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ARTICLE

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Short-rotation coppice agroforestry for charcoal small business in Papua New Guinea

I. K. Nuberg [a], J. A. Mitir [b] and B. Robinson [c]

[a]School of Agriculture, Food and Wine, University of Adelaide, Glen Osmond, Australia; [b]National Agricultural Research Institute, Lae, Papua New Guinea; [c]Forestry Commission, Bristol, UK

ABSTRACT

Fuelwood is an integral part of the Papua New Guinea domestic economy, with consumption estimated at 1.8 m^3 $person^{-1}$ $year^{-1}$. Social stress in many districts is evident by high prices for and the conflict generated by competition for fuelwood. This paper describes three related activities designed to develop small businesses based on short-rotation coppice (SRC) agroforestry systems for fuelwood. These activities are: 1) a survey of domestic fuelwood consumers and vendors (n = 4110) in fuelwood-stressed districts in urban and rural areas of lowlands and highlands; 2) field trials of ten candidate SRC species, at two spacings, in 2–3 year rotations, with measurements of wood volume after two years, coppice vigour, burning characteristics, and market acceptance; and 3) facilitating the establishment of SRC-grown charcoal businesses. The survey found the fuelwood economy has a very short, direct supply chain in a completely informal environment. This paper summarises the fuelwood economy and illustrates the opportunity to create a new fuelwood supply chain that could deliver sustainably harvested and value-added fuelwood to consumers, especially in urban areas and the commercial sector. The SRC systems appealed to landholders because they could intercrop vegetables in the first year, and had the option of carrying over some trees to grow on to poles. The best SRC woodlot species were *Eucalyptus grandis* for the highlands and *E. tereticornis* for the lowlands. *Calliandra calothrysus* is also a suitable SRC species for alley systems in highland gardens. In the highlands, SRC firewood and charcoal production yield higher estimated returns to labour (43 and 24 PNG Kina $person^{-1}$ day^{-1}, equivalent to $US 20–11 $person^{-1}$ day^{-1}) compared with the main alternative crops of sweet potato and coffee (21 and 15 Kina $person^{-1}$ day^{-1} respectively). As SRC-grown wood appears different from the normal, wild-collected wood for sale, there was resistance to it in the market. As a value-adding option, the establishment of charcoal producer groups was facilitated in Mt Hagen and Lae. The group business structures in the two centres were very different, reflecting their socio-cultural contexts. A flourishing SRC-based biomass energy sector will require a multi-sectoral national fuelwood policy.

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Introduction

Papua New Guinea (PNG) is a small country with relatively large per-capita resources of mineral, gas energy and forests. The PNG population of 7.2 million people (FAO estimate 2015) is growing at a rate of 2.3% per annum. This growth rate is increasing at three times the rate at which the area of land being used for agriculture is increasing. Consequently, the intensity of land use is increasing (Allen et al. 2001). This has led to increasing pressure on the environment, as for example the already minimal forest cover in some highland provinces and the denuded woodland associated with the National Capital District (NCD). Over the period 1972–2002, 15% of PNG rainforest was cleared and 9% was degraded to secondary forest. The expansion of subsistence agriculture contributed to 46% of the net forest change over this period (Shearman et al. 2009). In the highland districts dominated by grasslands, people need to walk significant distances in search of fuelwood. Even the existing highland bush fallow systems do not provide adequate fuelwood, as evidenced by the inferior fuel often used (e.g. bamboo and grass) and the long hours spent in fuelwood gathering. In and around urban areas, these changes have led to an increasingly serious shortage of fuelwood at affordable prices.

While fuelwood is used across the whole nation, the main districts where it is recognised as a significant part of the local economy are in the highland provinces of Chimbu, Enga and the Eastern, Western and Southern Highlands. Many of these districts have been assessed to be under significant agricultural pressure and overall relative social disadvantage (Hanson et al. 2001). In addition, the urban areas around the NCD, the highland city of Mount Hagen and the coastal city of Lae have large settlements of highland migrants. These populations no longer have access to customarily owned trees, and usually lack financial resources to purchase other energy sources such as gas or kerosene. Despite the prominence of fuelwood in the domestic economy, the PNG Forest Authority has no fuelwood policy and is not involved in the production or regulation of fuelwood harvest or trading. Consequently, fuelwood is sourced ‘freely’, but in a highly contested environment.

The central premises behind the work described here are that PNG is at a point in its economic development where: 1) there is a need for purpose-grown fuelwood production; 2) there are great small business opportunities if this production occurs in the hands of small landholders; and 3) short-rotation coppice (SRC) systems, producing fuelwood in cycles of about two years, will be more readily

CONTACT I. K. Nuberg ian.nuberg@adelaide.edu.au

adopted by landholders interested in growing fuelwood on smaller areas than would conventional forestry regimes for fuelwood (with production cycles of >15 years).

