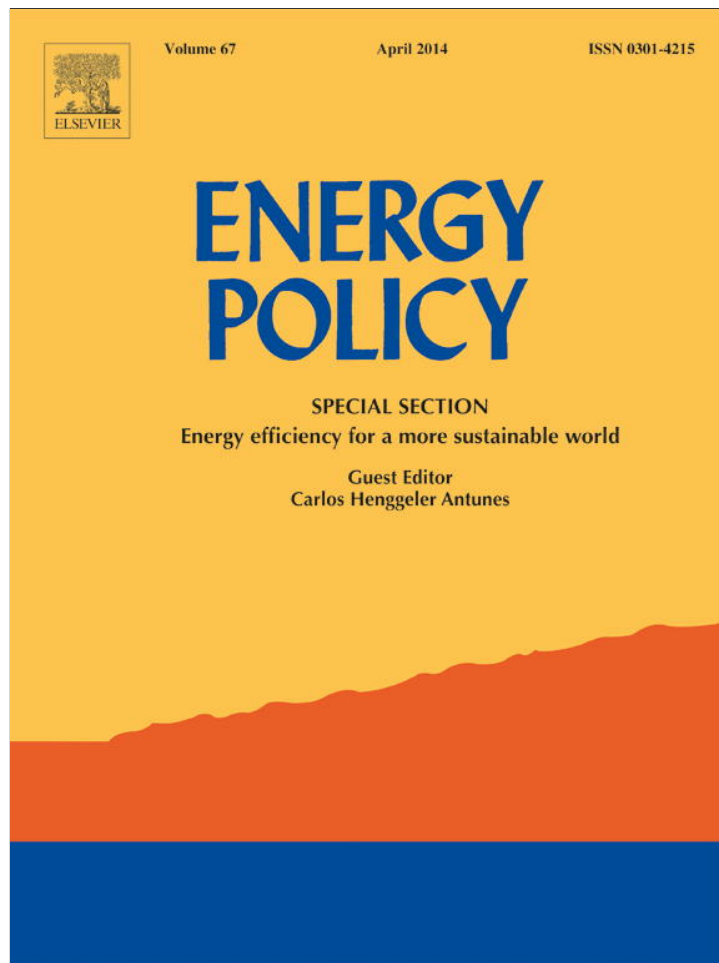


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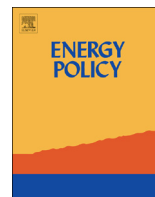
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Energy Policy

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Socio-technical barriers to the use of energy-efficient timber drying technology in New Zealand



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HIGHLIGHTS

- Firms processing timber in New Zealand use two main drying technologies.
- Relatively inefficient vented dryers dominate over energy-efficient heat pumps.
- Operating costs are similar but the socio-technical regime supports vented dryers.
- Stasis is created by fixed energy cultures both within firms and across the sector.
- Stasis hampers technical development in heat pump drying and business innovation.

ARTICLE INFO

Article history:

Received 27 March 2013

Received in revised form

3 December 2013

Accepted 9 December 2013

Available online 31 December 2013

Keywords:

Energy efficiency

Socio-technical barrier

Energy culture

ABSTRACT

This study of industrial energy behaviours identifies barriers to the use of energy-efficient drying technology in the New Zealand timber industry, and explores these barriers through the “energy cultures” lens. Vented kiln dryers were preferred by larger firms and heat pump kiln dryers were used by smaller firms. Although few firms could specify all their costs, we found no significant differences in the average operating costs, drying costs or commercial success of the larger and smaller firms. We found that socio-technical barriers create “energy cultures” at the level of both the firm and the sector, supporting the dominance of vented kiln dryers. The prevailing technologies, practices and norms at the sector level strongly support vented kilns, the status quo being embedded in the socio-technical context, hindering technological learning, improved energy efficiency and innovation. Influential stakeholders in the industry were thus part of, and locked into, the industry-wide energy culture, and were not in a position to effect change. We conclude that actors external to the prevailing industry energy culture need to leverage change in the industry norms, practices and/or technologies in order to reap the advantages of energy-efficient drying technology, assist its continued evolution and avoid the risks of path-dependency.

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1. Introduction

It is well accepted that improved consumer energy efficiency is an important and cost-effective option for reducing global greenhouse gas emissions (Laitner, 2013). Referring to earlier IEA studies, Stern (2007: xiii) noted that energy efficiency has “the potential to be the biggest single source of emissions savings in the energy sector” by 2050, a view further endorsed by the International Energy Agency, (2012). However the diffusion of energy efficient technologies is relatively slow (York et al., 1978; Shama, 1983) because energy technologies tend to be long-lived, capital intensive, interlocked with

other technology networks, and have high learning needs. The possibility of accelerating the uptake of energy efficient technologies is widely seen as a challenge in economics, innovation studies and energy systems (Chai and Yeo, 2012; Geels and Schot, 2007; Grübler et al., 1999; Klapowitz et al., 2012; Lutzenhiser, 1993; Stephenson et al., 2010; Thollander and Ottosson, 2007).

Among the theoretical models for energy consumption decisions is the Energy Cultures framework proposed by Stephenson et al. (2010) to integrate multi-disciplinary perspectives on the drivers of energy decision-making, drawing in part from socio-technical systems literature (Rotman et al., 2001; Geels, 2004; Smith et al., 2005). Applying the framework to the energy decisions of industrial firms, it distinguishes the external drivers of a firm's decisions from the internal, over which the firm has agency. External drivers include commercial pressures, technology

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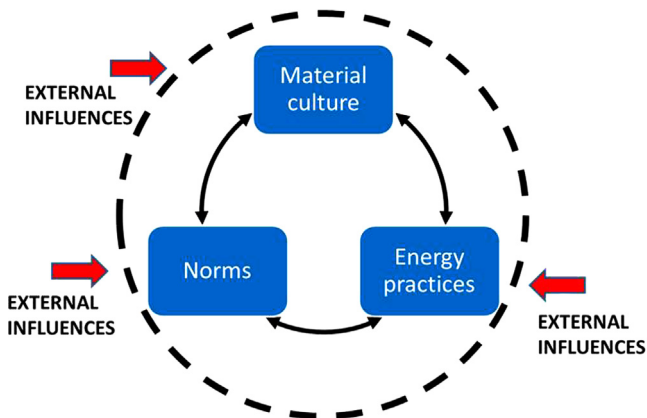


