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Establishing a benchmarking for fish farming – Profitability, productivity and energy efficiency of German, Danish and Turkish rainbow trout grow-out systems

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Abstract

The promotion of Blue Growth in aquaculture requires an understanding of the economic drivers influencing the sector at farm level, but the collection of reliable and comparable data at this level is time-consuming and expensive. This study suggests an alternative strategy for qualitative sampling of freshwater trout farms in Germany, Denmark and Turkey, using a combination of existing data, group discussions and interviews with trout farmers, consultants and researchers. Nine 'typical' trout farming models are described, focusing on profitability, productivity and energy efficiency and allowing in-depth comparative economic analyses of different production systems at farm level, across regions. Our results show that the majority of the farms investigated have been profitable. Turkish farms benefit from competitive advantages due to low wages, low capital investment and favourable climate conditions. Large German farms profit from local market prices and advanced farm management. Danish farms using recirculating techniques remain competitive thanks to enhanced productivity and economy of scale. However, small traditional farms in Germany and Denmark may struggle to stay competitive in the long term. Organic farms in both countries face challenges of high feed costs and comparatively low productivity with mixed success. Using edible protein energy return on investment (epEROI) as an indicator of ecological sustainability, all surveyed farms compared very favourably with the terrestrial systems of animal meat production were investigated so far.

Keywords: benchmarking, EROI, fish farming, grow-out, profitability, rainbow trout

Introduction

Growth in the aquaculture sector is unevenly dispersed around the globe. The leading producers of freshwater finfish are found in South-East Asia, while marine fish farming is dominated by Norway and Chile (FAO 2014). Many authors see the rising control over biological processes via technological improvements and in consequence an increased productivity as a driving force for aquacultural growth (Asche 1997; Anderson 2002; Asche 2008). The adoption and diffusion of innovations seem to play a key role in technological development to overcome production bottlenecks and lower production costs (Lasner & Hamm 2014; Kumar & Engle 2016). Notwithstanding, developed countries like the USA and the EU-28 are struggling with stagnation or even decline in the aquaculture sector. Reliable and comparable economic data at farm level would be useful in identifying the factors behind this heterogeneity of growth worldwide. In an ideal world, data pertaining to economic performance should conform to internationally compatible standards. Furthermore, in order to examine the cost structure, profitability and productivity of production systems, it should provide basic indicators of competitiveness of models in different regions (Deblitz 2010; Walther 2014). As it stands, information about the costs and returns of fish farming is rarely available and only a few countries such as Norway (Asche & Bjorndal 2011) and Denmark (Statistics Denmark 2014) collect annual data on farm performance. While current aquacultural statistics programs such as the EU Data Collection Framework (DCF) should improve data coverage and quality of farm economic variables (STECF 2014), there are serious shortcomings.

From a micro-economic perspective, highly aggregated statistical data sets providing detailed technical or species information are not always suitable for analysing the impacts of management decisions or changes to economic framework conditions. Recognition that fish production and fish markets are global highlights the need for a data collection strategy that can provide internationally comparable farm data sets.

Establishing of a network of interregional farm data sets for aquaculture that includes detailed micro-economic information is not an easy task. Gathering data on all relevant economic parameters from a large and diverse sample of farmers may be almost impossible, unless in a considerably reduced or simplified form such as the DCF, which then lacks the necessary detail to address questions of competitiveness across the sector.

To overcome these challenges, we suggest an empirically grounded engineering approach, which has previously been used for data collection in the agriculture sector by the network *agri benchmark*[1] (Isermeyer 1993; Deblitz, Hemme, Isermeyer, Knutson & Anderson 1998; Isermeyer 2012; Deblitz 2013). This *typical farm approach* serves as a supplement to existing statistical databases and could enable farm-level benchmarking of aquaculture competitiveness worldwide. *Agri benchmark* follows in the tradition of information systems like the Farm Accountancy Data Network (FADN) which has analysed the development of agricultural business since 1965 (Isermeyer 2012). Furthermore, *agri benchmark* has simplified and extended the analyses of agricultural production on a global level. The benchmarking compares internationally the profitability of production systems (*cf.* Liese, Isvilanonda, Tri, Ngoc, Pananurak, Pech, Shwe, Sombounkhanh, Möllmann & Zimmer 2014) and evaluates the effects of political (*cf.* Deblitz 2015) or technical changes (*cf.* Deblitz 2012) towards farms. Simultaneously, non-economic disciplines have focused the question of energy efficiency of US food production systems in the recent years (*cf.* Pelletier, Audsley, Brodt, Garnett, Henriksson, Kendall, Kramer, Murphy, Nemecek & Troell 2011). Only very few studies did this for European agricultural farms (*cf.* Nguyen, Hermansen & Mogensen 2010a,b). Even less authors have adopted life cycle assessment towards aquaculture systems (*cf.* Samuel-Fitwi, Nagel, Meyer, Schroeder & Schulz 2013). Searching for sustainable food production systems, our benchmarking includes economic and environmental indicators as a starting point. This study examines the production of rainbow trout, *Oncorhynchus mykiss* (Walbaum), in inland farms and related production systems in three different countries and makes direct comparisons of cost structure, productivity, energy efficiency and profitability. It is the first study to apply the typical farm approach to aquaculture.

The market for portion-sized trout

The *agri benchmark* network assumes that every farmer in the world is linked via markets. However, the degree of market interaction differs worldwide depending on the product and the methods used to get it to market. Further influences include factors such as political framework conditions and international trade agreements. Fish and fish products are globally traded commodities, and worldwide exports of fish accounted for € 98.8 billion of trade in 2013 (FAO 2014). In total, this accounts for about 10% of the total value of global agriculture.[2] Regarding food markets only, seafood has a traded volume of 39%, which makes it to the most traded food commodity worldwide (Tvetera, Asche, Bellemare, Smith, Guttormsen, Lem, Lien & Vannuccini 2012; Asche, Bellemare, Roheim, Smith & Tvetera 2015).

