterson (2000); Ostrensky and Silva (2017a)
	Biometry	Weekly	Ostrensky and Barbieri-Júnior (2002); Ostrensky and Silva (2017a)
	Feeding	4 times a day	Carvalho (2004, 2016)
	Crude protein in feed	35 a 40%	Fernandes da Silva Neto *et al*. (2008); Carvalho (2016)
	Final survival	68–70%	Magalhães (2004); ABCC (2017a,2017b)
	Final weight of shrimp	12 g	Magalhães (2004); Abcc, (2013); ABCC (2017a,2017b)
	Cultivation time	90–100 days	Magalhães (2004); ABCC (2013, 2017a,2017b)
	Productivity	3500 kg ha^{-1}	Magalhães (2004); ABCC (2013, 2017a,2017b)
	Number of employees	1.8 per ha	Rocha (2015); ABCC (2017a,2017b)
Harvest	Reduction in the pond water level	70%	Ostrensky and Silva (2017a)
Emergency harvest	Water treatment	46 ppm chlorine per m^3	Castilho-Westphal and García-Madrigal (2017)

Based on the most common data and the characteristics identified in the Brazilian shrimp farms (Tables 2–4), the hypothetical farm represented in Figure 3 was proposed. This hypothetical farm has 9 1-hectare ponds and their support infrastructure (deposit of fertilizers and soil correctives, laboratory, administration office, garage, repair shop, men's and women's restrooms and locker rooms, and others) are presented in Table 5. According to the national

Table 4 Description, specification, equipment and materials used during the nursery and grow-out phases in a typical Brazilian shrimp farm

Phase	Description	Specification	Source
Nursery	Acclimatization tank	500 L	Silva (2017b)
	Floating pump	200 m^3 per h	Silva (2017b)
	Radial compressor	5 Hp	ABCC 2010; Silva and Ostrensky (2016)
	Air diffusers	1 per m^2	Boyd (1998); ABCC 2010; Silva (2017b)
	Silicone hose	6 mm	Boyd (1998); ABCC 2010; Silva (2017b)
	Transport tank	1000 L	ABCC 2010; Silva and Ostrensky (2016)
Nursery/ grow-out	Refractometer	–	ABCC 2010; Silva (2017b)
	Oximeter	–	ABCC 2010; Silva (2017b)
	pH meter	–	ABCC 2010, Silva (2017b)
	Neubauer chamber and optical microscope		ABCC 2010
	Thermometer	–	ABCC 2010, Silva (2017b)
	Secchi disc	–	ABCC 2010, Silva (2017b)
	Equipment for individual safety	–	NORMA REGULAMENTADORA 6 – NR 6
	General tool kit	–	Silva (2017b)
Grow-out	Net screen frames	Water supply, drainage, stop-log, harvesting	ABCC 2010, Silva (2017b)
	PVC tube	20 mm	ABCC 2010
	Axial flow pump	20 hp	Silva (2017b)
	Vertical substrates	–	de Lima *et al.* (2008); Gomes de Medeiros *et al.* (2009)
	Fixed feeders	35 per ha	de Lima *et al.* (2008); Gomes de Medeiros *et al.* (2009)
	Kayak	Fibreglass	ABCC 2010
	Paddle wheel aerators	2 hp	Boyd (1998); Silva (2017b)
	Diesel generator	8 a 10 KVA	Silva (2017b)

standards, this farm would be classified as a small-scale venture.

In this hypothetical farm, the supply channel, which has an average volume of 24000 m^3, is allocated to the highest part of the terrain. This channel is the structure responsible for the distribution of water to the reservoir, which has a storage capacity of 19200 m^3, as well as to all the shrimp ponds using only the force of gravity. The uptake of water to the supply channel is via two 20 hp pumps housed in a masonry construction called a "pumping station" (dos Santos *et al.* 2017).

The operational system adopted in the farm is biphasic (Moura 2013), that is, the newly acquired post-larvae are received and kept temporarily in nursery tanks before being transferred to the growth-out ponds. These nursery tanks were designed to represent the average size (55 m^3) used by most Brazilian shrimp aquaculturists and were prepared according to the good management practices (GMP) recommended by Abcc (2005) (Table 5). After the nursery phase, the PL are transferred to the growth-out ponds, which are properly managed and prepared to receive them (ABCC 2010; Ostrensky & Silva 2017a) (Table 6).