Fig. 1. The Energy Cultures framework (adapted from Stephenson et al. (2010)) showing energy culture as the self-reinforcing internal interactions between material culture (energy-related technologies and physical infrastructure), energy practices and norms. These in turn are affected by external influences that may either act to reinforce the culture or to change it.

networks and supply firm interventions. Internal drivers are grouped into energy-using activities (“practices”), physical technologies and infrastructure (“material culture”), and mental models of what is normal or appropriate (“norms”). Because of feedbacks, these multi-level influences have the potential to create a durable culture of habitual energy decision-making (Fig. 1), representing a socio-technical barrier for a firm to change its energy decisions. For effective policy responses, it is important to understand the interactive nature of socio-technical barriers affecting the deployment of energy efficient technologies (Geels and Schot, 2007), so that they can be addressed effectively.

In this paper we use the Energy Cultures framework to identify and understand socio-technical barriers influencing the energy decisions of small and medium-sized timber processing firms in New Zealand. Because timber drying, on average, requires more than 95% of the energy consumed by these firms (EECA, 2005), the paper focusses on the drying operation.

In New Zealand most timber is dried using conventional vented dryers, but about 3% is dried using heat pump dryers, which are more energy efficient and have a number of environmental and commercial advantages. One might reasonably expect heat pump drying technology to be used more than this and it is unclear why many firms in this industry reject heat pump technology so comprehensively. The purpose of this paper is to identify the drivers and barriers for the timber drying decisions of these firms.

In Sections 2 and 3 we discuss the timber processing industry in New Zealand and describe our research methods. The results of interviews with twenty small and medium-sized timber firms in 2009 are presented in Section 4. In Section 5 we discuss the results and their implications by considering four questions, formulated iteratively as our understanding of the issues evolved. They are: What is the main success factor in timber processing? Why are certain timber dryers preferred? Are there socio-technical barriers to alternative dryer technologies? Is there a future for energy-efficient timber drying? In our conclusion, Section 6, we consider what we can learn from this study to inform low-emission, energy-efficient, technology deployment more generally.

2. Industry background

New Zealand produced 3.5 M m³ of sawn softwood from plantation sources in 2009 (MPI, 2012). The price paid for logs at that time was approximately \$NZ120/tonne (MPI, 2013) and radiata pine dominated both domestic and export timber sales.

Based on EECA, (2005) and MED, (2012) data the sawmilling industry in New Zealand uses approximately 2% of all domestic consumer energy and 4% of electricity production. Drying is important because it reduces biological attack, distortion and crack development in sawn timber (Perré and Kee, 2006) and reduces transport costs. The quality of the drying process determines the market value of the sawn-wood (Alexiadis, 2003).

Conventional vented kilns operate at temperatures of 70–120 °C and the energy used is typically 3.2 GJ/m³ (EECA, 2005). Of this energy, 7% is supplied as electricity, the balance being in the form of heat produced by burning coal, natural gas or sawmill residues. Heat pump kilns are different; they use a type of air-conditioner to dry the timber (Carrington, 2007), and consume only electricity, typically 0.5 GJ/m³ (Van der Pal et al., 2005). Based on these data, heat pump dryers are 84% more energy efficient than vented kilns. The reason heat pump dryers are so efficient is that heat is recycled within the dryer. On the other hand, they typically use twice the electrical energy per cubic-metre of sawn-wood as vented kilns and operate at lower temperatures, 50–60 °C, so drying times are longer.

Atmospheric emissions represent another point of difference between the two technologies. Vented kilns produce combustion emissions, such as particulates and carbon dioxide, generating 345 kg CO_{2-e} per cubic-metre of sawn timber, based on the emission factors for wood combustion and electricity in 2009 (MBIE, 2012). If all of New Zealand’s sawn softwood were dried with such kilns, the atmospheric emissions would be 1.1 Mtonnes CO_{2-e} per annum, 3.9% of national combustion emissions (MBIE, 2012). By comparison, the emissions per cubic-metre of product dried with heat pump kilns are 25 kg CO_{2-e}, a reduction of 92%. This comparison does not take account of the fact sawmill residues, used by many firms, are a carbon-neutral fuel. Approximately 75% of New Zealand’s electricity is generated from renewable resources, so the emissions benefit is larger than in countries where the fraction of electricity generated by fossil-fuels is greater.

Particulate emissions are regulated in New Zealand, but volatile organic compounds (VOCs), mostly monoterpenes (McDonald et al., 2002), are not. Based on the rates reported by Pang et al. (2006), national emissions of VOCs by vented timber drying kilns are approximately 300 t per annum. By comparison, in an unvented heat pump kiln the release of VOCs is substantially reduced or eliminated. Simpson (2004) reported no terpenes in the condensate of an unvented heat pump kiln drying radiata pine.

Another difference between the two technologies is the effect of the higher temperatures used in vented kilns on product quality. Drying at higher temperatures reduces the value of high-quality grades of radiata pine due to colour development (McCurdy et al., 2004), kiln-brown-stain (Kreber and Haslett, 1997) and internal checking (Haslett and Dakin, 2001). These effects are reduced by drying at the lower temperatures presently used in heat pump dryers (Perré and Kee, 2006).

In spite of these features, heat pump kilns have limited penetration in the New Zealand market, producing some 2.8% of the volume of dried lumber in 2001 (Bannister et al., 2002), which is similar to other countries with significant softwood processing industries. Alexiadis (2003) found that 8.8% of timber kilns in Canada were of the heat pump type. A report by Cooper (2003) on energy efficiency in wood drying kilns in Europe indicated that heat pump timber kilns were not viewed there as a mainstream technology. In a review of wood drying principles and practices internationally, (Perré and Kee, 2006) include heat pump dryers among the “less-common drying methods”.