The current benchmarking case study focuses on freshwater facilities producing rainbow trout, the second most important salmonid in global aquaculture after Atlantic salmon, *Salmo salar*

[1] www.agribenchmark.org.

[2] Data exclude products from forestry.

(Linnaeus) (Adeli & Baghaei 2013). According to Nielsen, Setälä, Laitinen, Saarni, Virtanen and Honkanen (2007), the market for rainbow trout has two components, one for small, portion-sized fish with white meat and other for large-sized fish with red meat, considered a substitute for salmon. Portion-sized trout have a finishing weight between 250 and 400 g, and production takes place mainly in inland farms (EUMOFA 2014). The EU, Iran and Turkey are the main producers, with the EU and Iran producing almost exclusively for domestic consumption (Adeli & Baghaei 2013; Kalbassi, Abdollahzadeh & Salari-Joo 2013; EUMOFA 2014). Within the EU, trout production is located mainly in Italy, Denmark and France (FEAP 2015, Nielsen, Asche & Nielsen 2015; Eurostat 2015). Trout farming has a long history in European countries dating back to the second half of the 19th century. The majority of European trout farmers are smallholders which still rear the fish in traditional earth ponds (Nielsen *et al.* 2015). The EU is also the world's principle consumer of portion-sized rainbow trout, and excess demand is met principally by Turkey, which supplies 70% of the total EU imports (EUMOFA 2014). Germany is the largest market for portion-sized trout (Nielsen *et al.* 2007; EUMOFA 2014) and accounts for the majority of Turkish trout imported to the EU, while Denmark is the most important internal supplier to the German market.

Denmark, Germany and Turkey have been selected for the current benchmarking exercise because of these close market ties. The case study focuses on trout grow-out operations and comparative advantages in relation to cost-efficiency, profitability and productivity (Fig. 1).

Trout farming in Turkey started in 1971 and has increased dramatically in the last decade (Yildiz, Doğan & Bayir 2011). From 2004 to 2013, production has tripled from 43 432 mt to 122 873 mt, and Turkey is now the leading producer of trout in Europe (TurkStat 2014). Almost 55% of rainbow trout produced are destined for export, mainly to the European Union, and 19% of exports go to the German market (TurkStat 2014). Danish production has registered a slight decrease in the last years, stabilizing at around 27 000 mt (FEAP 2015, Statistics Denmark 2015). More than 90% of Danish production is exported, of which 65% is destined for Germany. In contrast, Germany is a net importer and produces almost solely for the domestic market. In 2013, German rainbow trout production was around 10 000 mt (FEAP 2015).[3]

While sharing a common market, the three countries vary in terms of climate and the availability of suitable trout production sites. Each of the national industries operates under different political and environmental framework conditions, which have influenced the development of farming techniques in different ways and might be expected to stimulate a range of interesting business strategies to maintain competitiveness.

Materials and methods

The typical farm approach is a means of engineering empirically grounded 'virtual' farm data sets (Isermeyer 2012; Walther 2014) via a triangulation of qualitative methods (focus groups, expert interviews, farm observations). Significant rainbow trout production regions in Germany, Denmark and Turkey were identified from the literature and national production statistics. According to the standard operating procedure (SOP) of *agri benchmark* (Deblitz *et al.* 1998; Deblitz & Zimmer 2005; Agri benchmark 2015**)**, various farm types were examined to identify whether they represented typical production systems or significant alternatives with relevance for the sector. Focus group discussions formed the core tool for defining 'typical' and 'alternative' trout farms, and were organized on a transdisciplinary basis with expert participants from aquaculture research and the business sector. The discursive validation continued until the experts reached a consensus, and the farm data sets were regarded as coherent. Thus, all data resulted from a close interaction between farm practitioners, consultants and researchers (Fig. 2).

The resulting farm data sets contained a maximum of 686 variables covering direct and indirect costs, market returns, profit and interests, growth performance, work-input and energy consumption.

[3]The population of German fish farmers is defined by the central register for fish diseases. The register has not been completed yet in every federal state and does not consider recreational and smallest scaled fish farms (Brämick 2013). The official statistic counts the fish, which is sold for human consumption only; former statistics counted the harvested fish. Hence, the official statistics have been criticized for not being valid (Klinkhardt 2014). In consequence, the quantities given for Germany should be read under reserve and are certainly underestimated.

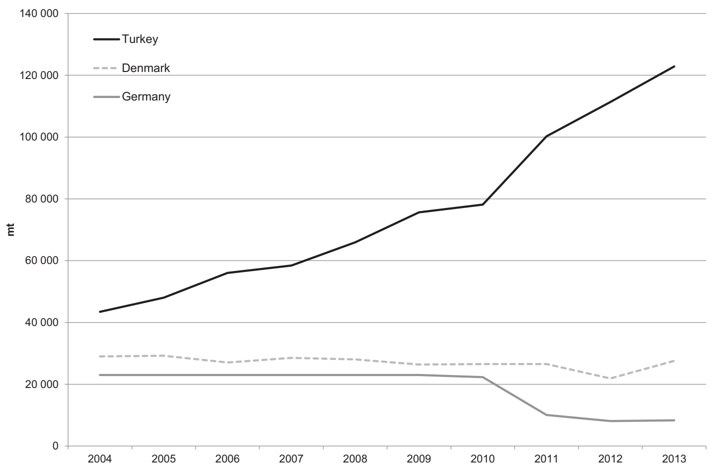

Figure 1 Production of portion-sized rainbow trout in Turkey, Denmark and Germany 2004–2013 (FEAP 2014, FEAP 2015) (*Note:* In 2013, German trout farmers produced 8333 mt of portion-sized rainbow trout. The remarkable decrease since 2010 is most likely caused by the methodical changes and continuing improvement of the data collection by the national statistical agency (Destatis) and not by a crisis in the German trout sector).