Development of fuelwood production will lead to an appropriate intensification of small-holder agriculture. The potential direct beneficiaries are broad and many. People (especially women) who have to carry fuelwood long distances will have more time available for other more productive pursuits. Individual landholders and community groups will have opportunity for extra income generation. The creation of such small business opportunities will absorb surplus unemployed labour, which is believed to be one of the causes of increasing lawlessness and violence.

Recognising these needs and opportunities, the Australian Centre for International Agricultural Research (ACIAR) funded projects over the years 2008–2013 to: 1) describe and quantify the fuelwood economy in areas of fuelwood-related social stress, and evaluate candidate SRC species (project FST/2006/088); and 2) facilitate the establishment of charcoal producer–vendor groups (project FST/2011/058).

The evaluation of SRC species in the first project encouraged us to look for opportunities to add value to SRC fuelwood by converting it to charcoal. Charcoal is not widely used in PNG, but it offers a healthy, smoke-free alternative to fuelwood and offers an opportunity for small business. The aim of the second project was to understand the appropriate collective small-business structures for this sector through an action research process with charcoal producer–vendor groups in Mt Hagen and Lae.

Some specific aspects of the work described here have been reported elsewhere: for example, the fuelwood survey (Nuberg 2015) and the SRC trials (Nuberg et al. 2013, 2015; Nuberg & Mitir 2013), and a selection of data from these works is reproduced with the publishers' permission. The work on this paper also provides results in regards to charcoal producer–vendor groups, as well as an overview of the complete body of work from understanding the fuelwood context, to determining fuelwood species options, to facilitating a nascent charcoal industry.

Methods

Surveys to understand the fuelwood economy

A large questionnaire survey (Q-survey) of domestic and commercial fuelwood use was undertaken in 2008–2009 comprising 3954 questionnaires of urban and rural domestic fuelwood users and interviews with 156 fuelwood sellers. The survey focused on areas where there is known fuelwood stress in PNG. These regions were determined to be the NCD, Lae (Morobe Province), Mt Hagen District (Western Highlands Province), Chuave District (Chimbu Province) and Henganofi District (Eastern Highlands Province).

In terms of populations, the provinces from which these districts are selected represent 36% of the national PNG population of 5 190 000, as measured at the most recent census (NSO 2000). The population of districts sampled represents about 10.7% of the national population. The total sample represents 0.9% of the total regional population in the recognised firewood-stress regions. This was considered a very intense and robust survey. Similar fuelwood surveys in India were considered very robust with sampling intensities of 0.5% (Pandey 2002).

The structure of the survey of fuelwood users elucidated the following:

- the physical and social context of the user household
- energy consumption patterns, including of non-fuelwood energy
- gender relations in collection and purchase of fuelwood
- sources of gathered fuelwood
- distances and costs involved in gathering
- expenditure patterns for fuelwood conflict associated with fuelwood gathering
- access to trees and tree planting history
- knowledge and use of charcoal
- preferred fuelwood species
- use of fuelwood in generation of income.

Urban and rural surveys were slightly different so that they could capture information specific to the two contexts. Household weekly fuelwood use was estimated by presenting 10 kg samples of fuelwood and asking how many would have been used in that week.

The fuelwood sellers' survey elucidated the following:

- demographic details of the seller
- enterprise size and nature (gatherer-seller, wholesaler, retailer)
- location and frequency of selling
- fuelwood source and arrangements with landholders
- transportation and bundling
- buying and on-selling practice
- annual income and costs involved with selling fuelwood
- ability to grow trees to sell
- problems associated with the business
- knowledge of and attitudes to selling charcoal.

The relationships between bundle type, weight and price were measured using a portable grocer's balance.

The Q-survey was complemented by: 1) directly measuring the daily fuelwood use of 36 households over two one-week periods to calibrate respondents' estimated fuelwood use with actual use; and 2) 50 semi-structured interviews of commercial or industrial users of fuelwood and institutional stakeholders in the fuelwood economy.

Only a targeted selection of the information gathered from this survey is discussed in this paper. The full survey is available in Nuberg (2015).

SRC field, laboratory and consumer trials to evaluate candidate species

Ten fuelwood species were evaluated in SRC systems in three replicated field sites around Mt Hagen in the Western Highlands Province (WHP; annual rainfall 2586 mm, elevation 1800 m) and Port Moresby in the NCD (annual rainfall 995 mm; elevation ~150 m). Trees were grown at two spacings (1.0 m × 1.5 m and 2.0 m × 1.5 m) and evaluated against locally used non-coppicing species (e.g. *Casuarina oligodon* in the highlands). Some candidate species were also grown in farmer-managed woodlots and alley-farming systems through WHP and Chimbu Province.

The evaluation of SRC productivity included growth measurements after two years with volume estimates of merchantable fuelwood, and tree form and coppice vigour scores. The burning characteristics of candidate species as firewood and as charcoal were determined using the method of Gardner (1989). This is a pragmatic method of measuring the time for a specified amount of firewood to boil 2 L water and wood then remaining (which can be used as a proxy for fire longevity).