3. Research methods

The authors of the paper have disciplinary backgrounds in sociology, engineering/physics, consumer psychology and human

geography. We studied twenty small-to-medium-scale firms in the New Zealand timber processing industry between May and September 2009: ten in the southern South Island and ten in the northern North Island. These regions have similar rural infrastructure but are at opposite ends of the country. The firms were selected on the basis of existing contacts and ease of access for data-gathering. The purposive sample captured the biggest energy users in the regions as well as some smaller operations. The size of the firms ranged from fewer than 5 employees to more than 130.

Data were collected from the firms by interviewing a senior manager with a good understanding of the business. Fewer than half the participants were owner operators. The interviewer, who was unknown to them before the project began, had not previously worked on timber industry issues and had a strong background in social science research. Interviews were semi-structured with open-ended questions to explore the activities that the Energy Cultures framework suggested could influence a firm's energy decisions:

- Business practices: product types, drying methods, fuel sources, waste-streams, labour, management, marketing activities.
- Current infrastructure: sawmill plant, drying equipment.
- Mental models relating to energy decision-making: history, values, beliefs, knowledge, needs, concerns, and expectations.
- External influences: markets, legal, environmental, technology, research, resources, the economy, and financial issues.

Recorded interviews were transcribed verbatim for interpretive analysis. Two of the authors read and coded the interview transcripts independently and then met to compare their interpretations. All differences were resolved iteratively during the analysis process. Relevant numerical data and attributes were recorded in a data matrix for framework analysis (Ritchie and Lewis, 2003) and the text was analysed for trends relating to the categories listed above through constant comparison (Glaser and Strauss, 1967).

In-depth analysis compared specific characteristics of firms using different drying technologies. To do this we developed "indicator" scales, drawing from the data matrix to create an approximate but helpful indicator of average differences between the resulting three groups of firms.

There were difficulties in analysing the cost data obtained from the interviews because the monthly operating cost was not provided by one firm and the costs provided by four others were considered to be misreported because they appeared to omit the cost of timber. The cost data for these five firms was excluded from the analysis and the values presented here for the operating costs per cubic-metre are the averages for the remaining firms. Similar difficulties arose in determining the costs of electricity and fuel for drying, and for seven firms these data were excluded. It appears that in a face-to-face interview situation, few firms could specify all their costs in a nutshell.

4. Results

To present the results we have used the three themes of the Energy Cultures framework in Sections 4.1–4.3, focussing respectively on the business practices, the current infrastructure and the mental models of the firms interviewed. In Section 4.4 we discuss significant external influences identified in the interviews.

4.1. Business practices

4.1.1. Timber processing

Eighteen of the twenty firms interviewed had sawmilling operations where 40–60% of the log was converted into sawn

timber, the residues being wood-chips, bark, core-wood, slabs, shavings and sawdust. The firms identified a number of end-uses for the residues including wood-pulp, landscaping, farm-litter, wood-pellets, boiler-fuel and community-use firewood. Where the residues were sold, the price obtained was normally \$NZ20–30/tonne (wet), much less than the original log cost of around \$NZ120/tonne. Two firms purchased sawn timber from external sources.

Structural and industrial timber grades were mostly dried in vented kilns at temperatures of 120 °C or more to achieve rapid throughput. Higher quality appearance grades were normally dried at 70–90 °C, the duration of the process being about 2 days. Energy for drying was mostly provided by steam or hot water heated in a furnace. One firm used a third type in its cluster of dryers, a small vented kiln that was directly heated by a coal-fired furnace.

Eight of the firms dried at least some of their timber using a heat pump dryer, five using heat pumps only. For the three dual-technology firms, the heat pump kilns were not in regular use. We note that the firms using heat pumps dried approximately 3% of the production volume, which is consistent with Bannister et al. (2002). For further analysis the firms were clustered by drying methods: ten with vented kilns, five with heat pump kilns and three with both technologies. Two of the twenty firms had no kilns, using air drying only.

4.1.2. Cost control

A number of firms were under financial stress, those selling into commodity markets especially being trapped between the log prices they paid suppliers and the prices their customers paid. Their response was to trim processing costs and improve control of their operations. These firms emphasised the importance of cost control, one manager stating: "It is crucial to business. Our business in general is now about cost control, whether it be electricity or whether it be the price of a duster or a pen. It is just the way it is".

Most firms were also concerned about equipment costs, many purchasing second-hand equipment. One manager said, "if you put brand new technology in a lot of New Zealand mills, they would go broke instantly, because you can't afford the interest rate and the capital payment and the depreciation". However older boilers tended to have higher emissions of particulates and the efficiency of a second-hand sawmill was usually lower than newer equipment. Three of the smallest firms were responding by upgrading "very old-fashioned" saws to reduce the width of the saw-cut. Some of those with heat pump dryers had reduced costs by building their own kiln chambers. This was a risk, because heat pump dryers lose performance if the chamber is poorly insulated (Carrington et al., 2000).

Based on such comments we assigned an indicator to the importance each firm placed on cost control, 1 for low and 5 for high. The average score for the firms with vented kilns was 3.2, for those with heat pump kilns 3.6, and for those with a mixture of both kiln types 2.5. The difference between the first two categories of firm was not significant but firms with both types of dryer were evidently less focussed on cost control than the others.

4.1.3. Products and markets

Considering first the eighteen firms with drying facilities, twelve dried only radiata pine, four processed both radiata pine and other species, and two focused on specialty timbers, such as imported species and swamp kauri. Their products included: processed timber such as decorative moulded-profile boards for export; structural timber for the domestic and export building

industries; and specialty products for local use, including retaining walls, stock-yards, fencing, and power-transmission poles.

Of the ten firms using only vented kilns, nine processed radiata pine primarily, two having some Douglas fir as well; five sold most of their product into the commodity markets. The three firms with both heat pump and vented kilns processed only radiata pine which they sold into niche markets. Two of five firms using just heat pump kilns processed radiata pine only, the others drying a range of timbers including radiata pine, Douglas fir, macrocarpa and swamp kauri. The products of these five firms were sold into both commodity and niche markets.