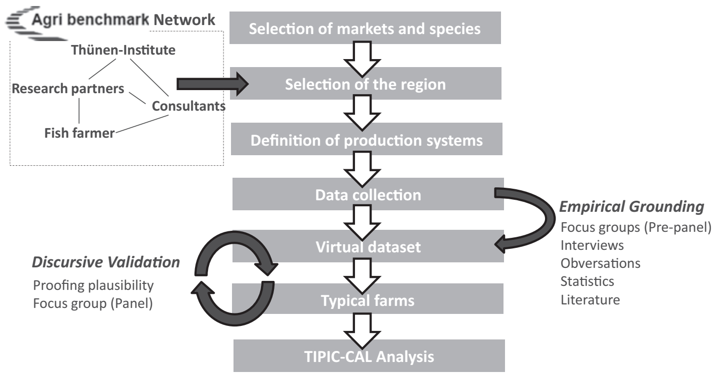

Figure 2 Scheme of the typical farm approach.

Each model farm was allocated a farm code in which the first letters refer to the ISO 639 country code and the following number refers to the typical annual production in weight. For instance, 'TR_500' describes a Turkish model, producing 500 mt of trout per year.

Worldwide, trout farms differ in many ways, including the extent to which different aspects of production such as broodstock management hatchery nursery grow-out processing and marketing are integrated, in the starting and finishing weights of stock, in overall scale and in the culture of secondary species such as brook trout. In order to enhance comparability, our benchmarking protocol focused solely on rainbow trout grow-out systems, starting with the stocking of fingerlings weighing 10–25 g per fish and ending with the harvest of edible/re-stocking fish with a live weight between 200 g and 380 g. The allocations used refer to either the returns of the grow-out system or production of the grow-out and to the contribution of rainbow trout to the profit and loss accounts for the whole farm. Fish farmers and consultants were able to provide confident estimates of costs, based on their own experience. Raw data were computed using the *agri benchmark* simulation model TIPI-CAL (Deblitz & Zimmer 2005), which performs a range of economic efficiency analyses, with particular emphasis on comparative cost calculations. In the analysis, cost components were categorized into three classes as follows, according to the *agri benchmark* approach (*cf.* Deblitz 2013):

1. *Cash costs*, comprising costs of land or leaseholds, water charges, maintenance (buildings, ponds, machinery and equipment), administration (environmental controls, advisory service, certification, accounting), memberships, insurance, business operations and promotion; feed, fingerling stock, veterinary services (vaccination and drugs), smaller outlays on operational equipment, energy (electricity, diesel vehicles,

oxygen) and other variable costs, such as wages (costs for paid labour) and ancillary labour costs.
2. *Depreciation costs*, reflecting a linear decline in the value of machinery, buildings and systems over time. However, because calculations of depreciation are not a universal feature of accounting in every country, this study took replacement value as a preferred starting point.
3. *Opportunity costs*, quantifying the value of self-owned resources such as using family labour (calculated as family working hours * wage for qualified local labour), land (own land area * regional land rents) and capital (non-land equity * long-term government bonds interest rate).

To avoid double accounting of capital costs in full-cost pricing, borrowed capital (A_{borrowed}) was excluded from total assets (A_{total}) for the calculation of opportunity costs of capital (O_{capital}):

$$O_{\text{capital}} = (A_{\text{total}} - A_{\text{borrowed}}) * 0.04\,\text{government bonds interest rate}$$

Profitability is the difference between costs and market returns. The market returns gathered are the weighted mean of the returns reported in interviews via different sale channels. The final calculations of short- (P_S), medium- (P_M) and long-term (P_L) profitability for a production system were calculated simply by subtracting the values of cash costs (C), depreciation costs (D) and opportunity costs (O) from market return (R):

$$P_S = R - C$$

$$P_M = R - (C + D)$$

$$P_L = R - (C + D + O)$$

All economic values shown are calculated without value added tax (VAT). All economic results refer to € per kg live weight (abbr. 'kg LW') and grow-out in the production system in 2013, unless otherwise stated.[4]

The edible protein energy return on investment (epEROI) for the selected systems was calculated as an environmental indicator, in line with a scientific tradition dating back to the 1970s (Gupta & Hall 2011). epEROI describes the ratio of industrial energy input to protein energy output for food production and allows for comparison of energy efficiency between different food sectors (Tyedmers 2000; Gupta & Hall 2011; Pelletier *et al.* 2011).

In the case of trout aquaculture, there are three main types of industrial energy input: feed, electricity and oxygen. Further, diesel is considered too, because one case has significant costs there. In order to allow for comparisons to be made these disparatenputs, kWh equivalents were calculated for each, as shown in Table 1.

The epEROI of rainbow trout is calculated as a percentage, assuming an average fillet yield of 57% (with skin), a wet weight fillet protein content of 20% (Dumas, de Lange, France & Bureau 2007) and a gross energy content of protein of 23.6 MJ kg^{-1}, equivalent to 6.56 kWh (Pelletier & Tyedmers 2007). After the total energy consumption of a grow-out system has been quantified in this way, the ratio of the sum industrial energy input to output gained during the grow-out process can be computed very simply (adapted from Hall, Balogh & Murphy 2009):

$$\text{EROI}_{\text{trout LW}}(\%) = \left(\frac{\text{protein energy return}_{\text{kWh}}}{\text{industrial energy required}_{\text{kWh}}}\right) \times 100$$

A high epEROI percentage value indicates high protein energy productivity.

Results and Discussion

The section reports the economic performance of nine typical trout grow-out operations in Denmark, Germany and Turkey. The selected farms are characterized with respect to the national sector. The cost structure and profitability of the grow-out systems are analysed and productivity is evaluated with respect to inputs of labour and energy.