The production regime adopted is semi-intensive, which is also adopted by most Brazilian producers. The average stocking density is 43 shrimp per m^2. Aeration used in the growth-out ponds would be performed by two 2 hp paddle wheel aerators (4 hp/ha). The required amount of fuels and lubricating oils has been estimated based on the Larsson *et al.* (1994), which evaluated the cultivation of *L. vannamei* in a semi-intensive regime. The productivity of this shrimp farm was based on Rocha (2015), totalling 3500 kg ha^{-1} or 31500 kg of shrimp produced in 9 ha at the end of a 90-day growing cycle.

At the end of the growth-out phase, the shrimp harvest is carried out. The effluents generated from the drainage of the ponds are transported through monks to the drainage channel (Ostrensky & Silva 2017a). The drainage channel (21600 m^3) was projected at a lower quota of the terrain and endowed with chicanes to increase the sedimentation rate of the suspended particulate matter (SILVA 2017a). From the drainage channel, the effluents are directed transported to the decantation pond (with 21160 m^3). To raise the dissolved oxygen concentrations to the minimum limits established by the Brazilian National Environmental Council Resolution n° 357/05, 2 hp aerators are used (Brasil, 2005). After proper stabilization, the water can be reused or released into the environment (Moura 2013; Silva 2017b). The materials and equipment are shown in Table 7.

Sankey diagram

The results were represented through a Sankey diagram, a specific type of flowchart in which the width of the arrows is proportional to the amount of the flow. This type of