Consumer preference for candidate species was evaluated by distributing bundled fuelwood samples to ten households—five in Mt Hagen and five in NCD. The householders were given evaluation forms to rate each species (in comparison to the normal firewood they use) for the following qualities: smokiness, time to cook a meal, amount of wood used to cook a meal, heat produced, light produced, life of coals, ease of handling, and appearance.

Samples of each candidate fuelwood species were also given to groups of firewood sellers at Mt Hagen and NCD markets. Records were taken of the weights and prices of wholesale and retail bundles of each species, the time taken for all bundles to be sold, and the sellers' initial and final opinions of the saleability of each species.

Action research facilitation of charcoal producer groups

Action research methods and participative community engagement over an 18-month period facilitated the establishment of two charcoal producer–vendor groups in Mt Hagen and seven in Lae. Participants also engaged in the training activities of small business planning, charcoal production, charcoal stove construction, and learning nursery techniques for SRC fuelwood species suitable for charcoal production.

A parallel survey was undertaken to discover models of collective engagement that are current and feasible in PNG. This activity entailed 41 semi-structured interviews with individuals involved in community and rural development, with particular focus on group business and community forestry. Interviews were completed in Mt. Hagen, Lae and Port Moresby. Most interviewees were employed by government departments, independent Non-Governmental Organisations (NGOs), private businesses or academia.

Results and discussion

A fuelwood economy ready for interventions to enhance small business

Broadly, the fuelwood economy in PNG has a very short and direct supply chain in an informal environment with no government engagement in supply, marketing, distribution, pricing or taxation. Fuelwood is regularly used by most of the population for domestic and commercial cooking, even in urban areas where there is good access to electricity and other energy sources. Fuelwood consumption is estimated to be 1.8 m^3 $person^{-1}$ $year^{-1}$. This is much higher than consumption patterns from similar surveys in 16 south and south-east Asian countries, which reported an average of 0.32 m^3 $person^{-1}$ $year^{-1}$. The only country to exceed PNG in that series of surveys was Bhutan with 2.35 m^3 $person^{-1}$ $year^{-1}$ (RWEDP 1997).

It is estimated that 2.1 million m^3 $year^{-1}$ of fuelwood was collected in the surveyed regions in 2007–2008; an extrapolation to a national value would be 9.34 million m^3 $year^{-1}$. The annual expenditure on fuelwood in 2007–2008 was in the order of US$ 8.5 million across the surveyed districts. There is significant variation in the price of fuelwood across urban and rural regions. About 3% of urban and 10% of rural people sell fuelwood, mainly on a part-time basis. While 88% of fuelwood users also use other energy sources that are becoming more accessible, fuelwood will remain the dominant domestic energy source for quite some time, especially in rural areas.

Table 1 presents a selection of estimates derived from the survey. It highlights the distinctions between urban and rural populations. Not surprisingly, the rural populations are high fuelwood users, but even in the urban areas most households used fuelwood at some time of the year. This was even the case for households with access to electricity; fuelwood is used in times of power disruption, is used because it provides cheaper energy, and is used for ceremonial and celebratory occasions. Gathering or purchasing fuelwood occurs about two and three times a week in urban and rural areas respectively.

For many who purchase fuelwood, expenses on fuelwood purchases represent a large proportion of the household income. From the data in Table 1, average annual expenditure on fuelwood in the NCD was about PNG Kina 536.90 $year^{-1}$. Meanwhile, the minimum wage for PNG is set at PNG Kina 37.50 $week^{-1}$, which is equivalent to PNG Kina 1950 $year^{-1}$. It would be inappropriate to deduce that the average household spends 28% of their income on fuelwood because most people are not on the minimum wage and many households have more than one income stream. However, fuelwood expenditure can be a significant impost on the weekly household budget.

Both collection and purchase of fuelwood are a relatively gender-neutral activity in the NCD. There are equal gender proportions for these activities in the urban surveys. Outside the NCD men are more likely to buy the fuelwood for the household, and only in the Lae rural sample do women appear to collect fuelwood more than men do. There is bias in these indices in that the highland rural samples had 80% male respondents, and there is likely to be some favourable self-reporting. Nevertheless, male household members in PNG do appear to have a more active role in fuelwood acquisition than do men in many other developing countries, where women are the main fuelwood collectors.

Before the survey, the general perception among PNG forestry researchers was that fuelwood is becoming more difficult to access. There is a solid logic to this: the population is growing, especially in urban areas, and trees, while they may seem abundant to the casual viewer, are either under customary or municipal ownership. The seeming abundance of trees is not tantamount to availability of supply of fuelwood or alleviation of fuelwood scarcity (Mahiri 2003). The survey indicates that the reality of access to fuelwood is more nuanced: it depends on who needs the trees and where they are located. The main reason cited for the problem of access to fuelwood in urban areas was immigration. Immigrants from outlying districts and provinces have no traditional access to local trees, and compete amongst themselves and local people for whatever combustible material is available. However, 35% of the urban population felt there was no problem at all accessing fuelwood as they either lived close to the city margin, to NCD hills, or to mangroves. In the highlands, the satisfied rural respondents had ready access to coffee gardens and trees on their own land or nearby.