To rate the firms on the degree to which they sold their products into niche markets, we used a scale of 1 (commodity) to 5 (niche). The firms with vented kilns scored 2.8, those using heat pump kilns only were rated 3.0 and the firms with both types of dryer scored 3.8. There was little difference between the vented kiln and heat pump groups, but the firms with mixed drying facilities were more successful in accessing niche markets.

4.1.4. Price-setting

The interviews provided data from which the capacity of firms to determine their product prices was assessed. For example, some firms sold their products through marketing agents, which meant they did not have close links with their customers and had little influence on their prices. Others were better positioned by having strong customer service and support systems in place. On a scale of 1 (price-taker)–5 (price-setter), the firms with vented kilns scored 2.0; the firms using only heat pump dryers scored 2.6; and the firms using both types of kiln scored 3.3.

This indicates that there was, on average, some difference between the firms with vented kilns and those with heat pump dryers in their ability to secure acceptable prices. The group of firms using both types of kiln was evidently able to influence its prices more than the other firms. This group engaged in niche markets more effectively (Section 4.1.3) and was also the most profitable (Section 4.4.2), although its operating costs were higher than the others (Section 4.2.1).

4.1.5. Fuel choices

Typically for vented dryers more than 90% of the energy needed for timber drying is used for kiln heating (EECA, 2005). Eight of the thirteen firms using at least some vented kilns used wood residues as their furnace fuel, two used coal, two used both residues and coal, and one used gas. In New Zealand, the use of residues to fuel boilers became an established practice in the timber drying industry after about 1990. Generally the ability to use sawmill residues was seen as an attractive feature of vented kilns. It avoided potential disposal costs and the use of greater log recovery to provide boiler-fuel was seen as being more sustainable. “The big energy source would be heating for the kilns and that's all wood waste”, said one manager. However, some firms were too small to generate a reliable supply of fuel from residues. Supply was also affected by changes in the timber market, as noted by one manager, “if the demand for dressed product falls away, then sometimes we have to bring in wood waste.”

None of the firms considered that the potential sales value of residues consumed as boiler-fuel should be counted as a business cost. Had they done so, this would have contributed approximately \$6/m³ to the cost of drying (Section 4.2.2), not including the cost of recovering, drying and storing the residues. The sales value of sawmill residues, \$NZ20–30/tonne, is about 5% of the retail price for wood pellets in New Zealand. This suggests that there is room for the value of residues to rise if, as expected, demand grows for wood-sourced biofuels. Hall and Jack (2008) estimated that the demand for wood residues for liquid biofuel production

would exceed the current supply and that the process would be economically viable using low-quality logs costing up to \$NZ65/m³. Some managers recognised the emerging pressure from biofuels, one stating “We are already experiencing that now, not ourselves but the industry is, where the demand for that wood waste, for the wood pellets, biofuels is already having quite an impact on supply.”

4.2. Current infrastructure

4.2.1. Relation to firm scale

The scale of the firms varied widely. Table 1, shows those using vented kilns only were much larger on average than those using heat pump dryers, as indicated by the production rate and the number of employees. In spite of this, the average operating cost per cubic-metre of sawn timber was not significantly different between the firms using vented kilns and those using heat pumps. The scale of firms using both types of kiln was between that of the two groups using one or the other. A feature of this group was that their average operating cost per cubic-metre of sawn timber was significantly higher than the other two (Table 1).

4.2.2. Influence of infrastructure on drying costs

None of the participants indicated they had an understanding of the total cost of drying including capital amortisation, maintenance, energy and the value of wood residues consumed. To fill this gap we estimated an average total cost of drying using data supplied in the interviews, other published data and our own background knowledge.

The difference in the set-up costs and production rates of the two drying technologies at the entry-level is a significant industry issue (Section 5.2). The capital cost of an entry-level heat pump dryer, which would dry some 3000 m³ pa, is approximately \$NZ400k. By comparison an entry-level vented kiln would have a larger drying capacity, approximately 13000 m³ pa. The cost, including the furnace, wood-residue drying and storage facilities, is in the order of \$NZ2M.

The cost of drying is the value added by drying (\$NZ/m³) in order for the dryer investment to break-even after meeting capital, interest and operating costs over the financial life of the dryer. Capital and interest are amortised in equal annual payments over this time. The energy requirement for a vented kiln is based on data published by EECA (2005) and that for a heat pump dryer is based on data reported by Van der Pal et al. (2005). Other assumptions include: financial life of the equipment 10 years; interest on loans 10% per annum (pa); maintenance costs 3% of capital pa; electricity cost 11.7¢NZ/kWh (MBIE, 2013); cost of

Table 1

Numerical data for the eighteen firms using timber drying kilns. The operating cost (including the log cost) and energy cost per cubic-metre of sawn timber are estimated from the interview responses that were considered to be reliable. Purchased energy excludes use of own timber residues. Costs exclude goods and services tax.

Technology group	Vented kilns	Both types of kiln	Heat pump kilns
Number of firms in category	10	3	5
Average age of the business (yr)	32	41	36
Average volume sawn-timber per month (m ³)	4193	1253	256
Average number of employees	61	33	8
Average volume sawn-timber/month-employee (m ³)	69	38	32
Operating cost/volume sawn-timber (\$NZ/m ³)	339	475	344
Purchased-energy-cost/volume sawn-timber (\$NZ/m ³)	10	16	20

Table 2

Indicative average drying costs for vented and heat pump kilns in \$NZ per cubic-metre of dried timber, excluding goods and services tax. The assumptions are presented in the text.

Cost category	Vented kiln (\$NZ/m ³)	Heat pump kiln (\$NZ/m ³)
Capital, interest and maintenance	32	30
Electricity	7	15
Wood waste	6	0
Total	45	45

wood-residue for boiler-fuel \$NZ20/tonne-wet; wood-residue moisture content 100% dry-basis; labour \$NZ50000 pa per capita; initial and final sawn-wood moisture content 100% and 10% dry-basis respectively; kiln utilisation 90%; total drying cycle time 50 h (vented kiln) and 150 h (heat pump kiln).