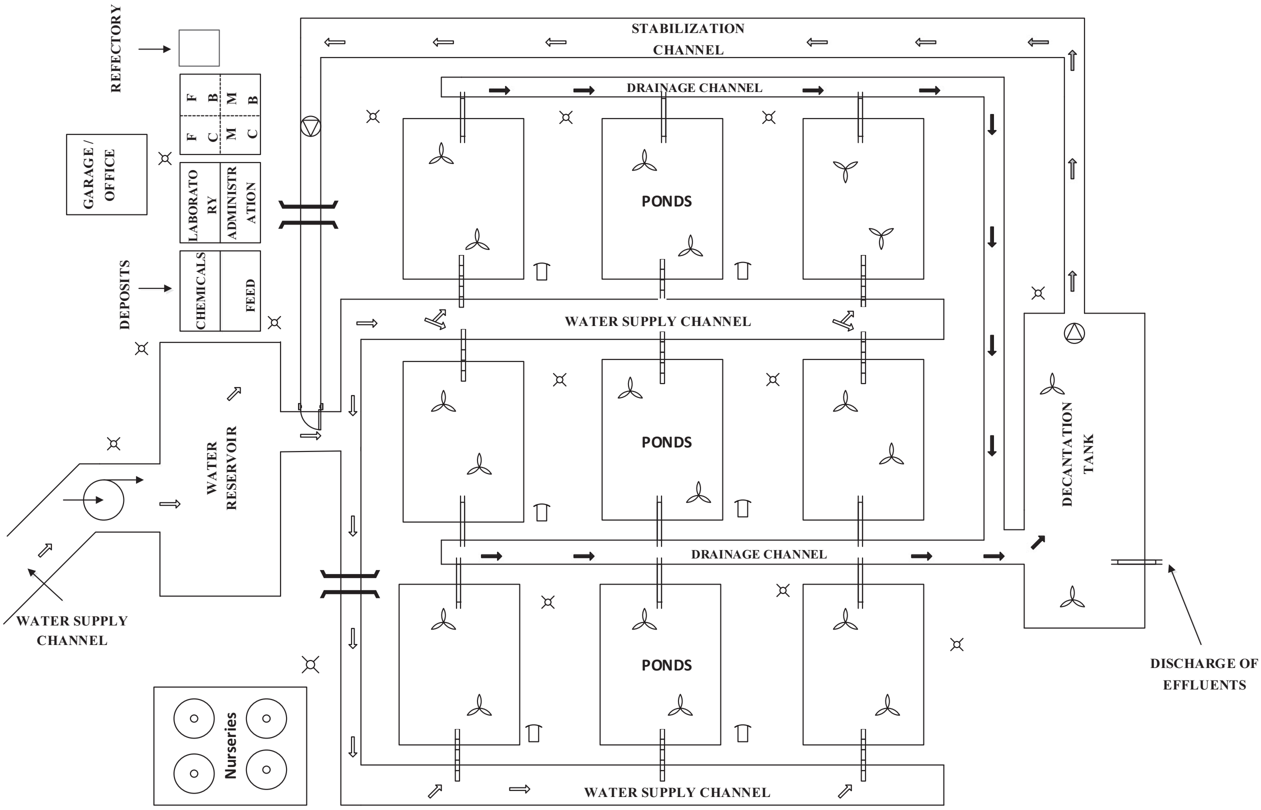

Figure 3 Schematic representation (not to scale) of a model semi-intensive shrimp farm in Brazil used to study flows and efficiency in the use of energy. Identification: (⟹) Affluent; (➡) Effluent; (⟹) water under treatment; () Aerator; () Secondary feed deposit; () Motor pump; () Pumping station; () Light pole; () Bridge; () water inlet; () water outlet; *(MB)* Men's room; *(FB)* Ladies's room; *(MC)* Male locker room; *(FC)* Female locker room.

diagram uses arrows to represent the amount of energy, costs or material transfer between processes. The diagram was elaborated according to the methodology described by Soundararajan *et al.* (2014) using the *software* Sankey MATIC (BETA) developed by Steve Bogart, USA.

Results

technical and operational data of the hypothetical farm

Based on the parameters established in CONAMA Resolution n° 312 from 2002 (Brasil, 2002), it can be stated that semi-intensive shrimp farm ponds are the main form of shrimp production in Brazil and that this activity is carried out mainly by small producers. According to Albertim- Santos *et al.* (2015); ABCC (2017a,2017b), the size of the ponds varies from 1 to 8 ha, and the productivity obtained ranges from 500 to 5000 kg ha^{-1}. As reported by Silva (2015, 2016), this variation in productivity can be associated with the different cultivation strategies adopted, such as the form of stocking (using nurseries or not); the pond preparation protocols; the use of feeding trays; the different stocking densities employed (ranging from 10 to 50 shrimp per m^2); and the capacity of investment and incorporation of technologies by the entrepreneurs.

According to Carvalho (2016); ABCC (2017a,2017b), 94% of Brazilian producers use balanced and nutritionally adequate feed. The majority (96%) feed the shrimp through food trays (35 trays ha^{-1}). Although more laborious and expensive than a manual feed supply, the use of food trays allows for direct observations of the consumption of feed by shrimps, reducing losses.

Energy accounting

The estimated total energy cost for the hypothetical farm was 835.597 MJ, referring to the production of 31.5 tons of shrimp in 9 ha semi-intensive shrimp ponds for each productive cycle. The most representative energy inputs were those associated with feed (72%), fuel and lubricant use (13%) and electricity (9%), which together totalled 94% of the energy consumption in the hypothetical farm; this reflects the importance of these inputs in the production process, as demonstrated in Table 8.

Table 5 Main infrastructure designed for the model semi-intensive shrimp farm

Type of infrastructure	Description	Specification	Quantity
Nursery	Nursery tanks	55 m^3	4
Growth-out	Ponds	10000 m^2	9
	Water supply channel	24000 m^3	1
	Reservoir	19200 m^3	1
	Drainage channel	21160 m^3	1
	Decantation tank	21160 m^3	1
Ancillary facilities	Feed deposit	100 m^2	1
	Fertilizer and agricultural correctives	100 m^2	1
	Laboratory	100 m^2	1
	Administration office	100 m^2	1
	Garage	100 m^2	1
	Mechanical office	100 m^2	1
	Bathroom	10 m^2	2
	Locker room	10 m^2	2
	Refectory	50 m^2	1
	Secondary feed deposits	4 m^2	6
	Main access routes	7 m	9
	Secondary access routes	3 m	9

Table 6 General inputs required and zootechnical indexes achieved in the model semi-intensive shrimp farm

