Biomass and Bioenergy 115 (2018) 244–252

Contents lists available at ScienceDirect

Biomass and Bioenergy

journal homepage: www.elsevier.com/locate/biombioe

Research paper

New biomass products, small-scale plants and vertical integration as opportunities for rural development

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ARTICLE INFO

Keywords:
Microchips
Pellets
Forestry
Agriculture
Logging

ABSTRACT

The study surveyed eight small-scale operations designed to produce wood pellets and microchips, the latter intended as a low-price pellet surrogate. Surveyed operations were equally spread between the two product types, and they all targeted residential users. They were all run by forest owners or forest contractors, driven to the new business by the need to increase the value of low quality wood and to fill the gap created by a dwindling firewood demand. Production cost averaged 228 € t^{-1} for pellets (9% water mass fraction) and 134 € t^{-1} for microchips (water mass fraction between 11 and 18%). For each process type, three entrepreneurs out of four accrued meaningful profits, estimated at 10% and 6% for pellets and microchips, respectively. However, profitability differences between the two production chains were deprived of statistical significance. Raw material cost accounted for 28% and 50% of total cost respectively for pellets and microchips, and it was significantly lower for forest owners. Product drying was always obtained with renewable energy sources, such as wood or solar radiation. The most important success factor reported by all entrepreneurs was direct sale to final users, without intermediation. Additional success factors were: self-construction, use of unutilized resources at marginal cost, control of raw material supply and capture of opportunity wood. Entrepreneurs who ceased operation attributed their decision to the lower cost of imports, the absence of a receptive market and the higher profitability of alternative products.

1. Introduction

The consumption of wood pellets has increased very rapidly in recent years, exceeding 18 million t in 2014 [1], and scholars predict further dramatic growth by year 2020 [2]. That is the consequence of a resolute EU bioenergy policy, aimed at curbing on greenhouse gas (GHG) emissions [3]. In order to decrease GHG emissions, both the EU as a whole and the individual member states support bioenergy through a mix of subsidies, tax exemptions and mandatory targets [4].

The growing unbalance between supply and demand has generated a lively global trade, where biomass is shipped to Europe from wherever it is available at competitive cost and quality [5,6]. Pellets are especially suitable for long-distance transport, due to their high energy density and market price, and it is estimated that 50% of the global pellet production is the object of cross-border trading [7]. That includes a substantial flow of pellets from outside the EU and into her borders, since the EU represents 85% of the global pellet consumption, but only 60% of production [8]. Canada and the US are currently the main suppliers [9], also because long-distance sea transportation seems more efficient than road transportation between European countries [10].

Compared with other solid biofuels, pellets offer a number of advantages, and especially homogeneity and high energy density. These qualities make pellets the ideal fuel for small-scale boilers, as those used in residential heating. For the same power output, pellet plants are simpler, cheaper and smaller than chip-fed plants, while more convenient than firewood installations that cannot be automated. It is not by chance that Italy is the largest global consumer of pellets in residential heating applications, with an annual demand estimated at 1.4 million tons. This large demand is matched only in part by national production, quantified at 0.8 million t and largely supplemented by imports [11].

Three main factors contribute to the extraordinary success of pellet plants on the Italian market. First and foremost, the very large population of Italy makes residential heating a mass market, which magnifies the effect of any trends, including the current shift towards bioenergy. Second, the Italian gas prices are among the highest in Europe [12], which explains the search for alternatives. Third, the mild climate of Southern Europe limits heating hours below the threshold required

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https://doi.org/10.1016/j.biombioe.2018.05.004
Received 19 October 2017; Received in revised form 12 May 2018; Accepted 14 May 2018

for the effective depreciation of capital-intensive solutions, such as those offered by chip-fed plants and district-heating systems [13]. Furthermore, any radical changes of the household heating system are best effected within the scope of new building projects [14], but the housing industry has been the worst hit by the recent economic crisis with the consequent slump in new construction projects.

At present, most Italian households are heated through individual boilers fired with natural gas, which is distributed by a dense pipeline network. Until now, the main alternative has been traditional firewood, which is still immensely popular and reaches an estimated annual consumption above 18 million t [15]. Firewood logs are burned in simple stoves and boilers, that are relatively inexpensive but offer little convenience. In contrast, pellet heating systems offer the convenience of automated operation, while remaining still cheaper than natural gas systems. That is especially significant against the background of an aging population, with an increasing aversion towards heavy tasks, such as the management - and often the harvesting - of firewood. In short, wood pellet systems offer the ideal combination of low capital investment, affordable fuel and convenience that best suits the Italian market for residential heating and explains their overwhelming success.