Selected farms in Germany, Denmark and Turkey

The trout farming industries of Germany, Denmark and Turkey differ considerably in terms of production volume and techniques deployed. These differences were reflected in the farms selected for the current study. Figure 3 shows the main trout

[4]The currencies were standardized to Euro according to exchange rates of Internet-based forex trading and currency from 31 December 2013 (www.oando.com).

Table 1 Types of energy input into a trout farm and its kWh equivalents according to literature; protein as output of fish farming and its kWh equivalent in addition

Type of energy (unit)	Energy equivalent (kWh)
Electricity (kWh)	1 kWh kWh^{-1}
Feed (kg)	5 kWh kg^{-1} (D' Orbcastel, Blancheton & Aubin 2009; Boissy, Aubin, Drissi, van der Werf, Bell & Kaushik 2011)
Oxygen (kg)	0.74 kWh kg^{-1} (D' Orbcastel *et al.* 2009)
Diesel (L)	9.86 kWh L^{-1} (Kuchling 2011)
Protein (kg)	6.56 kWh kg^{-1} (Pelletier & Tyedmers 2007)

producing regions of each nation and the location of the selected farms.

According to official statistics, Germany has 2600 registered trout farms, but despite this large number, national production is relatively modest, at around 10 500 mt per year (but c.f. footnote no. [4]) (Destatis 2014). The majority of these farms are small operations in Bavaria (south-eastern Germany), run as supplementary income operations by smallholders, who as a rule cannot afford to innovate or invest as commercial farms do. Fish are reared in traditional earthen ponds while larger scale farms use prevailing aquaculture techniques such as modern raceways or (partly) recirculating aquaculture systems (RAS[5]). The traditional German model of earthen pond aquaculture is represented in this study by DE_10^{org}, a farm that integrates broodstock management, hatchery, nursery, grow-out, processing and direct marketing, and all produce is sold to local consumers. A particularity of DE_10^{org} is its conversion to organic methods. The organic niche market is seen as a promising form of ecopreneurship for small-scaled farms in suburban areas (Lasner & Hamm 2014). The main centre of trout production in Germany is Baden-Württemberg, in the south-west, where production in 2013 amounted to about 2700 mt or 75 kg km^{-2}. Of this, a majority is supplied by larger farms. Our own sources indicate that about 50 farms in Baden-Württemberg exceed 100 mt or more per year, while there the official statistic classifies only 40 farms which produce 64 mt on average (Destatis 2014). The few larger professional farms, represented in this study by DE_100^{top} and DE_500^{top}, are usually top managed and operate with raceways or with advanced technology such as recirculating aquaculture systems (RAS). They are larger than the average German farm and seen as better managed (*cf.* Destatis 2014). While DE_100^{top} is an example of a fully vertically integrated farm, DE_500^{top} specializes in grow-out.

In Denmark, the central and southern regions are important trout production areas, yielding 1207 and 958 kg km^{-2}) respectively. By this measure, Danish trout farming sector is the most intensive considered in this study. All in all, Denmark has 190 inland trout farms (Statistics Denmark 2015), of which 157 are traditional operations using earthen ponds such as model farm DK_150. On average, a traditional farm in Denmark produces 112 mt per year. With a total production of 17 568 mt, this type of farm is still the most important in terms of national production volume and in consequence the most typical in terms of the theoretical sampling applied. A few traditional farms, such as DK_55^{org}, have converted to organic methods, aiming at the German market for organic aquaculture products (Prein, Bergleiter, Ballauf, Brister, Halwart, Hongrat, Kahle, Lasner, Lem, Lev, Morrison, Shehadeh, Stamer & Wainberg 2012). Both DK_55^{org} and DK_150 hatch their own fingerlings for on-growing. Tightening of environmental regulations in recent decades is driving an ongoing restructuring of the Danish sector leading to larger farms, which internalize the costs of effluent discharge by investing in RAS technology (Nielsen 2011, 2012; Nielsen *et al.* 2015). There are currently about 33 RAS farms in Denmark (Statistics Denmark 2015), with the most advanced producing 594 mt $year^{-1}$. Model farms DK_270 and DK_700 are representative of the shift towards

[5]There is a range of different RAS definitions in the literature. We have a wide understanding of RAS and according to Pillay and Kutty (2005) RAS is defined as any applied aquaculture construction which treats the production water and reuse it for fish farming. According to our definition, the farms De_100^{top}, DK_270, DK_700 use RAS technology.

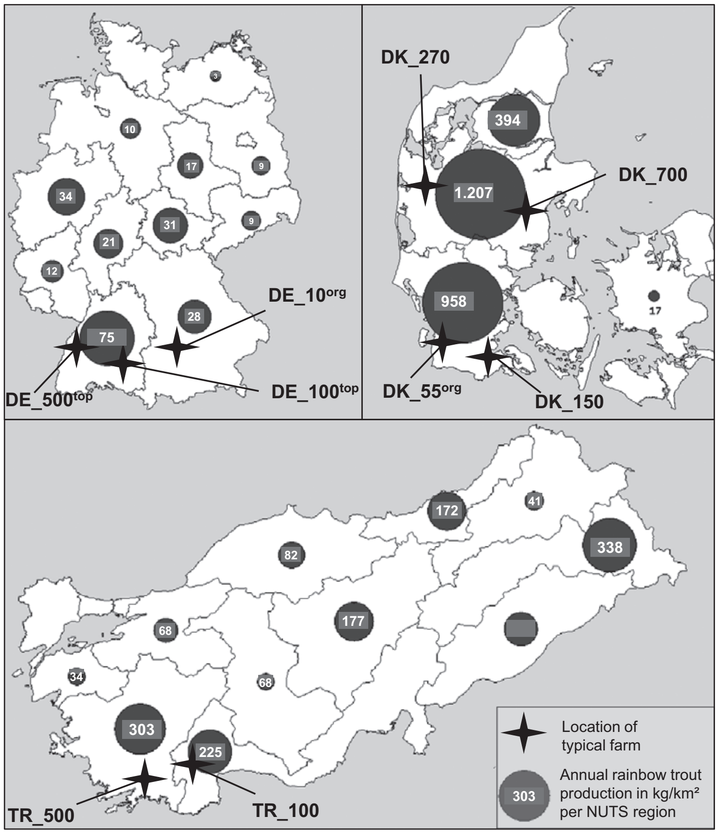

Figure 3 Production of rainbow trout in Germany, Denmark and Turkey 2013 per country and per NUTS (kg km^{-2}). The illustrated regions refer to the 'Nomenclature of territorial units for statistics', abbr. NUTS (European Commission No 1059/2003). Maps are not drawn to geographical scale.