Phase	Description	Quantity
Nursery	PL (initial number)	3.948.979 un
	Urea (fertilizer)	1 kg
	Triple superphosphate (fertilizer)	500 g
	Na_2SiO_3 (fertilizer)	400 kg
	$CaCO_3$ (corrective)	16 kg
	Vitamin B complex	80 mL
	Feed	31 kg
	Artemia (cists/biomass)	62 kg
Nursery/ growth-out	Kit for alkalinity analysis	13
	Kit for nitrite analysis	13
	Kit for ammonia analysis	13
Growth-out	Minimum ideal soil pH	6,5
	Complete chemical analysis of soil	9
	Physical soil analysis	9
	$CaCO_3$ (soil correction)	32220 kg
	Urea (fertilizer)	243 kg
	Triple superphosphate (fertilizer)	24.3 kg
	Shrimp initial density	43 PL m^{-2}
	PL (initial number)	3.870.000 un
	Initial weight	0.02 g
	Survival rate	68%
	Shrimp (final number)	2.625.000 un
	Final weight	12 g
	Final biomass	31500 kg
	Total expenditure on feed	50031 kg
	FCA	1.58
	Productivity	3500 kg ha^{-1}
	Electricity (maintenance energy)	673 Kw h^{-1} t^{-1}
	Electricity (pump + aerator) for 9 ha	21199 (Kw.h)
	Labour (workers/ha)	1.8
	Total number of workers	16

Based on energy consumption and energy productivity, the η, EP, EI and EB of the hypothetical farm were calculated. The analysis of energy accounting revealed that 77% of the energy provided to the productive system is dissipated during the nursery and growth-out phase. The accumulated energy inputs required to produce 1 kg of shrimp weighing 12 g were estimated at 27 MJ, the equivalent 92.844 MJ ha^{-1} of cultivated area.

Through the Sankey diagram, the total energy flux at the hypothetical farm was represented (Figure 4). The diagram shows the input of 835.597 MJ (in the form of feed, fuel and lubricants, electricity, fertilizers and correctives, labour, PL, maintenance of machinery, and equipment and installations) and an output of 192.465 MJ (in the form of shrimp for processing), which would represent 643.132 MJ lost during the transformation of this productive process.

Discussion

Semi-intensive shrimp farming in Brazil

Most of the production of the national aquaculture shrimp is destined for the domestic market. However, between 2015 and 2017, there was a reduction of 47% in production caused mainly by the occurrence of diseases such as white spot virus (WSSV) (Royo *et al.* 2016; ABCC 2017a,2017b). To mitigate the harmful consequences of these diseases as well as to control them, several techniques were used. One technique, described by Rodrigues (2015), was the popularization of the use of nursery tanks. This practice, according to Worranut *et al.* (2018), aims to increase food efficiency during the shrimps' early life stages; promote the growth capacity of PL, reduce the initial mortality; allow the attainment of larger juveniles that are more resistant to WSSV and reduce the time of cultivation in ponds.

Another trend, taken into account during the elaboration of the hypothetical farm proposed here but still used by only 40% of Brazilian shrimp farmers (Rocha 2015), is the installation of water recirculation systems in the growth-out ponds. As determined by Resolution n° 312/02 do CONAMA (BRASIL 2002), shrimp farming projects should include decantation tanks for the treatment and control of effluents as well as the installation of a water recirculation system. These structures assist in the prevention of diseases that can be introduced by the collection of contaminated and untreated water (Ng *et al.* 2018). In addition, these structures promote the proper disposal of effluents, reducing the possible environmental impacts generated by the nutrient output to adjacent environments (Cardoso-Mohedano *et al.* 2016) and contributing to reducing the

Table 7 Description and specification of the main materials and equipment used in the model semi-intensive shrimp farm

Phase	Description	Specification	Quantity
Nursery	Acclimatization tank	500 L	9
	Floating pump	200 m^3 h^{-1}	2
	Radial compressor	5 CV	2
	Air diffusers	1 per m^2	486
	Silicone hose	6 mm	220 m
	Transport tank	1000 L	3
Nursery/ grow-out	Refractometer	–	2
	Oximeter	–	1
	pH meter	–	1
	Thermometer	–	13
	Secchi disc	–	2
	Equipment for individual safety	–	10
	General tool kit	–	1
Growth–out	Net screen frames	Various	76
	PVC tube	20 mm	6 m
	Optical microscope and Neubauer chamber	–	2
	Axial flow pump	20 hp	2
	Vertical substrates	–	900 m
	Fixed feeders	35 per ha	315
	Kayak	Fibreglass	9
	Paddle wheel aerators	2 hp	18
	Diesel generator	8 a 10 KVA	2
Harvest	Cast nets	–	2
	Mechanical or digital scales	–	2
	Stunning boxes	500 L	6
	Fishing nets	–	2

economic losses associated with the cost of the electricity used in the pumping process (Boyd *et al.* 2007).