This success is gained at the expenses of traditional firewood, and that may not be a negative thing for itself, since traditional firewood installations are flawed with low energy efficiency and high emission levels [16,17], and pellet plants offer a marked improvement in that regard [18]. However, firewood is generally sourced in the immediate vicinities, supporting local entrepreneurs and forest owners [19], which is seldom the case of pellets. One of the goals of the European bioenergy strategy is to support rural development within the EU [20], and the rapid shift from firewood to pellet seems to defy it. In fact, the decreasing demand for firewood represents a challenge for an already fragile forest economy. Rapidly decreasing profits have favoured irregular operators, who cut corners by evading taxes and hiring illegals. While the presence of irregular operators is endemic in many rural economies [21], the crisis of firewood has exacerbated the issue until it has become a main challenge for most regular operators, who are being forced to leave the firewood business [22].

Therefore, the question is whether small-scale forest entrepreneurs must only incur damage from the expanding pellet sector, or if they can still obtain some benefits from it. One of the ways in which they can obtain some advantage is if they can offer viable fuel for the growing number of pellet stoves and boilers operated in the country. The goal of this study is to explore such opportunities, and in particular: the production of viable pellets in small-scale plants or the production of microchips, as a low-cost surrogate for quality pellets. The focus of the study is on initiatives launched by forest enterprises, alone or in partnership with some other parties. For this reason, the study excludes projects managed by other company types that have no direct connection with raw material production, but are managed by industrial or capital concerns and buy the wood raw material on the market.

2. Materials and methods

2.1. Pellet manufacturing plants

In the years between 2005 and 2010, when the market for pellets first started expanding in Italy, many companies considered installing a pellet manufacturing facility fed with the primary wood resource rather than sawmill residues. A number of feasibility studies were performed in order to gauge the potential of such endeavor. Most studies returned a negative forecast, further confirmed by the premature closure of a few plants commissioned in those years. Shortly afterwards, few small-scale local forest entrepreneurs cautiously started experimenting with the same concept, but on an even smaller scale. Today, an increasing number of small-scale pellet manufacturing plants fed with log material is operating successfully, and this study surveyed four such plants spread over much of Northern and Central Italy (Fig. 1).

All the plants in this study have a capacity below 1 t pellets h^{-1} and are fed with forest products or by-products, not sawdust or shavings. The sample covers a relatively wide range in plant size, capital investment and annual production (Table 1). All pellet plants in this sample deliver a standard product, matching the quality specifications set for commercial pellet (6 or 8 mm diameter, 9% moisture content). As customary for any commercial pellet plant, the plants in this study are equipped with one or more refining mills and with a dryer, which is fired with chips, pellets or firewood - never with gas or other fossil fuels (Fig. 2). The availability of refining mills, makes screening unnecessary. No debarking facility is included, because most operations use thin-barked hardwood logs, and those that also use conifer logs keep them in storage for at least one year in order to reduce moisture content and favor the loosening of bark, which is easily shed during handling.

2.2. Microchip plants

The term “Microchip” describes a very small (7 mm target length) homogeneous wood chip product that can be used to feed conventional pellet stoves and boilers, usually after minor modifications of the feeding system and a resetting of the combustion controls. Microchip production matches the need for replacing industrial pellets with a new product that can be manufactured by small enterprises, using locally available raw materials and low-investment technology.

Microchips cannot match the quality of pellets in terms of high energy density, extremely low moisture content and regular piece size: however, microchips are still dry, dense and homogeneous enough for feeding stoves and boilers that were originally designed for pellet fuel, and that are much cheaper to purchase than an equally powerful plant designed for accepting conventional wood chips. In fact, some manufacturers have developed new pellet plant models specifically adapted to feeding with microchips, which feature innovative moving grates (e.g. CS Thermos) and/or new and wider feeding ducts, often designed for feeding the fuel from below the grate (e.g. DielleItalia, Nemec Srl etc.). In fact, microchip operators 1, 3 and 4 (as well as pellet operator 1) offer their customers the full package, inclusive of fuel and adapted heating plant. In particular, operator Microchip 3 is a joint-venture between a logging company and a heating plant dealer, where the heating plant dealer took the initiative with the intent of producing their own microchips as part of a farseeing strategy aimed at selling their microchip plants with a guaranteed supply of fuel at competitive price.

While pellets are a standardized product, there are no standards defining microchips, although when they are quality certified (operators Microchip 3 and 4) the certificate makes reference to chip quality Class A1 +, according to standard UNI EN ISO 17225–1: 2015 (Table 2).

The microchip operations in this study are even more diversified than the pellet operations, representing a very large variety in capital investment (from 1500 to 345000 €), production capacity and technical characteristics. Yet, they are all harnessed to manufacture the same general product type, and for the same use. Since no refining mills are deployed, all plants include screening as a crucial stage in the process (Fig. 2). The drying of chips is obtained in different ways, often exploiting solar energy and only in one case through a chip-fired boiler. That also explains the large variety recorded for the moisture content of microchips. The most advanced microchip production systems also perform dust removal at some stage along the process, which is not the case for the simplest operations.