recirculating systems. Both specialize in grow-out. Most Danish farms distribute their products to processors, wholesalers or exporters.

In Turkey, the main centres of rainbow trout production are in Central East Anatolia (338 kg km^{-2}), the Aegean region in the west (303 kg km^{-2}) and the Mediterranean region in the south (225 kg km^{-2}). Model farm TR_500 is situated in the Aegean province of Muğla and TR_100 lies in the Mediterranean province of Antalya. In total, there are 1945 inland farms in Turkey (TurkStat 2014, 2015). Most operate in concrete raceways, with a smaller number of farmers using net cages in artificial lakes; 1397 of these inland farms are small, family-owned businesses with a production capacity of 1–49 mt per year mainly for domestic consumption, and such operations often supplement household incomes from agriculture or other sources. A second group, comprising 408 farms, is made up of more professional sole-proprietor businesses, which dominate the sector in terms of production volume. These commercial farms produce between 50 and 500 mt year^{-1} and are often vertically integrated. The trout are sold directly to the local gastronomy market, to wholesalers and to exporters. The third group of Turkish farms comprises 140 large commercial operations with annual production >500 mt, sometimes even >1000 mt. These are often owned by holdings. The Turkish focus group defined two medium-sized inland trout farms as typical: one vertically integrated operation using raceways and producing 500 mt annually (TR_500) and the second using net cages to produce 100 mt year^{-1} and focusing on grow-out (TR_100). Together, TR_500 and TR_100 represent the types of farms that dominate professionally managed trout production in Turkey.

The nine model farms selected and defined by local focus groups for this study are located in six different European regions and four climate zones (continental, coastal, northern European and Mediterranean). They use a variety of aquaculture systems (ponds, raceway, RAS, net cage), vary widely in scale (10–700 mt year^{-1}), are heterogeneous in their degree of vertical integration (full vertical integration to grow-out only) and deploy diverse distribution strategies (including direct sales, processors, resellers and wholesalers). In other words, the selected sample follows the principle of maximum contrast in qualitative research (Glaser & Strauss 2008).

Cost structure and profitability of trout grow-outs

The selected fish farms in Denmark, Turkey and Germany use different combinations of production methods and target diverse distribution channels. Input and output strategies directly influence cost structure and profitability. The largest and most important of the three cost classes defined in the *agri benchmark* approach is cash cost. Table 2 shows cash costs items (€ kg^{-1} LW) per farm in detail.

Feed is the most important cost item. However, its value varies widely between the systems investigated. In general, farms using traditional grow-out feeds in large quantities have the lowest feeding costs and small organic farms using specialized feed incur the greatest expense. Feeding costs are also influenced by the quality of feed, feed conversion rate (FCR) and country-specific requirements and prices. For instance, DE_10^{org} has the highest absolute feed costs per kg LW. With an FCR of 1, the organic farmer paid 2.04 € kg^{-1} for organic trout feed in 2013, more than twice the expense incurred by the farmer of TR_500 in Turkey (0.92 € kg^{-1}) for conventional feed in the same year. But the farmer of TR_500 operates with a FCR of 1.10, which negatively affects feed costs. For Danish farms, the low FCR of 0.94 might be seen as a direct result of strict Danish environmental regulation, which particularly regulates nutrient outflow (Nielsen 2011, 2012; Nielsen *et al.* 2015) and obliges farmers to use high quality feed.

The costs of fingerlings purchased by grow-out farms impact directly on production costs. In nurseries, however, labour costs are relatively more important than feed costs in determining influencing fingerling price. Thus, farms are influenced by national variations in the costs of labour, as shown by figures for DK_150 and TR_500 in Fig. 4.

The cost of labour for fingerling production at TR_500 is five times lower than at DK_150, which automatically leads to significant disparity in stocking costs, at 0.53 € kg^{-1} LW for DK_150 and 0.24 € kg^{-1} LW for TR_500. For EU-certified organic farms, the cost of fingerlings will be a future challenge. Until 2016, the complete organic life cycle has to be implemented and the option to stock conventional fingerlings will be no longer legal (EC No 710/2009). This changed legal condition will lead to increased costs for organic fingerlings.

High wages in Denmark partly explain the relatively high stocking costs for DK_150, DK_270 and DK_700, and low wages give Turkish farms a comparative advantage over those in Germany and Denmark. Typically, in 2013, a fish farm assistant earned around 8225 € $year^{-1}$ or 3.30 € h^{-1} in Turkey. In Germany, the same job paid between 15.70 € h^{-1} and 20.30 € h^{-1}, while Danish employees earned 26.30 € h^{-1}. However, the salary also depends on the worker's qualifications. At interview, Turkish farmers mentioned the shortage of skilled workers as a challenge to their competitiveness. Unqualified workers might negatively influence management and lead to increased losses in hatcheries and nurseries, which are particularly sensitive to management and handling. For instance, farm TR_500 loses around 40% of its eggs and 25% of fingerlings. At grow-out

Table 2 Cash costs in selected trout grow-out systems in different regions 2013 (€ kg^{-1} LW)