Feed is the most representative input in the operation of a typical semi-intensive shrimp farm in Brazil, reaching up to 70% of the production costs (Kubitza 2018). Therefore, adequate food and nutritional management has a direct effect on the success or failure of aquaculture enterprises.

In general, the practices observed in Brazilian shrimp farms do not differ substantially from those adopted in countries with great traditions of shrimp production, such as China, Thailand, Vietnam and Ecuador (Fao, 2018). However, poorly planned public policies and even a lack of such policies, barriers generated during the environmental licensing process and the chronic lack of access to technical assistance by shrimp producers are factors that directly influence the growth and productive performance of Brazilian shrimp farming. These problems could explain, for example, why Brazilian producers achieve an average productivity of approximately 3500 kg ha^{-1} (ABCC 2017a,2017b), while in China, the number of farms has been increasing rapidly in the last decades (Mello *et al.* 2017), with the average productivity reaching 5650 kg ha (Zhang *et al.* 2017) due to the adoption of public policies that foster exports (Rivera-Ferre 2009) and are a means of promoting economic development (Cao *et al.* 2011).

However, this expansion in China has had an enormous ecological cost, and we should consider that also in Brazil the loss of forest, biodiversity, indigenous peoples livelihood sources has and will have enormous cost. Although, energy analysis can help diagnose bottlenecks in the shrimp farm process, it cannot capture a wider range of benefits that result from production. Therefore, energy data should be discussed together with social, environmental, economic and market considerations, and not alone, since analysing only in terms of energy may not express the importance, impacts and degree of development of the activity.

Energy sources

In the present case, the energy directly contributing to the productive process in the hypothetical shrimp farm that simulated the average conditions employed in Brazil reached 99.5% of the total energy consumed. Consequently, the indirect sources accounted for only 0.5% of the total energy cost. These results corroborate the data obtained by Larsson *et al.* (1994), who, after identifying the necessary inputs for semi-intensive shrimp aquaculture on the Caribbean coast of Colombia, concluded that the direct sources of energy totalled 99% while the indirect sources accounted for only 1% of the total energy. Despite the similarity between the results found, it is important to emphasize that the proportions between the direct and indirect sources of energy can vary according to the type of cultivation regime adopted and the organism cultivated in aquaculture. Waldrop and Dillard (1985), for example, evaluated the economic efficiency of different aquaculture activities and observed that the energy use from the indirect sources reached 10% in the cultivation of American catfish (*Ictalurus punctatus*), a carnivorous species, and 58% in the cultivation of the bivalve mollusc *Mytilus sp.*, a filter feeding organism. According to Beber (1989); Henriksson *et al.* (2012, 2014), in addition to the cultivation regime and the trophic position occupied by the cultivated species, the different methodological approaches adopted for the calculation of energy (emergy or life cycle assessment method, for example), the criteria adopted for the separation of the inputs in the direct or indirect sources and the different parameters included in the calculation influence the results and, consequently, their interpretation.

The prevalence of the direct energy costs over the indirect energy costs is repeated with such frequency that Troell *et al.* (2004), when conducting a literature review on the techniques used to evaluate the energy performance in aquaculture, reported that most studies have excluded the

Table 8 Direct and indirect energetic parameters in a hypothetical 9 ha semi-intensive shrimp farm in Brazil

"Inputs and outputs"	Total energy consumption (MJ)	Relative energy consumption (MJ/ha)	Energy consumption (%)
Inputs			
Direct input			
Feed*	602.496	66.944	72
Fuels and lubricants	109.509	12.168	13
Electricity	76.318	84.79	9
Fertilizers and agricultural correctives	19.672	2.186	2
Urea	15.870	1.763	
Chlorine	3.480	387	
Triple superphosphate	309	34	
$CaCO_3$	9	1	
Na_2SiO_3	5	0.5	
Labour	17.971	1.997	2
PL*	4.817	535	0.6
Indirect input			
Depreciation of productive infrastructure	1.450	161	0,2
Depreciation of machinery and equipment	2.250	250	0,3
Depreciation of facilities	1.113	124	0,13
Total inputs (direct + indirect)	835.597	92.844	*100*
Outputs			
Direct outputs			
Total outputs (Shrimp)	*192.465*	*21.385*	*100*
Energy accounting			
Energy efficiency (η)	0.23		
	0.03		
Energy productivity – EP (kg MJ^{-1})			
	27		
Energy intensity – EI (MJ kg^{-1})			
	−71.459		
Energy balance – EB (MJ ha^{-1})			

*Including transportation. The values in italics indicate the total energy output the system represented in this work by the adult shrimp.

indirect energy costs because they are insignificant when compared with the direct energy costs.