Regardless of product type, all operations present the following common characteristics: they all use low-grade hardwood material, especially sweet chestnut (Castanea sativa L.), which is the dominant feedstock in all cases except for Pellet 2; chipping is always performed with a mobile forestry chipper, owned by the operator or contracted for the purpose, and used for a number of other jobs besides processing feedstock for the pellet or microchip production plant. Concerning chipping, it is worth noting that all chippers used for microchip

Fig. 1. Location of case studies.

Table 1
General description of the study operations.

Operation	#	Pellet1	Pellet2	Pellet3	Pellet4	Microchip1	Microchip2	Microchip3	Microchip4
Commissioned	Year	2010	2013	2013	2014	2008	2015	2015	2014
Output	$t\ h^{-1}$	0.3	0.1	0.4	0.8	0.8	1.1	1.0	0.8
Work	$h\ year^{-1}$	1333	550	500	1125	130	80	5000	500
Production	$t\ year^{-1}$	400	55	200	900	100	90	5000	400
Raw material	%	100 H	66 H/33 S	66 S/33 H	100 H	100 H	100 H	100 H	50 H/50 S
Raw material	$€\ t^{-1}$	40	30	40	55	30	30	45	75
Raw material	Origin	Bought	Own	Bought	Bought	Own	Own	Bought	Bought
Storage	months	2–4	24–36	12	4	12	12	12	3
Product	type	8 mm pellet	6 mm pellet	6 mm pellet	6 mm pellet	Microchips	Microchips	Microchips	Microchips
Moisture	%	9	9	9	9	18	16	11	15
Investment	€	200000	46000	120000	630000	38000	1500	345000	90000
Investment	$€\ t^{-1}\ h^{-1}$	666667	460000	300000	787500	47500	1364	345000	112500
Screening	type	None	None	None	None	Oscillating	Rotating	Both types	Rotating
Drying	type	Chip boiler	Firewood boiler	Chip boiler	Pellet boiler	Solar pad	None	Chip boiler	Solar barn
Bagging	type	15-kg	15-kg	15-kg	15-kg	15-kg	Big bags	Sacks	Big bags
Fine removal	step	–	–	–	–	at bagging	none	at sieving	at sieving
Electricity	kW	33	19	55	122	5	3	35	3
Main product	%	100	100	100	100	80	80	30	30
Certified quality		No	No	No	No	No	No	Yes	Yes
Status		Expanding	Stable	Stable	Ceased	Expanding	Ceased	Expanding	Ceased

Notes: Raw material is H = hardwood, S = softwood; the investment cost does not include the chipper, the tractors and the loaders when owned by the same operator, as these machines are acquired and used for other main tasks; 15-kg is the standard small plastic bag used for pellets; Electricity represents the cumulated power of all electric motors in the plant; main product represents the % of the main target product (pellet or microchip) issued from the plant. $€\ t^{-1}\ h^{-1}$ = specific investment per unit throughput.

production are disc types, except for the machine used in operation Microchip 4. Operators state that disc chippers are cheaper to operate and offer better product quality than drum chippers when used on log material, and their statements are supported by existing studies [23].

2.3. The survey

The study consisted in a simple survey of existing commercial operations. Operators were contacted and asked if they would accept to receive a visit and an interview. During the visit, the plants were inspected and the operators were administered a semi-structured interview, covering a wide range of different subjects, including: technical