The average cost of drying, based on these assumptions, is \$NZ45/m³ for both the vented and heat pump kilns. While there are differences in the cost contributions, shown in Table 2, the fixed costs and the total energy costs are similar, although the purchased energy costs are smaller than those reported in the interviews (Table 1). The average costs hide considerable variations between the firms. For instance, the energy use per cubic-metre of timber varies between sites by typically $\pm 30\%$ (EECA, 2005), in part due to variations in the board thickness and the drying temperature. One manager with vented kilns who used lower temperatures said, “Some run up to 120 °C and it takes up perhaps for 50 mil stuff, two-inch stuff, it might take us three, three and a half days to dry. They could do it in 24 h, but their end-use is not high-end furniture, it is framing. Just different end-use.” Based on our model assumptions, his cost of drying would have been \$NZ68/m³, whereas the cost for a firm drying structural timber in 24 h would have been around \$NZ30/m³.

Lower temperature drying has the potential to yield a higher price in the timber market, but successfully securing that premium is conditional on the marketing strength of the firm. Drying at lower temperatures is feasible with a vented kiln, but is more costly because the drying rate is slower. We estimate that drying in a vented kiln at the same temperatures used in a heat pump dryer, would increase the drying cost to \$NZ120/m³ from an average of \$NZ45/m³. Thus firms with vented kilns, that do not have good marketing strengths, have strong incentives not to dry at lower temperatures to increase quality.

4.3. Mental models

4.3.1. Energy costs

Managers tended to focus on either operating costs or capital costs, not the total cost of production. They were especially concerned about costs directly affecting their monthly cash-flow, such as energy costs. It was generally considered that the cost of drying was lowest for vented kilns using wood waste as fuel. One manager summed up this view: “the thing with kilns is the cheapest kiln you can put in is one that runs on electricity. The most expensive one is the one that will burn your own wood waste. The most expensive to set up, but longer term it will be the cheapest one over a period of time to run”.

The opportunity cost of using wood residues for vented kiln boiler-fuel was considered to be insignificant, although it was close to the cost of electricity used (Table 2). Yet there was a lot of discussion about electricity costs, a number of managers mentioning this as a determinant of the industry context beyond their control. “Electricity is what we are going to be stuck with, really,

but it is drying where the change is going to take place,” said one manager.

The managers of firms using heat pump dryers were generally concerned about their electricity costs, which were about twice those for firms with vented kilns (Tables 1 and 2). None of those interviewed indicated they had discussed demand-side-management options with their electricity suppliers with a view to obtaining price concessions.

4.3.2. Confidence and satisfaction

There were clear differences in participants' confidence and satisfaction in their drying technology. On a scale of 1 (low confidence and dissatisfied)–5 (highly confident and very satisfied) the average score of the ten firms with vented kilns was 5.0, for the five firms using heat pump dryers it was 2.7, and for the three firms using both it was 3.4. Clearly the firms using vented kilns were very confident in their drying technology. “We looked at alternatives very quickly before we built it, but there are not, at the moment, there are not any better ones, for us anyway”, said the manager of a larger firm with vented kilns. Nevertheless, opinions about vented kilns varied, one manager stating, “our kiln is totally different from [another firm]; we would not have one of theirs on-site.”

Generally the larger firms viewed heat pump dryers as being suitable only for small operations. When the manager of one with vented kilns was asked if he would consider heat pump dryers, he said “Not for large volume. It would be alright for a little factory that was wanting to dry a little bit of furniture grade or something like that”. Some of those with vented kilns knew of others with unsatisfactory experiences of heat pump kilns or had themselves moved on from them; “we used to have one twenty years ago ... a disaster!” said one director. None of the ten firms using only vented kilns considered they were locked-in to the technology unwillingly. By contrast, three of the five firms using just heat pump dryers said they would change to vented kilns if they could afford to do so, indicating that the heat pump industry was not meeting their expectations.

Yet several firms were satisfied with their heat pump dryers. The manager of one said, “I did not want boilers and things and these ones come up with nice, we did not have cracking and bowing of timber because they are a slower drying. Simple as that so they are not hard on the timber as much”. Another said his firm was happy with heat pump drying, although he was concerned about the cost of electricity. A third stated he did not have sufficient waste wood to run a boiler, he was glad to have no concerns about emissions and pleased that, without a furnace, his insurance costs were lower.

4.3.3. Emissions concerns

Of the ten firms using only vented kilns, seven expressed concerns about their particulate emissions, those with older boilers being especially worried. Because emissions are subject to regulation, they were a significant liability, forcing some firms to replace boilers. This had adverse financial implications, as noted by one manager: “What that'll do is, half of us will say – that's too hard, let's turn it off, let's turn the whole company off.”

Emissions tended to be worse when the demand for heat was less than the furnace capacity, especially when using coal, even for a modern boiler. Some firms tried to minimise emissions by increasing the heat demand deliberately during testing. “the last test we had they were running at low temperatures, we failed, [so we'll] make sure this time we run hot,” explained one manager.

Overall, on a scale of 1 (not concerned about particulate emissions)–5 (emissions could threaten the firm's survival), the ten firms with vented kilns scored on average 2.8, the five heat

pump firms scored 1.0, and the firms with both types of kiln scored 1.3. Thus vented kiln operators were more concerned about boiler emissions than the others.

Kiln vent VOC emissions seemed to be treated as a separate issue from combustion emissions and were not discussed by any of those interviewed. A number indicated that they were aware of greenhouse gas emissions, but it was not a matter on which they felt obliged to act.

4.3.4. Technology concerns

When asked, none of the firms using vented dryers said they would like to change to heat pump dryers to avoid emissions problems; they were more concerned about the risk of unsatisfactory heat pump performance than emissions. None expressed concerns about vented kiln product quality.

By contrast, the users of heat pump dryers had a range of concerns. Some wanted to reduce their electricity use. One said he would like to dry faster: "In theory, I think they're the way to go. They're clean and green, you know, keeping everybody happy, but we're just not humming right, just missing something." One was worried about mould formation during drying, which is likely to be due to kiln overloading, essentially a management issue. These comments indicated the firms using heat pump kilns were not satisfied with the operating costs, the drying speed and the fact the control was different from vented kilns (see [Bannister et al., 2002](#)). They also felt that the heat pump suppliers did not provide enough support.