Main energy inputs

Among the direct sources of energy used to produce shrimp in our hypothetical farm, feed represented the highest relative energy cost (72%). The great amount of energy associated with the shrimp feed observed in the present study is in agreement with the data obtained by Tyedmers *et al.* (2007) and Pelletier *et al.* (2011), which evaluated the different techniques for measuring the performance of aquaculture relative to energy intensity. Likewise, Aubin *et al.* (2009) analysed the environmental impact and energy use of rainbow trout (*Oncorhynchus mykiss*), sea bass (*Dicentrarchus labrax*) and turbot (*Scophthalmus maximus*) production systems by the life cycle assessment method (LCA). In the trout (carnivore) and sea bass (carnivore) production systems, the use of feed was the main contributor to energy use (72%), while in the turbot (carnivore) cultivation system, the contribution of feed to the total energy use was just 57%. This difference can be explained by the use of varied ingredients in the formulation of diets formulation and by the different nutritional requirements of the studied species (Tyedmers *et al.* 2007). According to Pelletier and Tyedmers (2010); Cao *et al.* (2011) and Hall (2011), the use of energy does not necessarily present a linear relationship with the economic parameters. However, our results showed that together with economic assessments (Kubitza 1999; Ribeiro *et al.* 2005; Rosa *et al.* 2015), the relationship with the energetic expenditure involved in the feeding of shrimp farmed in Brazil is also the most representative factor and may correspond to more than 70% of the energetic operational costs.

Usually, the production of food for shrimp farming can be classified as "energetically very demanding" (Ziegler *et al.* 2011) due to its dependence on ingredients from agriculture and fishing (Aubin *et al.* 2009; Pelletier *et al.* 2011). The ingredients from agriculture are dependent on the use of fuels, pesticides, fertilizers and irrigation, which require large amounts of energy in their synthesis processes (Ulbanere 1988; Ozkan *et al.* 2004). This can be observed when analysing the energy (ECOs) of the main agricultural inputs used in the elaboration of shrimp feeds, such as