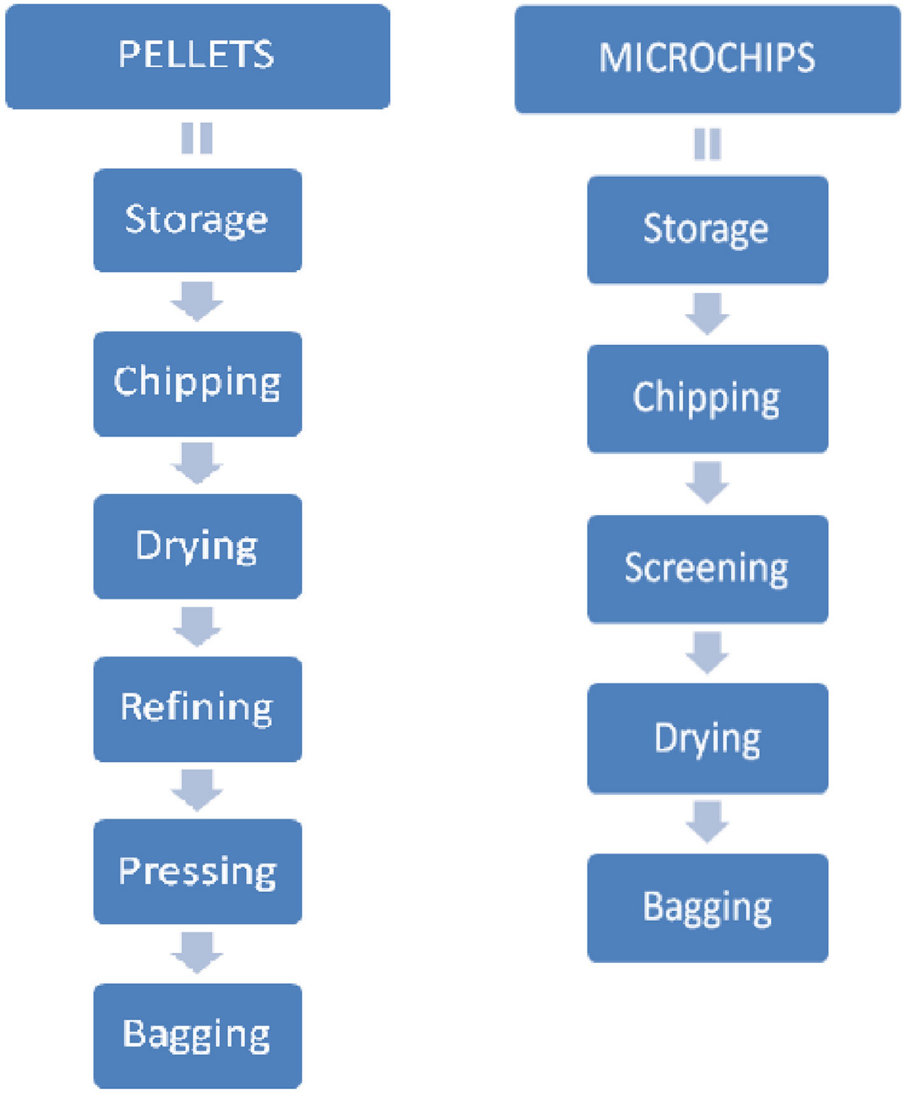

Fig. 2. Production diagrams for pellet (left) and microchip (right) operations.

Table 2
Quality characteristics of best quality chips, microchips and pellets.

Sample	#	Microchips	A1 + Chips	Pellets
Water mass fraction	%	10.4	11	≤10
Density	kg m^{-3} chips	190	233	600–750
Ash content	% on dry	2.0	0.7	≤0.7
Heating value	MJ kg^{-1}	15.8	14.5	≥16.6
Heating value	kWh kg^{-1}	4.39	4.03	≥4.60
< 3.15 mm	%	6	0	≤1
3.15–15 mm	%	94	35	≥99
16 mm-31 mm	%	0	65	0
> 31 mm	%	0	0	0

Notes: data for Microchips and A1+ Chips have been extracted from the certificates for the product of operation Microchip 3; data for pellets have been sourced from AEBIOM [41].

characteristics of the plant, operation cost and economics, drivers leading to the endeavor, main opportunities for business development and hurdles to successful operation. In particular, entrepreneurs were asked to describe in detail the different steps in the manufacturing process, the equipment used for each step, the cost of such equipment, its productivity and the amount and cost of all consumable used during operation. After the visit, a report was compiled and operation costs were recalculated in a dedicated Excel sheet, both of which were submitted to the operator for comments. At this stage, operators could clarify doubts and correct any misunderstandings. Cost calculation was performed under conservative assumptions, whereby labor cost was estimated at 16 € h^{-1} for a specialized worker and diesel cost was estimated at the 1.3 € l^{-1} full price, and not at 0.9 € l^{-1} as charged for subsidized red diesel. Similarly, capital immobilization consequent to prolonged wood storage was added to total cost assuming a 3% interest rate, although none of the interviewed entrepreneurs mentioned storage as an explicit cost. While some of the study operations had received public start-up grants, grant money was excluded from the calculations in order to reflect a pure entrepreneurial perspective. Production cost was balanced against the sale price of the product mix, considering that microchip operations produced a mix of different products, arising from the screening operation. These were normally: microchips proper, quality chips (A1+) and fines, the latter generally sold to pelletizing plants if they were recovered at all. In contrast, pelletizing plants produced exclusively quality pellets. Rejects from the pellet press were recycled through the system and finally turned into standard pellet.

Eventually, all surveys were consolidated into a single data file for statistical analysis. As a first step, descriptive statistic were calculated, separately for the main operation types (e.g. pellet or microchip). The statistical significance of any differences between operation types was tested with non-parametric tests, due to the relatively small number of observations. For the same reason, the elected significance level was $\alpha < 0.10$.

3. Results

Production characteristics are very different for the two operation types: pellet manufacturing plants offer a single product with the same standardized water mass fraction, whereas microchip manufacturing plants offer a product mix composed by variable proportions of microchips with varying water mass fraction (Table 1).

3.1. Product quality and quality certification

None of the pellet operators has acquired product quality certificates, likely due to the small production volume that can be completely sold on the local market based on personal networks and mutual trust. That is also true for the smallest microchip producers, whereas larger producers (Microchip3 and 4) have acquired product quality certificates issued by independent laboratories, with the intention of reaching a wider market.