	DE_10^{org}	DE_100^{top}	DE_500^{top}	TR_100	TR_500	DK_55^{org}	DK_150	DK_270	DK_700
Feed	2.04	1.32	1.02	1.10	1.01	1.47	1.11	1.03	1.03
Fingerlings	0.98	0.33	0.27	0.25	0.24	0.83	0.53	0.41	0.41
Wages	0.15	0.03	0.10	0.10	0.07	–	0.11	0.14	0.11
Energy	–	0.35	0.10	<0.01	<0.01	0.18	0.13	0.31	0.24
Interests	–	0.02	0.03	–	–	0.07	0.10	0.10	0.08
Veterinary	0.02	<0.01	<0.01	0.03	0.03	0.03	0.05	0.04	0.06
Administration	0.11	0.04	0.02	0.04	0.01	0.04	0.05	0.04	0.05
Maintenance	0.12	0.07	0.19	0.06	0.03	0.09	0.11	0.09	0.11
Other	1.49	0.09	0.05	0.02	0.02	0.27	0.17	0.16	0.07
Total	4.92	2.26	1.79	1.61	1.41	2.98	2.35	2.33	2.17

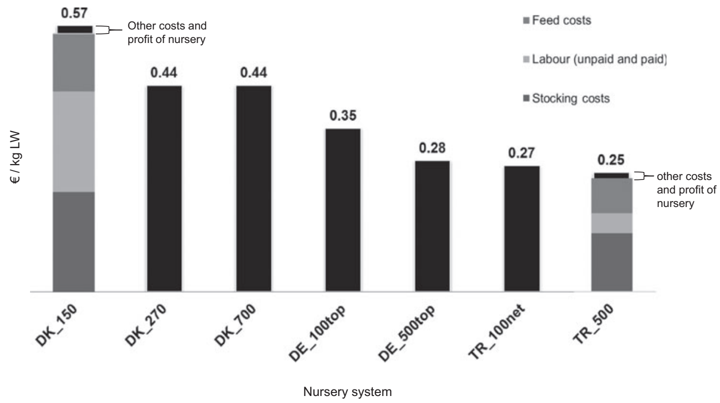

Figure 4 Total cash costs, feed, labour and stocking costs of selected conventional trout nurseries in different regions 2013 (€ kg^{-1} LW).

stages, the loss stabilizes at 5% of stock, a figure comparable to that in conventional Danish grow-out farms. However, earlier losses in Danish and German farms seem to be, in general, significantly lower. For instance, egg mortality in DE_500^{top} is only about 15% and that of fingerlings around 8%.

Regarding energy costs, De_100^{top}, DK_270 and DK_700 incur the highest expenses, because of the high level of automation inherent in recirculating systems. These farms also have to comply with stricter national environmental regulations on nutrient emissions and restrictions on water use. For instance, DK_700, which has the greatest reliance on RAS technology in the sample, uses only 0.13 L of water per second per mt trout produced. This low water usage demands a higher use of energy and is thus not without expense.

Veterinary expenses including vaccination and drug use make up a relatively small proportion of overall costs (<2.4%). Costs for administrative activities such as accounting, and compliance are also relatively small (<2.4%). Costs for maintenance and repair are greater for farms in countries with relatively high labour costs (e.g. DE_500^{top} 7.3% and DK_150 6.5%).

Danish farmers are dependent on investment capital loaned by financial institutions, resulting in significant interest costs. In contrast, the typical German farms have been family-owned for generations and the amount of borrowed capital is usually low. According to interviewed farmers in Turkey, entrepreneurs tend to boost their equity by borrowing capital from family or local social networks, which helps keep interest payments to a minimum.

To obtain a complete picture of costs, earnings and profitability, this study included values for depreciation and opportunity costs for own labour and capital and market prices obtained from each farm (Fig. 5).

Depreciation comprises the second class of costs described by *agri benchmark*. The relatively high depreciation costs for DE_10^{org} are caused by this farm's small scale. DE_100^{top} and DE_500^{top} have invested substantially in modern facilities to maximize water efficiency. In contrast, TR_500 has an average annual water abstraction rate of 1,000 L s^{-1} and a low level of automation. Furthermore, labour and material costs for investments in Turkey are comparably low. The small depreciation costs for TR_500 and TR_100 take these into account. For Danish farms, depreciation is calculated at an intermediate level.

The value of opportunity costs increases with the use of unpaid labour (own and family) and is thus higher in farms using less paid labour (categorized as cash costs) and lower levels of automation. For example, in the small family farm DE_10^{org}, opportunity costs for unpaid labour are a key cost driver (0.38 € kg^{-1} LW). In contrast, greater investments in automation renders opportunity costs very important for capital, as for DE_100^{top} (0.25 € kg^{-1} LW). The opportunity cost of capital indirectly reflects the relationship between equity and borrowed capital (*cf.* interest costs above). Danish farmers have made large investments in larger, more advanced farming systems in order to meet strict environmental regulations, and they face relatively high labour costs due to higher wages. DK_270 and DK_700 have a borrowed capital share of 70% and 82% respectively. Thus, Danish farms tend to have high interests costs, but low opportunity costs of capital, while for the analysed German farms the situation

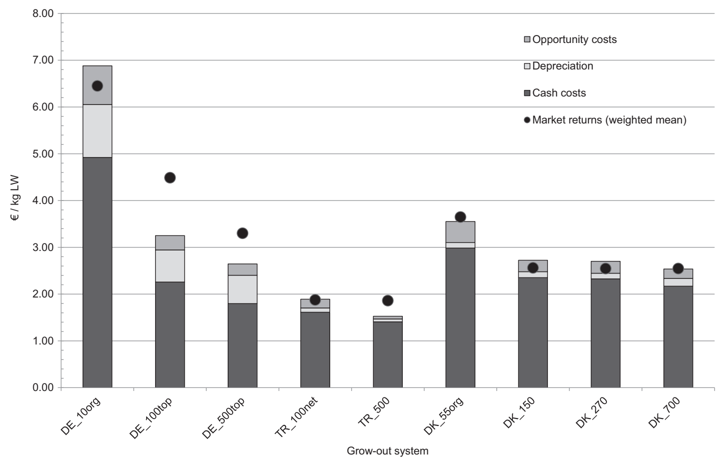

Figure 5 Cash, non-cash costs and returns in selected rainbow trout grow-out systems in different regions 2013 (€ kg^{-1} LW).

is reversed. Opportunity costs pertaining to land have not been included in this study, because the spatial requirements for trout aquaculture are low[6] in agricultural terms and unlikely to be a limiting factor on production.