Four of the eight firms with at least some heat pump dryers said they would like to change to vented kilns. Three of these four were struggling financially. They produced mainly structural timber products, they were price-takers, and they bought heat pump kilns because of their low initial cost. Evidently these firms were not well adapted to the limitations of heat pump dryers and were not getting commercial benefits from drying at lower temperatures.

4.4. External influences

4.4.1. Timber markets

For many firms, continuing change in the global market was the most significant external influence, an instability that constructed evident imperatives around operating flexibility. Variations in the exchange rate of the New Zealand dollar exacerbated these problems, as noted by one manager, "And the reality is when the exchange rate's low, you're making big profits, but when it goes high, most of us get absolutely trashed, here, alright?". External influences on energy use were embedded in the movement of the market, since that determined the level of demand for a product. For example, more than one firm described a complete reversal over the twelve preceding months from a previous ratio of 30:70 of domestic to export volumes to 70:30. This had implications for the flexibility requirements of these firms and influenced their drying technology decisions.

4.4.2. Profitability

The interviews provided several indicators of the profitability of firms, such as their business confidence, frustrations, plans for new investments, and focus on cost-cutting. For example, two firms in difficulty had restructured and a large number of staff had been lost in the months before the interviews. One manager, evidently under stress, said, "our biggest costs are our raw materials and staff ... the ones we've got to get rid of are staff".

Based on these and other indicators of profitability, firms were rated on a five-point scale from evidently failing (1) to clearly profitable (5). Firms with vented kilns scored an average of 3.7, those using heat pump dryers averaged 3.8, and the dual technology firms scored 4.3. Thus there was no real difference in the

average profitability of the vented kiln and heat pump dryer groups, while the three firms using both technologies were significantly better off. The latter group also scored higher as price-setters than the other two ([Section 4.1.4](#)), which may explain why it was the most profitable group despite having the highest operating costs ([Table 1](#)). These comparisons suggest that commercial success was not related to the choice of drying technology, but was more linked with an ability to secure high-value markets and achieve acceptable product prices ([Sections 4.1.3 and 4.1.4](#)).

Since the interviews, three of the ten firms with vented kilns and one of the five with heat pump dryers have closed down. These firms were mainly price-takers and were not selling into niche markets. All were located in the Southern region, two were less than 10 years old, and two had been in business for more than 40 years. In this context, there was a significant difference in the average profitability indicators of the Southern and Northern firms, being 3.0 and 4.4 respectively.

5. Discussion

In the following we consider the implications of the results using the Energy Cultures framework. The discussion is structured around the four questions set out in [Section 1](#).

5.1. Success factors

Although the average production rate of the firms with vented kilns was some sixteen times that of firms with heat pump dryers, their operating costs and profitability (per cubic-metre of sawn-timber) were essentially the same. There were also no real differences in other performance indicators for the vented kiln and heat pump groups, such as their focus on cost control, ability to access niche markets or capacity to influence their prices.

The firms that were clearly profitable included four of the ten using vented kilns and three of the five with just heat pump kilns. This suggests that the drying technology used was not a significant success factor in the industry, despite the clear belief by the firms interviewed that it was. Rather, profitability depended on whether the firms were price-takers, mostly in the commodity markets, or price-setters with well-established consumer market relationships ([Section 4.4.2](#)). The first group, which included the four firms that subsequently failed, was generally struggling, whereas the second was succeeding.

Key strategies for the price-takers were to respond quickly to varying market conditions and minimise their operating costs. For these firms a vented kiln was the most realistic option, if they were big enough to afford one, because they could change their drying temperatures to achieve flexibility and heat their kilns using wood residues as fuel to reduce direct operating costs. They sought to work-around problems such as limited product quality, boiler emissions and high equipment costs. It appears that these firms did not have the capacity to access more profitable markets.

The firms that used heat pump dryers only were more concerned about cost control than the vented kiln firms, but were stronger as price setters. Nevertheless, these two groups were similar in terms of their ability to find niche markets and in their profitability. Again, commercial success in both groups was determined not by their drying technology, but by their ability to access profitable markets.

The price-setters are illustrated by the group that had both vented kilns and heat pump dryers. On average, these firms were less concerned about cost-control and they engaged with profitable niche markets better than the others. Although they tended to prefer vented kilns, the profitability of firms in this group is unlikely

to have suffered had they used heat pump dryers. Rather, they would have been better positioned to secure higher value markets.

5.2. Dryer preferences

Vented kilns were the preferred choice of timber dryer for the larger firms and it was an ambition for many smaller firms wishing to expand their business. Vented kilns were seen as the industry norm, firms were satisfied with them and had high confidence in the technology. The main advantages of vented kilns were: (i) shorter drying times for structural timber than heat pump dryers; (ii) ability to use wood residues for boiler-fuel; (iii) acceptable electricity costs; (iv) flexible drying rates; (v) a reputation for satisfied users; and (vi) access to technical support. The disadvantages were the high initial cost and the high cost of drying higher value timber at lower temperatures.

The main attraction of heat pump dryers was that they were much cheaper than vented kilns, so they had an advantage for small start-up firms. One might imagine that this entry to the industry would be enough for the technology to succeed, since the suppliers needed only to satisfy these customers. There was indeed a group of satisfied heat pump kiln users, mostly the more successful heat pump users. Others, however, were not satisfied and were not well supported by the technology providers. For these firms the attractions of heat pump dryers were less urgent and compelling than those for vented kilns and they were also unhappy that their electricity use was higher than vented kilns.