The product quality certificates obtained for operation Microchip3 show a substantial difference between microchips and A1+ quality chips (Table 2). Microchips are characterized by a length within 15 mm and a small amount of dust, whereas A1+ chips contain a consistent fraction of chips in the 15–31 mm length class and no dust. Obviously, screening out longer chips for sending them to the A1+ pile results in an accumulation of residual dust within the smaller chip pile and the de-dusting devices in the plant seem unable to remove all dust. The density of microchips and A1+ chips is in the range of 200 kg m^{-3}, which is about three times lower than the density of pellets [24].

3.2. Cost, revenues and profitability

On an average, setting up a microchip operation requires half the investment required to set up a small-scale pellet manufacturing plant and offers three times the same product output, for an annual usage that is 60% higher (Table 3). However, none of these differences is statistically significant, due to the very large variety of different options. The only statistically significant differences between plant types are: electric power consumption, product price and production cost, all much higher for the pellet manufacturing plants.

Table 3
General comparison of pellet and microchip production.

		Pellet		Microchips		p-Value
		Mean	SD	Mean	SD	
Work	h $year^{-1}$	877	415	1427	2389	0.3094
Production	t $year^{-1}$	389	369	1398	2406	0.8845
Investment	€	249000	261670	118620	155220	0.2482
Power	kW	57.2	45.6	11.5	15.7	0.0814*
Storage	months	15.3	13.3	9.7	4.5	0.5585
Water mass fraction	%	9	0	15	3	0.0101**
Total cost	€ t^{-1}	228	26	134	30	0.0209**
Sale price	€ t^{-1}	248	15	137	6	0.0180**
Profit	% cost	9.7	12.0	6.1	20.8	0.5637
Process cost only, chipping and bagging excluded						
Capital	€ t^{-1}	47.4	9.4	9.1	8.2	0.0209**
Fuel	€ t^{-1}	9.9	7.2	0.7	1.0	0.0202**
Electricity	€ t^{-1}	25.8	8.3	1.5	2.4	0.0421**
Labor	€ t^{-1}	18.3	3.3	2.3	2.7	0.0172**

Notes: SD = standard deviation; p-Value = probability of Type I error, estimated with the Mann-Whitney test; € t^{-1} = Euro per metric ton of final product at the defined water mass fraction; sale price = mean price of all products issued from the plant, weighed by their contribution to total product mass; * = marginally significant difference (p-Value < 0.1); ** = significant difference (p-Value < 0.05) *** = highly significant difference (p-Value < 0.01).

In particular, the cost difference between pellet production and microchip production depends on process cost (Fig. 3), where "process" proper includes the central work steps after chipping and before bagging, and namely: drying, refining and pressing for pellets, or screening ad drying for microchips. Defined as such, process cost is on average 7 times higher for pellets compared with microchips: 101 € t^{-1} vs. 14 € t^{-1} respectively (mean values from Table 4). In contrast, mean raw material cost, chipping cost and bagging cost are not significantly different for the two product options. The pelletizing process incurs significantly higher depreciation, fuel, power and labour costs than microchipping (Tables 3 and 4). While capital cost is the dominant component of total process cost for both options (Fig. 4), differences are highest for energy cost, since fuel and power cost are respectively 14 and 17 times higher for pellet production than for microchip production (process stage only). The fuel used for drying the chips before pressing (pellets) or screening (microchips) is always renewable and consists of reject firewood, screened out chips or pellets. In general, the heat demand of all plants in the study is met with renewable sources: wood for all pellet operations and operation Microchip3, and solar radiation for operations Microchip1 and 4.

The higher price fetched by pellets results in pellet operations being more profitable than microchip operations, although the difference is deprived of any statistical significance due to the very large variation in the data pool. Conversely, the much lower investment required by a microchip operation pushes mean return on investment (ROI) slightly above 9%, against the 5% figure recorded for pellet operations (values estimated for successful operations only, after removing those operations that had to shut down). But this difference is not significant either, and for the same reasons. In fact, one can lose money or make good profits with both products, depending on plant management and local market conditions.

It is also worth noting that raw material cost is significantly affected by ownership, and it is estimated at a much lower value (30 € t^{-1} vs. 51 € t^{-1}, on average) by those entrepreneurs who source raw material from their own forests. That corroborates the free-format statements collected during the interviews, which pointed at the need to market one's own unutilized resources as an important motivator for endeavouring into pellet or microchip production (Table 5). Raw material cost includes immobilization of capital, which never amounts to more than 3 € t^{-1} of final product, or 6% of the total wood cost (2 years in storage at 3% interest). Therefore, immobilization represents a very small component of raw material cost, and it is not significantly different between the two systems. A relatively long storage period may serve several purposes: it compensates for the lack of active drying in most microchip operations, it favours natural bark removal in pellet operations, and it buffers intermittent raw material supply when opportunity wood is targeted.