Typical cost structures vary widely between farms and countries. However, in all cases, costs also depend on the specific market strategies that farms pursue. As such, farms with significantly higher costs per kilo of fish produced, such as DE_10^{org} with its organic market strategy, also obtain higher market returns. On the other hand, farms that pursue a high volume–low cost strategy earn less revenue per kilo of fish produced. The marketing strategy covers distribution. Profitability per kg LW at the farm gate achieved by the farms in the sample is shown in Table 3.

All nine examined farms are profitable in the medium term. However, it should be borne in mind that professional farms like DE_100^{top} and DE_500^{top} are unusual in the German national trout sector, which is dominated in number by smallholder operations, if not in volume. Top German farms are included in this study, because they are comparable in an interregional benchmarking of professional farms by their farm characteristics (*cf*. Materials and methods). The results highlight the fact that highly professionalized fish farm operations in Germany have good opportunities to be strongly competitive. A lack of profitability seems not to be a barrier to growth of (larger) trout farms in Germany. Thus future research could usefully focus on other possible barriers, such as a shortage of aquaculture licences or social acceptability of fish farming.

A dependence on exports and low market returns challenges the profitability of TR_100 and TR_500. But in the long term, TR_500 is very profitable (0.33 € kg^{-1} LW), and its reliable performance is due mainly to the comparably low depreciation and opportunity costs. At the other extreme, the traditional Danish farm DK_150 has good short-term profitability (0.21 € kg^{-1} LW), but struggles in the long term (−0.17 € kg^{-1} LW). DK_700 is the only conventional Danish farm with good long-term profitability. Our results confirm the observation of Nielsen *et al.* (2015) that large RAS farms in Denmark operate more effectively and profitably than smaller ones. The picture for organic farms is quite different. DE_10^{org} is the least profitable system in the long term, while in the Danish organic farm DK_55^{org} benefits from a medium-scale, less vertically integrated strategy that makes it the most cost-effective of all Danish farms sampled.

Labour and energy productivity

Not surprising, the greater the level of automation, the less the labour is required, and the greater the productivity of physical labour. Farms like DK_700, DE_100^{top} and DK_270, which use RAS technologies, are most productive in terms of physical labour. Physical labour productivity varies among grow-out systems, from 13.14 kg LW added h^{-1} at

[6]For the selected farms, the land usage differs from 0.2 ha (DK_55^{org}) to 50 ha (DE_500^{top}) at whole farm level or 0.01 m² kg^{-1} LW trout (DK_700) to 0.89 m² kg^{-1} LW trout (DE_10^{org}) for grow-out system isolated.

Table 3 Short-, medium- and long-term profitability of selected trout grow-out systems in different regions 2013 (€ kg^{-1} LW)

Profitability	DE_10^{org}	DE_100^{top}	DE_500^{top}	TR_100	TR_500	DK_55^{org}	DK_150	DK_270	DK_700
Short-term*	1.53	2.23	1.50	0.26	0.45	0.66	0.21	0.22	0.38
Medium-term†	0.40	1.54	0.90	0.17	0.39	0.55	0.08	0.10	0.21
Long-term‡	−0.43	1.24	0.65	−0.02	0.33	0.09	−0.17	−0.16	0.01

*Short-term profitability = market returns − cash costs.
†Medium-term profitability = market returns − (cash costs + depreciation).
‡Long-term profitability = market returns − (cash costs + depreciation + opportunity costs).

TR_100 to 164.52 kg LW added h^{-1} at DE_100^{top}. The reasons for the disparity are manifold. For instance, the physical labour productivity is relatively low in both Turkish farms, whose more extensive strategy is mainly driven by extraordinarily low labour costs. TR_500 has the highest total number of employees (15 paid workers) of any surveyed farm and the highest absolute working input (12 696 h $year^{-1}$), but the lack of automation leads to a physical labour productivity of 36.76 kg LW added h^{-1}. According to local experts, physical labour productivity in Turkish trout farms typically varies between 25 and 50 kg LW added h^{-1} depending on the specifics of individual farm management and the skill level of the workers.

The calculated epEROI of the model trout farms in this study ranges between 9.1% and 14.1% for trout fillet. Despite these variations, overall energy productivity in grow-out is influenced principally by feed input, with electricity and oxygen input as the second most important factor in most of the selected systems (Fig. 6).