This suggests the question: did the firms that changed from heat pump to vented kilns make rational business decisions, or were they being influenced by the industry's energy culture in which vented kilns were the norm? After all, vented kilns provided no cost or profitability advantages for higher value timbers (Sections 4.2.2 and 4.4.2), the drying technology used was not a significant business success factor (Section 5.1), and vented kilns limited the quality of the dried product (Sections 2 and 4.2.2). The change to a vented kiln also carried obligations for managing furnace emissions and sourcing boiler-fuel (Sections 4.1.5 and 4.3.3). And the perceived advantages of vented kilns were not as clear-cut as reported, since the advantages of shorter drying times apply only to structural grades. Admittedly heat pump kilns dry more slowly than higher temperature vented dryers, but the cost of drying more valuable grades is nevertheless lower (Section 4.2.2). Further, heat pump drying technology is scalable: at least one larger firm in New Zealand has operated a cluster of heat pump timber dryers (Perré and Kee, 2006). The fuel cost advantage of vented kilns is also difficult to sustain when the opportunity cost of wood residues is included (Table 2). This implies that the dominance of vented kilns among the larger firms in the sample is not simply due to these firms each pursuing their own economic interests.

5.3. The socio-technical regime

From the evidence we infer that the dominance of vented kilns in the New Zealand industry is not due to economic drivers alone; we therefore consider the influence of the prevailing socio-technical regime in this section.

As the industry norm, vented kilns were trusted and all the larger firms used them. These firms expressed support for drying standards and for timber drying research, and it was evident they had a strong influence on industry research priorities. They were comfortable with links between the vented kiln manufacturers and the timber research organisations. As one manager said, “with the assistance of Windsor [kiln supply firm] and Scion [industry research organisation], most people don't sort of vary too far from their recommendations.”

The dominance of vented timber kilns among the larger firms was endorsed by the technology providers and industry organisations, both of which provided timber processing firms with technical support. The disadvantages of vented kiln technology – high initial costs, product quality limitations, fuel costs, and atmospheric emissions – were accepted. Heat pump dryers were not seen as normal, they were used solely by the smaller timber firms, and were seen as being suitable only for such firms.

It is clear that the drying technology decisions of firms were strongly driven by the broader socio-technical context of this regime (Rotmans et al., 2001, Smith et al., 2005). Using the perspective of the Energy Cultures framework, we observe that there is a ‘culture’ of timber drying that centres on the use of vented kilns, in which norms, technologies and practices have generated a self-reinforcing culture supported by the broader feedback loops of the socio-technical regime. This culture is observable at the scale of individual firms and at the sector scale. For individual firms (Fig. 2), their adherence to vented kilns is reinforced by the acceptance of firm managers that this technology is the norm across the industry, and by their expectations of timber processing practices such as fast drying, processing flexibility and the availability of sawmill residues for boiler fuel. Key drivers of this energy culture included firm size, financial resources, a narrow focus on electricity costs, market variability, a belief that vented kilns were the industry standard and the provision of strong technical and research support (Fig. 2).

This set of influences sat within a broader industry culture that reinforced the status quo across the industry as a whole (Fig. 3). At the sector level, reinforcement between the dominance of vented kilns, the industry norms, and the technical and research support created a second “energy culture” at the industry level that positively

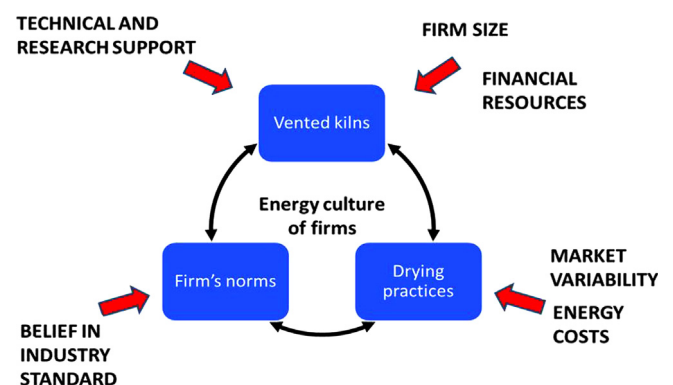


Fig. 2. The self-reinforcing energy culture of firms using vented kilns, and key external drivers of this energy culture.

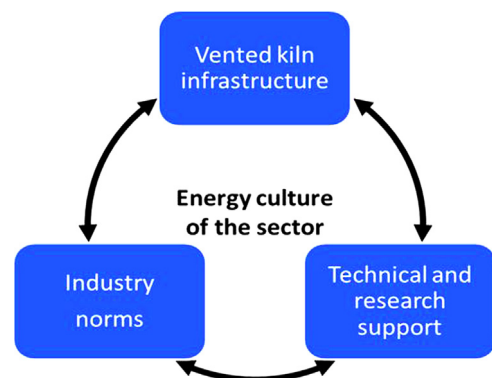


Fig. 3. The energy culture of the timber drying sector, showing the feedback loops that reinforce the dominance of vented kilns.

supported vented kilns, excluding serious consideration of alternative technologies and energy efficiency.

5.4. The future of heat pump timber drying

Heat pump drying has the potential to address the threats faced by vented kiln operators due to emissions restrictions, the rising prices of wood residues and a difficult market for lower value timber products. The current operational limitations of heat pump kilns – their slower throughput, inflexibility, and higher electricity use – are amenable to technology development (Minea, 2008). This raises the question: can heat pump technology achieve its potential in the timber drying industry?

None of the industry stakeholder groups with the capacity to lead culture change – the larger successful timber processing firms, the drying technology providers and the industry research sector – is in a position to do so. The larger timber processing firms and the vented kiln suppliers are strongly committed to vented kilns, and the research sector relies to a large extent on industry support for funding. Thus, none of the major stakeholders is able to promote change because their own energy culture is embedded within the prevailing culture of the industry, as illustrated in Fig. 4.

These barriers to technology change ensure the existing socio-technical regime is stable and is unlikely to change until there is movement in the external regime (Smith et al., 2005). Potentially influential changes include a price on carbon, a strong market for wood residues, advances in heat pump drying, good technical support for heat pump users and an increased capacity for market development in the timber industry. As indicated by the stresses observed in the interviews, the industry is already under pressure to secure higher product prices, which suggests it should put more emphasis on product quality and higher value markets. If these selection pressures persist, and the heat pump suppliers succeed in meeting users' needs, then heat pump drying could become accepted as a mainstream technology.