3.3. Motivation, opportunities and obstacles

Forest operators endeavour into pellet or microchip production for few but compelling reasons, and especially the need to find an outlet for their unutilized wood and to counter dwindling firewood demand (Table 5). In their attempts, they may join efforts with heating plant manufacturers or even start their own stove and boiler dealership, and the need to guarantee fuel supply to the plants they sell represents another important motivator. Different respondents indicate a variety of different success factors, but one is mentioned by all: direct sale to the final user, without intermediation. Other mentioned success factors share the same common goal of reducing production cost, and these are: self-construction, use of unutilized labour resources at marginal cost, control of raw material supply and capture of opportunity wood. Respondents indicate several different hurdles to successful operation, but

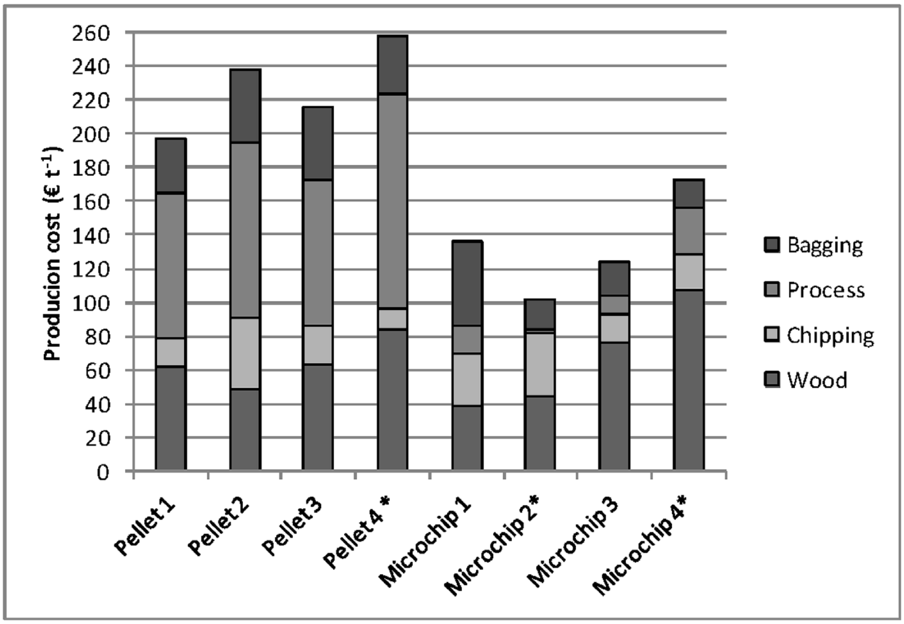

Fig. 3. Itemized production cost.
Notes: figures refer to the whole operation and include all necessary materials and processes required to obtain the final commercial product ready for sale; the term "process" describes the central work steps after chipping and before bagging and consists of drying, refining and pressing for pellets, or screening ad drying for microchips; the asterisk marks those operations that eventually shut down.

Table 4
Cost, revenues and profits of the study operations.

Operation	#	Pellet1	Pellet2	Pellet3	Pellet4	Microchip1	Microchip2	Microchip3	Microchip4
Wood	€ t^{-1}	61	49	63	84	39	44	76	107
Chipping	€ t^{-1}	18	42	24	12	31	38	17	21
Process	€ t^{-1}	86	104	86	127	16	2	10	27
Bagging	€ t^{-1}	32	44	44	35	50	17	20	17
Total cost	€ t^{-1}	197	238	216	258	136	101	124	173
Sale price	€ t^{-1}	240	270	240	240	146	131	135	136
Profit	%	22	13	11	−7	7	29	9	−21

Notes: all costs and revenues are referred to the metric ton of final product, at the water mass fraction recorded at the end of the process; wood cost includes immobilization of capital; sale price = mean price of all products issued from the plant, weighed by their contribution to total production; the term "process" describes the central work steps after chipping and before bagging and consists of drying, refining and pressing for pellets, or screening ad drying for microchips.