Nevertheless, the level of conflict associated with fuelwood collection is alarming. In the NCD, 48% of fuelwood

Table 1. Dimensions of fuelwood economy as determined by questionnaire surveys of domestic users and sellers, and case-study monitoring

	Region surveyed				
	Urban			Rural	
	NCD	Lae	Mt Hagen	Lae	Highland[2]
Population[1]	254 158	78 692	27 877	40 486	150 916
Sample size	1 868	558	247	285	996
Parameters surveyed					
% using FW over past 12 months	73	90	87	98	100
Average frequency of FW gathering per week	1.4	2.0	2.9	4.8	3.4
Average frequency of FW purchase per week	2.4	1.9	2.6	1.8	1.8
% FW user population buying over last 2 week	24	27	47	7	4
Average spent over 2 weeks in PNG Kina[3]	20.65	21.60	20.39	27.61	24.10
(US$)[4]	(9.06)	(10.04)	(9.48)	(12.83)	(11.20)
Gender equity index for fuelwood collection[a]	1.0	0.9	0.6	1.1	0.9
Gender equity index for fuelwood purchase[a]	1.0	0.7	0.7	0.5	0.5
% FW users who have planted trees in past 2 years	44	25	54	83	96
% FW users who have experienced conflict over access to FW	48	40	58	51	61–88
% FW users expressing need for local woodlots	92	62	94	70	95
% FW sellers with access to land to grow trees	86	39	88	39	89
Average price PNG Kina per kg for FW on sale	0.30	0.49	1.15	0.58	0.33
Average maximum distance that sellers source their FW (km)	10	3	6	3	23
	(25)	(5)	(30)	(5)	(40)
% domestic FW users also using fuelwood commercially		26		58	
% domestic FW users also selling fuelwood		3		10	
% domestic users for whom FW more difficult to access over past 2 years		65		41	
Recalled daily household fuelwood use, kg d^{-1}	9.6	10.6	5.6	8.9	21.1
Daily household fuelwood use from monitoring case study households over 2 weeks					
Number of households monitored		13		23[6]	
Mean daily fuelwood use, kg d^{-1}		11.1		32.5	
Median daily fuelwood use, kg d^{-1}		11.6		27.3	

FW, fuelwood.[1] Population data from National Census 2000.[2] Aggregate value for Mt Hagen, Chuave and Henganofi highland rural districts.[3] Values reflect purchases for regular household use, as purchases > K100 for ceremonial and commercial use were excluded.[4] 1.00 Kina = 0.465 US$ (exchange rate at 2 April 2013).

[a]Gender equity index = ratio of proportion of instances of female activity to sample size, to instances of male activity to sample size. If men and women share equally the load of collecting and buying fuelwood, index = 1.0; if there are more instances of men's activity, index < 1; if there are more instances of women's activity, index > 1. A change in the index of 0.1 reflects a change in 10% of the regional population.[6] The rural case study households were all in the Highlands and not around Lae.

Source: Reduced and modified from Nuberg (2015), reproduced with permission

users experienced conflict in the process of fuelwood collection. If the NCD hills were under customary ownership, this figure would probably be much higher. The levels of conflict were even higher in the rural areas, with 61% in Mt Hagen rural areas, to 88% in Henagnofi. Some of the conflict arising over competition for fuelwood is far from trivial; it can lead to bloodshed and rape. Accordingly, there is a strong agreement for the need to plant fuelwood trees across all districts, although less so around Lae. Levels of conflict over trees are relatively low in Lae as it appears that fuelwood is still relatively easy to access.

The estimates of annual fuelwood use are based on respondents' recall of how much wood they had used in the two weeks prior to interview. The values for each region are expressed in daily rates in Table 1. These are likely to be under-estimates, as the carefully monitored actual use of 36 urban and rural households shows their daily usage rates to be much higher.

Figure 1 illustrates the various wood flows along with estimates of their volume and value in US$. It shows the various sources of free wood and wood destined for sale. The important information from this figure is that the supply chain is very simple and informal. There is nothing like specialist transporters, wholesalers or re-packagers that occur in other fuelwood markets (e.g. see Regional Wood Energy Development Programme (RWEDP) 1997). Nevertheless, 3% and 10% of the urban and rural populations respectively earn income from selling fuelwood, and a further 26% and 58% respectively earn income from using fuelwood (e.g. in preparation of food for sale, smoking fish, burning lime).