However, such a niche-based regime change (Schot and Geels, 2008: 551), driven by market pressures that are currently weak and incremental technology advancements, is likely to be slow since it would not address the economic interests of the main stakeholders in the current socio-technical regime (Ottosson and Magnusson, 2013). The heat pump innovators, as small supply firms, would struggle to find the resources required to advance the technology and provide good support to users. Such a slow change

would be economically inefficient and damaging to the industries involved.

A transition could be accelerated if the influences on the energy cultures of individual firms were to change. Increases in the value of sawmill residues (for example, due to growth in the biofuels market) could give rise to a major change in the energy cost driver. If stronger emissions regulations were introduced, a driver that is currently ineffective would be strengthened. Realistically, however, it is unlikely tighter limits on either combustion or VOC emissions will be introduced in the short term in New Zealand. Pang et al. (2006: 802) noted that “there are no international regulations in place to limit the emission level [of VOCs] in the industry, partly due to the resistance from industry”.

Alternatively, new stakeholders could create a faster transition by changing the broader industry energy culture. For example, a large timber processor with a mature and independent approach, working with the heat pump firms and the research sector, could stimulate a culture change by bringing financial resources and legitimacy to the process. Another possibility is an electricity retailer, or demand aggregator, engaging with this market in order to access electrical base-load amenable to demand-side management. A large company such as this could stimulate an industry-wide culture change by helping to resource and legitimise the heat pump drying industry. To be effective such initiatives should also involve the incumbent kiln supply industry as a major stakeholder.

Another potentially influential stakeholder is the Government, which has an interest in increasing the productivity of the timber processing firms, reducing their atmospheric emissions and ensuring they manage emerging risks prudently. A Government initiative could help to shift the industry culture through targeted R&D funding and promoting better market development within the timber industry. Again, such initiatives would need to engage major existing commercial stakeholders to be successful.

6. Conclusions

Our analysis of the socio-technical regime from an “energy cultures” perspective concludes that there is a dominant energy culture within the timber processing industry of New Zealand which supports vented kilns through industry-wide norms, infrastructure, advice and research support. This industry-wide culture legitimises vented kilns and marginalises heat pump kilns, making it hard for individual firms to change their own energy cultures.

While individual firms using vented kilns may perceive that they are making rational economic decisions, it is evident that heat pump drying is more energy efficient, is cost effective, has lower emissions and has the potential to provide a higher quality product. Heat pump drying is slower than higher temperature vented kilns, but the operating costs per cubic-metre of product were much the same for the two methods, for firms in this study. Moreover, the choice of drying technology has no effect on the commercial success of these firms, which is driven mainly by their capacity to secure profitable markets. The more successful firms have the capacity to benefit from greater use of heat pump dryers.

The operating cost advantage of vented kilns may be lost in time if, as expected, the value of sawmill residues increases due to growth in the biofuel industry. A tightening of emissions standards would also threaten the viability of firms using vented kilns. In this respect, the present practice by larger firms to invest solely in vented kilns increases the risk that the industry will be locked mainly into low-value markets and stranded in a technological dead-end in the future. There are clear advantages for the industry in retaining vented kilns in its arsenal of drying technologies, but the technological development of vented kilns is mature, while heat pump dryers are at an earlier stage of development. It is

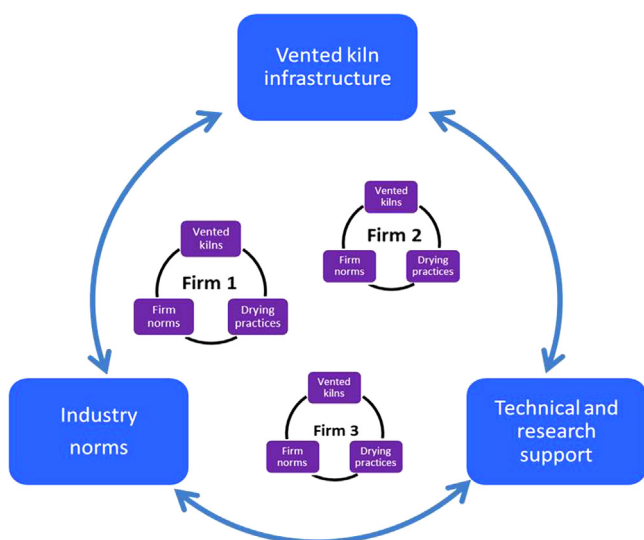


Fig. 4. The energy culture of individual firms is not able to be changed because it is embedded within the wider prevailing energy culture of the timber drying sector.

therefore undesirable for the sector to be committed to a single drying technology, rather than engaging with the possibilities of a different technology which is already viable and has the potential for further evolution to better suit the needs of the industry. The potential benefits of change are significant, including increases in the productivity and resilience of the timber processing industry, new demand-side management opportunities for the electricity industry, and reductions in atmospheric emissions.

At present none of the stakeholders in the industry (timber firms, technology suppliers or research providers) are well-placed to address the barriers to change in its energy culture. The existence of smaller firms using heat pump dryers indicates that the current culture is being tested, but these firms are seen as outliers to the industry norm, and significant change would happen only if their numbers and influence were to grow. In the longer term, pressure from growth of the biofuels sector is likely to challenge the incumbent energy culture, as is any future tightening of atmospheric emissions requirements.

Finally, what can we learn from this case study to help inform energy technology transitions in other sectors? The main finding is that socio-technical barriers have the potential to hinder the development and uptake of energy technologies not seen as mainstream. Technologies that have been at the margins of an industry for some time, without their potential being realised, are particularly exposed to such impediments. Even significant numbers of small firms with a different energy culture are not sufficient to change the culture of the industry as a whole. For the timber processing industry, new stakeholders, such as a large independent commercial player, an electricity retailer or a Government agency could accelerate change, by bringing new influences to bear on industry norms, practices and technologies.

Acknowledgements

We wish to thank Dr. Rebecca Ford, Dr. Ian Simpson, Dr. Eric Scharpf and Professor Shusheng Pang for their suggestions on a draft of this paper and acknowledge the University of Otago Research Committee for providing financial support. We are also most grateful to three anonymous journal referees for their helpful comments. Finally, we thank the timber processing firms for their participation in the research during a particularly challenging time for the industry.

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