Overall, variations in epEROI among the studied trout farm systems was notably low, although systems that differ in their techniques also vary in the source of manufacturing energy used. There are few published studies of epEROI for farmed fish. Pelletier and Tyedmers (2007) found values from 7.8% to 17.8% for farmed Atlantic salmon depending on feed formulation. Compared to rainbow trout, salmon has a higher fillet yield with an average of 65%, but the energy investment is also higher due to the lower feed efficiency and of the greater use of energy-intensive feed ingredients, mainly fish oil and fish meal (Pelletier & Tyedmers 2007). Thus overall, epEROI of rainbow trout is comparable to that of salmon, with the lower fillet yield compensated by a lower energy input as feed. Common carp reared in relatively extensive culture systems achieve epEROI values from 11% up to 70% due to very low or negligible energy input requirements (Tyedmers 2004). The average epEROI of global fisheries has been estimated at 8%, but values vary widely between 2% and 56% depending on the abundance and catchability of target species (Tyedmers 2004). All study farms compared favourably in energy terms with coastal fisheries using purse seiners (epEROI 5.8%) or

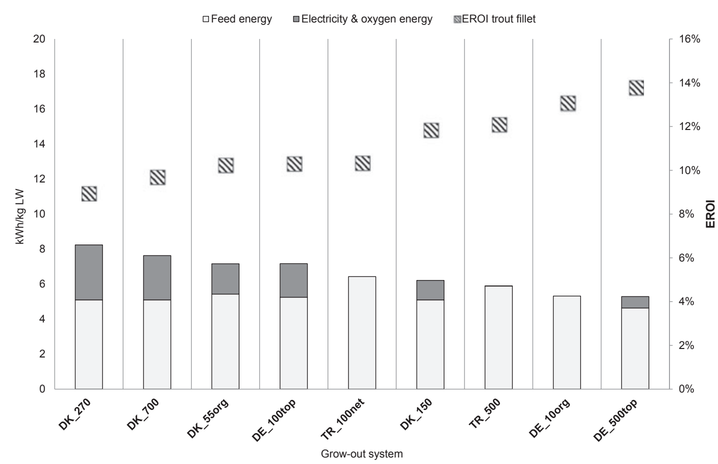

Figure 6 Energy consumption (kWh kg^{-1} LW) and epEROI of trout fillet (%) produced in selected trout grow-out systems in different regions 2013.

trawlers (epEROI 18.3%) (Vázquez-Rowe & Villanueva-Rey 2014).

Compared to epEROI achieved in other sectors of livestock production, the farming of rainbow trout is highly competitive and outperforms most farmed terrestrial species. Broiler poultry is regarded as the most efficient system of terrestrial livestock farming, with an average epEROI of 17.7% and up to almost 25% in the USA. For ruminants, epEROI is very low, at 2.5% for beef and 1.8% for sheep (Pimentel 2004; Pelletier 2008). The trout values improve, if the EROI would refer to kg trout LW instead of kg trout filet: some trout farms in the sample (DE_10^{org}, DE_500^{top} and TR_500) would achieve an EROI over 17% and thereby compete with poultry towards the top position in the above ranking. Nonetheless, our study focuses on epEROI for comparable analytic reasons and in this context; we are restricted to fillet or fillet plus skin.

A known weakness of measures like epEROI is that the energy of human labour is generally not taken into consideration. This leads to an underestimation of energy consumption, especially in labour-intensive farms. This significant input was taken into account for the three German farms in the current study, using an energy value of 36 MJ per working hour, according to Zhang and Dornfeld (2007). The recalculated epEROI including energy of human labour led to the revised picture of energy efficiency shown in Fig. 7.

In the labour-intensive small farm, DE_10^{org}, energy input value increased from 5.32 kWh kg^{-1} LW to 5.71 kWh kg^{-1} when energy for human labour was included, and epEROI dropped from 14.1% to 13.1% as a result. Thus, in energy terms

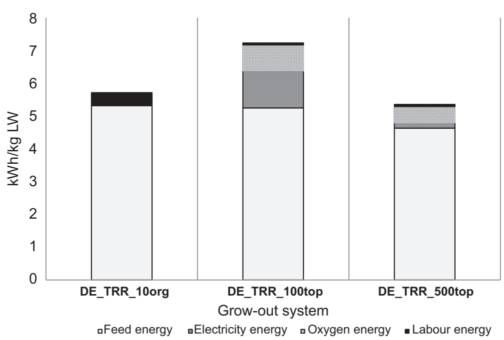

Figure 7 Energy consumption (kWh kg^{-1} LW) including labour energy in German labour-intensive (DE_10^{org}) and labour-saving systems (DE_100^{top}, DE_500^{top}) 2013.

labour-intensive grow-out systems such as DE_10^{org} do not automatically perform better than systems with higher electricity consumption like DE_500^{top}.

Conclusion

Our study confirms that the typical farm approach permits a detailed analysis of trout farm profitability and productivity as well as providing ecological indicators that might facilitate robust and insightful assessments and allow useful national and international comparison to be made.

The most striking outcome of the study is profitability achieved in all countries. While this varies considerably, it still outperforms most European terrestrial animal farming and raises a question as to why this fact alone is not apparently enough to stimulate sustained growth of the sector in all European countries.

Cash cost is the most important *agri benchmark* cost class and accounts for 68–92% of total costs. Regardless of the aquaculture technique applied, feed is the most vital component of cash costs with a share of around 40–70%.

Regarding the second class, depreciation costs, farms with low levels of automation have significant advantages, with highly mechanized facing costs up to twelve times higher to cover depreciation on machines, equipment and buildings.

A similar picture emerges for opportunity costs for the use of own capital, in which low mechanization or a high levels of borrowed capital can reduce opportunity costs for capital to <2% of total costs, while for the other farms the average is around 8%. On the other hand, farms with lower mechanization are disadvantaged in terms of opportunity costs for their own labour, which for some smaller family farms amounts to as much as 11% of total costs.

The use of epEROI data as an indicator of ecological sustainability shows that all aquaculture farming systems are highly competitive compared with the range of terrestrial animal meat production thus far investigated.

All in all, this study demonstrates the potential of the typical farm approach in producing data sets that enable deep and holistic analysis. The resulting data sets are not statistical representations because, for example, they depend on feedback from individual farmers and the knowledge of selected experts. However, the data does provide a new and valuable supplement to current accounts and production statistics. It enables further in-depth analyses of individual farm economics and delivers archetypes that will aid decision-making by fish farmers. Moreover, the typical farm approach allows comparable benchmarking on an interregional basis, where other statistics are unavailable or incompatible. Finally, the approach can also claim the pertinent advantage of reducing the time and cost of data collection.

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