In summary, it is evident that fuelwood will remain a dominant component of the energy sector in both rural and urban areas. Fuelwood remains in use alongside alternative energy sources, such as kerosene, gas and electricity. Access to fuelwood is becoming more difficult and leading to conflict, especially in the highlands where the price of fuelwood can be very high. The fuelwood economy is large, mostly informal, simple and flat, with very few intermediaries between collector and seller. There are possibilities to develop more efficient supply chains that would overcome some of the diseconomies of scale associated with a high number of low-volume traders. The fuelwood sector is an easy market to enter. The most cited problem in the trade is transport of fuelwood to market. This problem might be overcome by more organised and capitalised traders. There is no government participation, intervention or regulation of the fuelwood market. While this means there is no institutional support for fuelwood traders, at least there are no barriers or extra costs associated with permits to cut, transport and trade. It appears there is a great opportunity for entrepreneurs to create a more sophisticated fuelwood supply chain that could deliver sustainably harvested and value-added fuelwood to consumers, especially in urban areas and the commercial sector.

The best species and end-product for SRC-grown fuelwood

If there are to be interventions to improve the fuelwood supply chain based on sustainable harvest, then the production systems will need short rotation cycles of coppicing species. To favour their adoption, the products from these systems should find a ready market and a return on the investment of effort comparable or better than other land uses. The trials reported here evaluated ten species under

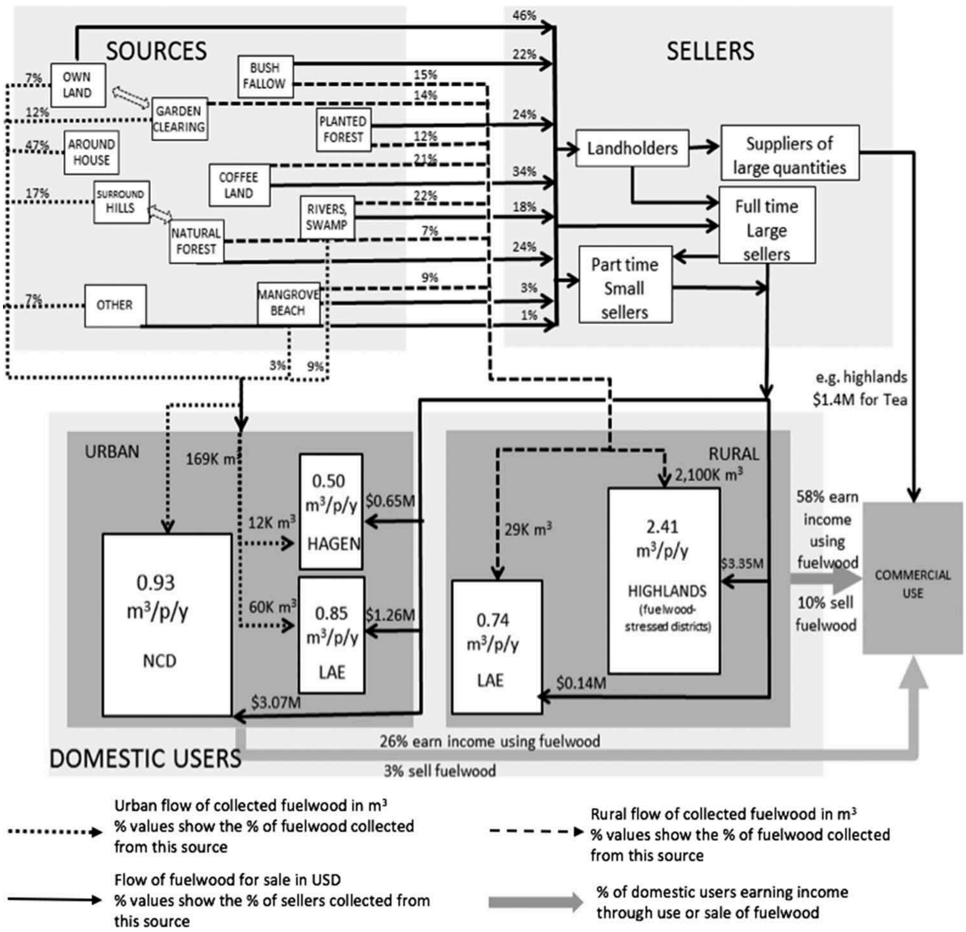

Figure 1. Fuelwood flows, volumes and value (USD) in fuelwood-stressed districts of PNG
NCD = National Capital District
Source: Nuberg (2015), reproduced with permission

such a system. The evaluation of candidate species required three phases: 1) biophysical performance; 2) product acceptance and value-adding; and 3) comparing SRC fuelwood systems with competing land uses.