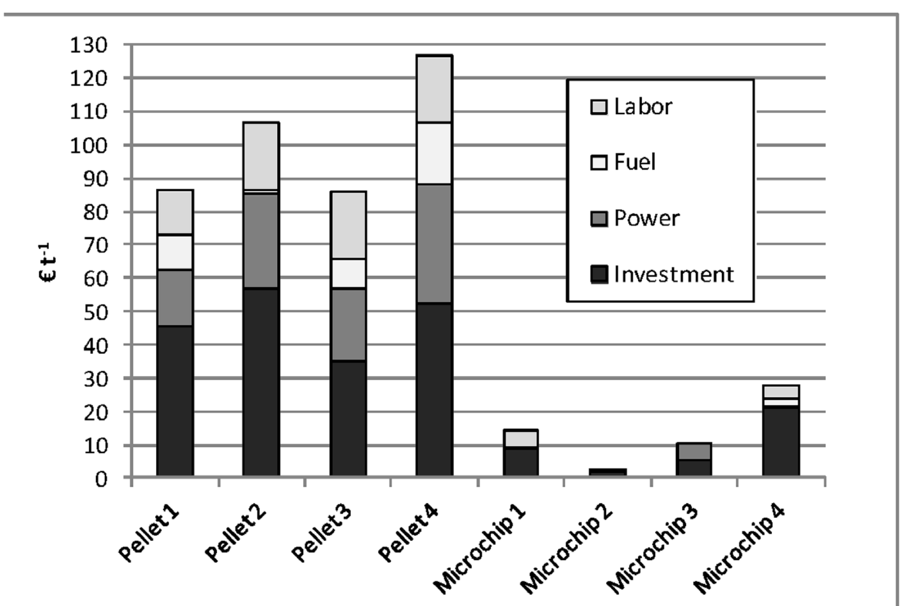

Fig. 4. Contributors to process cost.
Notes: figures refer to process cost only, excluding wood, chipping and bagging.

Table 5
Motivator, success factors and hurdles.

Operation	Pellet1	Pellet2	Pellet3	Pellet4	Microchip1	Microchip2	Microchip 3	Microchip 4
Reasons to endeavor into pellet or microchip production								
Finding an outlet for low-value wood		x		x	x	x		
Replace firewood production		x	X					x
Guaranteed fuel supply to boiler buyers	x				x		x	
Supply own plant/stove						x		
Key success factors								
Control of raw material	x	x			x	x		
Direct sale to final users	x	x	x	x	x	x	x	x
Marginal use of labor		x			x	x		
Sells boilers as well					x		x	
Self-constructed equipment	x	x			x	x		x
Use of opportunity raw materials	x	x					x	
Integrating multiple products		x			x		x	x
Main hurdles to business survival and growth								
High cost of raw material								x
High cost of electric energy	x		x	x				
Limited demand for product					x	x		
Cheaper price of import				x				x
More profitable alternative uses								x
Darker colour of pellets	x		x	x				

Notes: results extracted from operator responses to free-format interviews.

three pellet operators out of four mention the high cost of electricity and the darker colour of hardwood pellet as the most serious limitations. In that regard, it is most interesting to analyze the reasons for closure, as declared by those entrepreneurs who ceased operation. These are different from those just listed above, and include: lower cost of imports (Pellet4), absence of a receptive market (Microchip2) and higher profitability of alternative products, namely A1+ chips (Microchips 4).

4. Discussion

4.1. Study limitations

First of all, it is important to state upfront the limitations of the study, and namely: a) the use of a small and widely variable sample and b) the adoption of entrepreneur declarations as base reference figures.

Small sample size is an inevitable limitation when investigating a pioneering sector, characterized by a small population. In particular, very few microchip operations are available that may offer reliable data. To our knowledge, there are only two other microchip operations in Italy, but they have just started and are largely experimental, which makes them poor candidates for the extraction of reference figures. Despite being launched almost 10 years ago [25], microchipping started to gain some traction only recently, and there are still very few operators who can offer sufficient experience with this new business. Although slightly larger, the number of small-scale pellet operations is also limited and most such operations are run by farmers or wood working entrepreneurs, not forest operators. The stated goal of the study was to explore cases of vertical integration in the forest sector, which are still relatively rare. Besides, the need for a balanced sample led to reducing the number of pellet cases to the same level as obtained for microchip cases.

Use of owner declarations was dictated by the difficulty in obtaining access to operator accounts, as well as by the lack of comprehensive and accurate records that often characterizes small-scale rural operations. Readers must be aware that the accuracy of the figures in this report depends on the truthfulness of these declarations. However, there is no particular reason why operators should have provided deceitful answers, and the answers they provided were found to be consistent with the conditions offered by local markets and with the observed characteristics of the plants, which were all visited and inspected. For this reason, the figures in this reports are likely free of gross inaccuracies and if they are not exact, they are certainly plausible.

In any case, these limitations suggest cautious interpretation of results, which may be considered preliminary and should be corroborated by later studies, once the sector has grown to some larger extent. Similarly, the trends underlined in the study are likely indicative, rather than conclusive.

Furthermore, readers must be reminded that the study was based on standardized conservative estimates for labour and fuel cost, and that subsidies were not included in the calculations. In fact, some of the operators did accrue additional economies from one or more of the opportunities listed above, and therefore their financial results were likely better than reported in the study. Similarly, prospective operators who can obtain a public grant, access subsidized fuel or use marginal labour resources will likely obtain higher profits than indicated here.