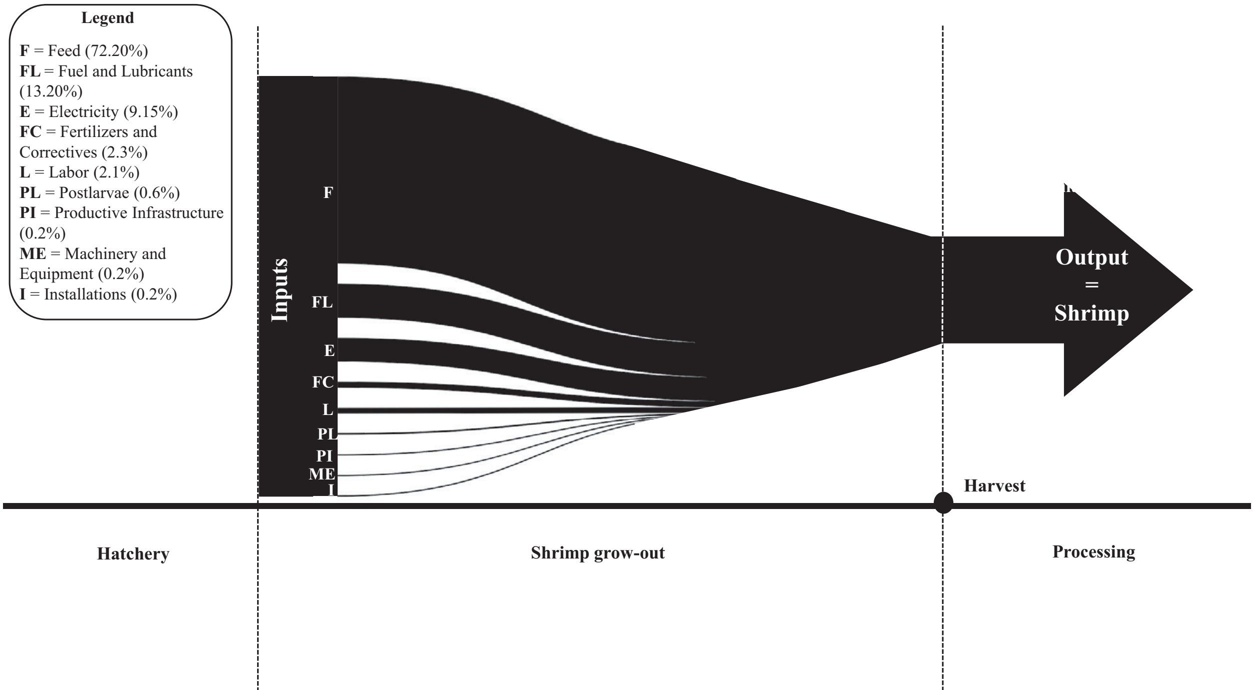

Figure 4 Sankey diagram representing the energy flow in a hypothetical 9 ha semi-intensive shrimp farm in Brazil.

16 MJ kg^{-1} for maize (Gonçalves & Carneiro 2003), 18 MJ kg^{-1} for soy (Assenheimer *et al*. 2009) and 9 MJ kg^{-1} for wheat (dos Santos *et al*. 2000). Fish-derived ingredients such as fishmeal are still widely used in shrimp feeds (Tyedmers *et al*. 2005). According to FAO (2018), shrimp farming is among the world's largest consumers of fishmeal (ECO of 16.03 MJ kg^{-1}), using 20% of the total world production.

The use of fuels and lubricants corresponded to 13% of the amount of energy consumed during the growth-out phase of shrimp aquaculture. The energy cost contribution of fuels and lubricants calculated in the present study was similar to that reported by Stewart (1995) and Scorvo Filho *et al*. (2010), which evaluated the sustainability and energy use in salmon cage farms and calculated the share of fuels, mainly diesel, at 12%. The fuels were used in the electric generators and in the vehicles used on the farms (cars and tractors, for example). Diesel oil, which is the most commonly used fuel, has a high ECO (56 MJ L^{-1}). This is because it is obtained from the fractional distillation of petroleum and in its composition are substances such as hydrocarbons and organic compounds with nitrogen, oxygen and sulphur (Nogueira 2010). Lubricants, mainly represented by grease, are used in shrimp farms for their antioxidant properties to minimize the action of salt water in equipment among many other uses. The high energy incorporated in the grease comes from its composition of mixtures of mineral lubricating oils of various viscosities and their additives in addition to fatty acids, generally called soap, which form an emulsion with the oils of mineral origin and act as a thickening agent (Raugei *et al*. 2012).

The energy cost from the use of electricity also occupies a prominent position in our hypothetical farm, representing 2422 MJ kg of the shrimp produced or 9% of its total energy cost. The electricity costs are related to the use of machinery to maintain water quality, such as aerators and pumps, which implies that more energy is incorporated into the system (Boyd *et al*. 2007). At the same time, Ayer and Tyedmers (2009) reported that there is a proportional increase in the energy from electricity as the intensity of the cultivation regime increases. In fact, Henriksson *et al*. (2014) detected higher energy demands (10.800 MJ kg^{-1}) for the intensive production of *L. vannamei* in Asian countries.

Energy accounting

Among the inputs quantified in the shrimp grow-out phase, the energy expenditure of feed represents 72% of the total energy used in the process, which is equivalent to 602.496 MJ. In the hypothetical farm evaluated, 1588 kg of feed was required to obtain 1000 kg of shrimp; that is, 588 kg of feed was "lost" for every 1000 kg of shrimp produced. In terms of energy, this represents 223.189 MJ (37%) dissipated only in the form of feed. The other causes of energy loss are related to energy dissipation during the operation of equipment, such as Joule losses, maintenance energy costs, material and input waste, water evaporation in the ponds and mortality. For example, the estimated energy loss from shrimp death during the grow-out phase was estimated at approximately 1628 MJ.