Wood volume, form and coppicing ability

A summary of merchantable fuelwood volume estimates from the replicated field trials is given in Table 2 (full details of data and analysis are probided in Nuberg et al. 2015). In terms of fuelwood production, *Eucalyptus grandis* and *E. robusta* in WHP and *E. tereticornis* in the NCD performed best, with volumes after 2 years of respectively 2.97, 2.55 and 0.80 m^3 for a 500 m^2 woodlot at the 1.0 m × 1.5 m spacing. The woodlot with narrower spacing (1.0 m × 1.5 m) produced a greater wood volume, but the wider spacing (2.0 m × 1.5 m) produced larger diameter trees, which is a consideration if farmers want to grow poles as well. *E. grandis* and *E. robusta* produced trees of the best form for poles in WHP, while *E. pellita* produced trees of the best form in NCD. The poor growth rates around the NCD make a two-year rotation cycle unfeasible. *Calliandra calothrysus* may also be a suitable SRC species for alley systems in highland gardens.

Best coppice performance was observed in *E. robusta* in WHP and *E. tereticornis* in NCD. The ability for SRC fuelwood species to coppice (and this produce multiple crops without tree re-establishment) is important because the cost of establishing trees is much more than the cost of establishing alternative crops, such as vegetables. The ability of eucalypts to coppice has long been studied (Wimbush 1948). For pulpwood production, trees can be grown at closer spacings (e.g. 1666 stems hectare^{-1}: Little & Garner 2003) and harvested at 8–14 years age (Sandrasegaran 1966; Stubbings & Schönau 1980; Schönau 1991; Shiver & Brister 1992). In recent years, attention has shifted to tree performance as short-rotation energy crops: for example, 5000 stems hectare^{-1} harvested at three years (Sims 1990; Sims et al. 2001), and 2500–10 000 stems hectare^{-1} at 3–4 years (Sahunalu et al. 1990; Thapa & Subedi 2001).

In PNG, the opportunity cost of occupying garden plots with SRC woodlots was the incentive to attempt a two-year rotation in our trial. We estimate that at that age the stems would produce fuelwood pieces 5–7 cm in diameter, which is similar to the size of split wood already sold in PNG markets. A major concern was the extent to which inter-tree competition affects coppicing ability. Fortunately, the *E. robusta* in the Mt Hagen site survived well (95%) and coppiced strongly, while only 67% of cut *E. grandis* stumps coppiced.

In summary, at the WHP site *E. grandis* produces more fuelwood in the first harvest but *E. robusta* is likely to maintain higher productivity over successive harvests. At the NCD site, *E. tereticornis* was the best performer in both the volume of wood at first harvest and coppice vigour.

Value and acceptance as firewood in market

The primary value of candidate species is their burning characteristics as firewood. We used a simple water-boiling experiment (Gardner 1989) to measure the practical heating value to the consumer, rather than a precise calorific value (Tietema et al. 1991). Our fast-grown SRC species were as

Table 2. Predicted median wood volumes and pole lengths for two spacings per 500 m^2 woodlot of different species after 2 years, adjusted by expected survival rates

Species	Median volume, m^3 (SEM)		Mean pole length, m (SEM)	
Highland site, WHP	1.5 m × 1 m	1.5 m × 2 m	1.5 m × 1 m	1.5 m × 2 m
Eucalpyus grandis	2.97 (0.154)	1.56 (0.109)	2542 (194)	1122 (97)
Casuarina junghuhniana	0.44 (0.088)	0.35 (0.062)	1518 (194)	734 (97)
E. pellita	1.32 (0.109)	0.85 (0.077)	2095 (194)	900 (97)
E. robusta	2.55 (0.142)	1.39 (0.101)	2330 (194)	998 (97)
C. oligodon	1.57 (0.111)	1.03 (0.079)	2153 (194)	1036 (97)
Lowland site, NCD				
E. alba	0.23 (0.053)	0.12 (0.038)	1000 (114)	494 (57)
Azadirachta indica	0.66 (0.093)	0.33(0.066)	855 (116)	423(58)
E. pellita	0.66 (0.088)	0.33 (0.062)	940 (138)	477 (69)
E. tereticornis	0.80 (0.092)	0.40 (0.065)	1542 (153)	765 (76)

WHP = West Highland Province; NCD = National Capital District. Values in parentheses are SEM as estimated in the REML analysis
Source: Reduced and modified from Nuberg et al. (2015), reproduced with permission

effective in bringing water to the boil as conventional mature firewood. However, more SRC wood was required to bring water to the boil in a given time, because of its significantly higher air-dry moisture content (e.g. SRC *E. grandis* 27 ± 1.4% compared to *Leucaena diversifolia* 32 ± 1.7% and mature *Casuarina oligodon* 18 ± 1.8%) (Nuberg et al. 2013).

Regardless of laboratory evaluation, the more critical tests are in the home and market place. Across the two sites, ten SRC firewood candidate species were presented as 80 cm lengths with bark attached, and householders were asked to compare the wood against their normal firewood. The Mt Hagen consumers found that 2-year-old *E. grandis* is at least as good as the local mature *C. oligodon* for cooking, is easier to use, and its smooth bark has a more appealing appearance. The results in Port Moresby were equivocal, possibly because those households use a wider range of species for comparison.