4.2. Key success factors

The study describes clear differences between the two operation types. Microchip production is a simple process, which can be implemented with a very small investment. Screening is the characterizing step, present in all operations. For the same investment level, a microchip operation will yield a larger product volume than a pellet operation, serving more users and utilizing larger forest areas. Microchipping is often a part-time job, conducted during seasonal lulls in activity. Microchips represent a new product, largely unknown, which currently arouses much curiosity but still needs to gain widespread trust. In contrast, pellet production is a relatively complex process, which incurs larger capital and operating cost. Drying, refining and pressing are the characterizing steps, and pellet production is a parallel job that can improve time use of labour engaged with low-intensity tasks, rather than a part-time job for the seasonally idle. Pellets are a well-known product, very popular and easily traded on all markets.

Further expansion of both business types may certainly benefit from a public information campaign aimed at gaining the trust of prospective users. These need to be reassured about the capacity of modified pellet stoves to handle microchips, and about the potential good quality of dark pellets. Pellet quality is independent from its colour [26], which is a deceiving indicator: however, many users fear that dark pellet may have been obtained from agricultural residues, which are notorious for their high ash content [27] and emissions [28], and are regarded with suspicion for the risk of residual contamination with the pesticides liberally used in modern agriculture [29]. In that regard, quality certification from independent accredited laboratories may play a crucial role, and so would a certificate of origin. Developing local trademarks could be an alternative and may find the support of regional agencies in most European countries. On the other hand, most operators target their neighbours with which they can establish a direct relationship based on mutual trust, and therefore certification is less crucial than it would be for a mass commodity sold outside local circuits. Occasional diffidence about pellet colour could be overcome by releasing free trial sacks, at a lower cost than incurred for obtaining a certificate. In contrast, general marketing and information campaigns could be launched by more producers, joining under a shared-cost agreement, possibly with the support of public agencies. As a matter of fact, the growing curiosity about microchips is partly due to the visibility offered to this new product by R&D projects supported with public funds.

Direct sale to final users is reported as the key success factor, and is exactly the same strategy adopted earlier with firewood by most entrepreneurs, which is consistent with their declarations about venturing into the new production in order to replace dwindling firewood demand. In that regard, it is worth noting that the current price of microchips is about the same as that of split firewood, but the new product offers better user convenience, which favours replacement.

Of course, targeting residential users requires packing the product into convenient small-size units, which makes bagging an indispensable component of most plants. Those who opted for delivering their product into big bags did cut their bagging cost (i.e. 41 vs. 17 € t^{-1}) but limited their potential market to relatively large users only. Coincidentally, these two operators (Microchips 2 and 4) ceased production, which does not bode well for exclusive reliance on big bag sales.

4.3. Opportunities for improvement

The studied systems represent pioneering operations, and as such they are likely to offer some room for improvement [30]. In particular, one may try to reduce pellet production cost by experimenting with different raw material mixes instead of using a pure hardwood feed, especially considering that hardwood has been found to be the most difficult to pelletize [31]. Similarly, one could gauge the potential of dedicated microchippers [32,33], instead of adapting standard chippers to a job they were not designed to perform [34,35].

Optimized chipping could further decrease the impact of a process where chipping represents the main consumer of fossil fuels [36], since the large energy demand generated from drying is already covered with renewables, as recommended in previous studies [37]. Use of renewable electricity would boost the environmental performance of pellet operations, since electricity accounts for 90% of the impacts derived from pellet production [11]. Renewable power could be generated on site with a small-scale wood gasification plant, which could also offer process heat, thus offsetting the energy cost incurred with drying [38]. However, commissioning such a plant would incur relevant additional investment and may be outside the reach of the smallest entrepreneurs.

Finally, the substitution potential of pellets and microchips is still unclear. Pellets can replace firewood, and that is what they are actually doing, but local small-scale pellet manufactures find a strong competitor in the industrially-produced import product, which can be produced at a cost below 200 € t^{-1} [39]. Previous studies indicate that small-scale pellet production can be sustainable, but risks are higher than for large-scale production and the presence of suitable conditions for its deployment should be checked with much care before commissioning a plant [40]. Microchips can replace firewood, because they offer better performance for the same price, but their capacity to surrogate pellet is still debated. Their cost is lower, but so is their convenience: a much lower energy density imposes a substantial increase of storage space, which may not be acceptable for the smallest users. However, the fact that many reputed pellet stove manufacturers are developing microchip-worthy models may represent a good indicator of concept potential.

5. Conclusions

Small-scale pellet and microchip production may represent a viable opportunity for forest owners and operators confronted with a declining firewood market. These new products may support rural development more effectively than the massive import of industrial pellets does. The study fails to describe a standard production chain, because such chain does not exist: both systems are implemented at a pioneering stage, and are based on flexible models that can be adapted to the disparate array of rural entrepreneurs, each facing his/her own peculiar local market and working conditions. Data analysis confirms the potential of small-scale pellet and microchip production, and is corroborated by widespread interest among stove and boiler manufacturers.

Acknowledgements

The research leading to these results has received support from the Italian Ministry for Food, Agriculture and Forestry Policies (MIPAAF) within the scope of project SUSCACE (Scientific Support to the Conversion of Conventional Agriculture Towards Energy Production).

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