In contrast, the energy dissipated in the form of fertilizers and correctives, labour, PL acquisition and indirect energy inputs (depreciation of the productive infrastructure, machinery, equipment and facilities) was substantially reduced compared with the energy dissipated in the form of feed, fossil fuels and electricity.

Based on the use and, the EI and η of the hypothetical farm were calculated. Because there is no similar literature on energy efficiency in the grow-out shrimp pond farmed in Brazil or in the world, it was not possible to perform any direct comparisons with past data, which reinforces the importance of the numbers presented in this study as a basis for future comparative analyses.

The energy needed to produce 1 kg of shrimp on the hypothetical farm (EI equivalent to 27 MJ kg^{-1}) is lower than that reported for other aquaculture activities, such as salmon (*Salmo salar*), trout (*Oncorhynchus mykiss*) and sea bass (*Dicentrarchus labrax*) farming, which had EIs of 98 MJ kg^{-1}, 78 MJ kg^{-1} and 55 MJ kg^{-1}, respectively (Aubin *et al.* 2009). However, it is necessary to consider that *L. vannamei* is an invertebrate and has an omnivorous alimentary habit (Ostrensky 2017a,2017b). In addition, the crop cycles of the listed fish species have an average duration of approximately 18 to 24 months (Blanco-Cachafeiro 1995; Grisdale-Helland *et al.* 2017), while *L. vannamei* reaches commercial size in 90 days or less. As the fish culture time is longer, higher feed expenditures would naturally be expected. Therefore, based on this reasoning and the calculated values, it can be stated that shrimp production in ponds is a very intensive activity in relation to energy demand.

Efficiency (η) is the result of the ratio between the amount of energy employed in an activity and that which is made available in the form of the final product. From this concept, the results of the η calculation indicate how much of the energy made available in a given activity was transferred to the final product and how much was lost or dissipated during the production process (Patterson 1996). From a practical standpoint, values of $\eta \leq 1.0$ indicate that the evaluated system loses much of the channelled energy in the productive process (characteristic of technologically most advanced systems) (Doering *et al.* 1977; Doering 1980; Quesada *et al.* 1986; Beber 1989). Thus, it can be stated that, on average, the semi-intensive shrimp growth process in Brazil uses substantially high levels of energy in the form of inputs ($\eta = 0.23$) and turns only 23% of that energy into product. In other words, 77% of the energy initially contributed to the system is lost. In contrast, the hypothetical shrimp farm showed an energy efficiency only slightly lower than that of land animal production systems [broiler chickens ($\eta = 0.29$) (Santos & Lucas Júnior 2004) and pork production ($\eta = 0.31$) (Souza *et al.* 2009)]. In turn, the η of Brazilian shrimp farming is positioned within the estimated variation gradient for the fishery system (shrimp trawling), which, according to Tyedmers (2001), can vary from 0.11 to 0.25.

Final considerations

The results obtained here show that increasing energy efficiency is one of the essential conditions for the truly sustainable production of long-term Brazilian shrimp farming not only for environmental reasons but also mainly for economic reasons.

The identification and quantification of the energy fluxes performed in this work indicate that it is possible (and necessary) to obtain energetic gains in practically all stages of cultivation. This should involve the adoption of practices and actions, such as building farms facilities that follow more modern and efficient designs with water reuse and adequate effluent treatment; maintaining water quality; reducing water infiltration in soil; preventing the occurrence and spread of diseases leading to reduced shrimp growth and survival rates; and optimizing the use of pumps, aerators and general supplies. However, because of the high energy values involved, perhaps no action is more important than the use of balanced and more efficient feed and diet programmes and the adoption of good management practices at all phases of the production process, mainly to minimize feed losses and reduce the feed conversion rates.

Even so, the increase in energy efficiency in Brazilian shrimp farming does not depend solely on the producers. The industrial sector also plays an important role in this process, especially the feed industry. One possibility for neutralizing the energetic efficiency impairment is related to alternative formulations, which totally or partially replace marine fish meal with flours or the coproducts from the filleting of tilapia (a growing sector in Brazilian aquaculture), for example. This may imply a significant reduction in the energy and financial cost of feed production, which in turn accounts for more than 72% of the final shrimp production costs in a typical Brazilian shrimp farm.

Acknowledgements

We thank the National Council for Scientific and Technological Development (CNPq) for providing a research grant to Antonio Ostrensky (Process 304633/2017-8).

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