Fuelwood is sold in the market in bundles and large pieces at prices set for easy transaction (e.g. PNG Kina 1, 2, 5, 10 or 20), however there is considerable regional variation in the weight of wood in bundles of similar price. For example, the market value of fuelwood in Mt Hagen was surveyed at PNG Kina 1.15 kg^{-1} while in the NCD market it was only PNG Kina 0.30 kg^{-1} (Table 1). The sellers presented the other SRC fuelwoods as bundles for 5 PNG Kina but packed so they were much better value on a per kilogram basis, yet still they found it difficult to sell these specimens, except perhaps the *E. grandis*. In Port Moresby, the firewood sellers found it very easy to sell only fast-grown specimens of the species already in the market (i.e. *C. oligodon* and *E. alba*), or species that had a similar appearance to existing firewood (i.e. *C. junghuniana*). Unfortunately, none of these species perform well as SRC crops.

Despite the good burning qualities of SRC firewood, and the favourable evaluation by householders, it became apparent that it would be very difficult to sell SRC fuelwood in the market because it does not look like the conventional firewood. Most consumers buy only what they already know and understand. An education campaign could change consumer attitudes to SRC-grown fuelwood but would be a very long-term endeavour and was beyond the resources of the project. Also, price discounts for SRC-grown fuelwood would diminish its relative value. Once this was realised, the focus of our research was re-directed to charcoal as a value-added SRC product.

Charcoal as a value-added SRC product

Even though charcoal will cost more, it could be a popular alternative to firewood because it is nearly smokeless, much lighter and transportable, and once lit is easier for the cook to use (Wood & Baldwin 1985). However, virtually all commercial charcoal used in PNG is imported from Australia, and is sold at an average retail price of PNG Kina 10 kg^{-1} for use on barbeques of the urban elite. It is culturally and financially out of reach of the village consumer. In the 1980s there was a program to introduce charcoal into the domestic energy economy in Port Moresby (Harris 1979; Gamser & Harwood 1982). This was unsuccessful because of unreliability of charcoal supply, and because of the lack of an effective demonstration and extension system (Gamser & Harwood 1983). Nevertheless, there remains a legacy of good, locally adapted information on charcoal as an energy source within the Appropriate Technology and Community Development Institute, PNG University of Technology.

To test the feasibility of introducing charcoal as an alternative energy source to the rural population, one of us (Jessie Waibaru-Abiuda Mitir) led a series of demonstration events at the annual Morobe and Mt Hagen cultural shows, at each market place along the Highlands Highway from Lae to Mt Hagen, and at the PNG Forest Research Institute headquarters. She ran competitions with cash prizes to test the comprehension of the audiences of our SRC-fuelwood and charcoal posters. Food was cooked on charcoal stoves at each event, and audiences were genuinely amazed that so much heat could be generated with so little smoke. The results of audience surveys encouraged us that the rural population could be receptive to charcoal as an alternative to firewood (Nuberg & Mitir 2013). Before we followed through with our attempts to facilitate a charcoal industry, we undertook a desktop evaluation to compare SRC firewood and charcoal production with competing land uses.

Comparing firewood and charcoal to sweet potato and coffee

For a new production system to gain acceptance, it must offer more advantage than existing systems. In rural PNG, the pivotal variable of production is return for labour input, not return per hectare. PNG village life is busy. When not engaged in subsistence food production, villagers may turn to cash crops to pay for consumer goods, healthcare and school fees. A significant amount of time is also spent in social exchange and cultural activities (Curry 2005).

Table 3. Estimated gross returns and return to labour of coffee, sweet potato and short-rotation coppicing for firewood or charcoal in Western Highlands Province

		Sweet potato	Coffee arabica	SRC firewood	SRC charcoal
Yield	kg ha^{-1}	12 000	900	10 425	2085
Price	PNG Kina kg^{-1}	0.60	4.50	0.70	2.50
Gross return	PNG Kina ha^{-1}	7200	4050	7297	5212
Labour inputs	Person days ha^{-1}	350	275	170	220
Return to labour	PNG Kina person^{-1} d^{-1}	21	15	43	24
	US$ person^{-1} d^{-1}	9.77	6.98	20.00	11.16

SRC firewood and SRC charcoal, *Eucalyptus grandis*. Sweet potato and coffee values from Table 5.20.1 in 'Food and agriculture in PNG' Bourke et al. (2009) with updates from Bourke *pers. com*. 20 February 2013. SRC firewood gross margin based on volume data of 1.5 m × 1.0 m spacing; price is conservatively set at 70% of surveyed firewood prices and pole value in Mt Hagen. SRC labour inputs (person days ha^{-1}) estimated as: ground preparation 60, planting 30, weeding in first year 20, harvest and prepare for market firewood 60, charcoal 110. SRC charcoal gross return and return to labour based on volumes and charcoal business plan prepared by Manapangkec (2012). 1.00 PNG Kina = 0.465 US$, exchange rate at 2 April 2013.
Source: Reduced and modified from Nuberg et al. (2015), reproduced with permission

The returns to labour for sweet potato and coffee were compared with estimates for SRC firewood and charcoal production in a desktop evaluation (Table 3). On the surface, SRC options yield better returns to labour than existing land uses. SRC firewood would give the best returns were it not for poor market acceptance. SRC charcoal is still a strong contender. However, the results require interpretation in the contexts of the commercial market and indigenous non-market economies.

Sweet potato and pigs are the foundation of highland subsistence agriculture. The sweet potato yields used here assume a healthy commercial system with improved planting material and modern agronomy. Yields under village conditions will be much less (Bourke et al. 2009). As a commercial crop, sweet potato provides good returns to labour considering the official minimum rural wage around Mt Hagen of PNG Kina 13 day^{-1} (IPA 2013). However, more than 90% of highland villagers are only engaged in subsistence production (Wegener et al. 2009). Subsistence sweet potato production systems engage the site for only 2–5 years of production between fallow periods of 5–15 years (Bourke & Ramakrishna 2009). These fallow periods are easily long enough for at least two rotations of an SRC fuelwood crop. Soil fertility will not be radically diminished from the tree crop as all the canopy and root biomass is kept on site, and dead stumps decay rapidly.

While coffee has a lower return to labour, it has the advantage of being a perennial crop with established export markets. Coffee is a partial source of income for at least half of rural households in the highlands (Bourke & Harwood 2009). Most of the labour component is at harvest and is undertaken by women. However, women receive only one-third of the returns to labour received by men from the household's coffee income. SRC fuelwood crops could be an appealing alternative to coffee for women, but traditional gender politics is not in their favour.

From this desktop analysis, we were cautiously optimistic about the feasibility of commercial charcoal production integrated with subsistence sweet potato fallow periods. SRC charcoal harvest and production is not necessarily seasonal, so could be integrated flexibly with other occupations. It has a high return to labour, but selling the charcoal will require patience and intelligent marketing. This realisation led us to the next phase of research.

Establishing charcoal producer–vendor groups

Once we realised that charcoal might be the best end-product for SRC fuelwood crops, we needed to know the best business structure for PNG landholders. This question was answered through two parallel activities: 1) interviewing key informants and stakeholders who had knowledge about successful collective small-business structures in PNG; and 2) training landholder groups in charcoal production and how to develop their own business plans and corporate structures.

Collective small-business structures in theory

Our discussions with experts in community development in PNG resulted in the following eight recommendations:

(1) **Business mentality**: People need education in how to share risk as well as profit. Recognition of the difference between revenue and profit, and an ethos of reinvestment, must be instilled in business members. This can be achieved through basic business education, such as bookkeeping and break-even projections, and through communal enterprise that attempts to check an individualistic mentality.
(2) **Traditional structures**: Use existing groups to introduce and facilitate projects, as these are existing stable regimes of structure and governance. Family groups are strong established structures, however groups outside the family structure (but within the clan/tribe) should also work well. Wantok[1] members not involved in the business must be educated in what is common property and what is business property, to overcome the exploitation of business resources and revenue.
(3) **Land tenure**: Where necessary, the groups must recognise that the whole clan has rights to a resource regardless of business requirements. Ideally, a project should keep the number of clans within a single group or association low, to minimise conflict.
(4) **Gender**: Allow gender equality to develop progressively in the community's own time so that it is truly realised. A clear division of labour ensures one gender

[1]Wantok is a term in the lingua franca of PNG, Tok Pisin, that translates as 'someone who speaks my language', or more directly 'one talk'. There are over 800 indigenous languages in PNG, and there is a deep sense of responsibility and obligation to others within one's 'wantok'. The positive aspect of wantok is that provides a system of social security, whereas on the negative side it underpins much of the corruption that plagues PNG.

or individual does not dominate. Women could be placed in positions of importance and influence, such as treasurer and secretary, whilst retaining the traditional male domination.

(5) **Church**: The church should be used as a vehicle for development, but not a base for business practice as this alienates other community members outside of these spheres, as well as threatening the strength of the societal value of faith structures within the community. The structural approach to management used by the church can be used as a model for governance.
(6) **Governance**: The executive board must be separate from management structure and from overseeing the day-to-day running of the project. This breaks up the decision-making process and puts checks in place. Governance must be focused on key values of transparency, openness, and free, prior, informed consent, outlined in a commonly agreed constitution.
(7) **Extension**: Work to the timescale of the community not the NGO or donor agency. Conflicting obligations of community members do not necessarily indicate a lack of interest. If possible, spend a considerable amount of time with the project stakeholders to build up trust and transfer skills, and marry objective completion with staged donor payments.
(8) **Capacity/participation**: Personal membership fees for those involved in business or project put a financial check on involvement, and ensure real ownership and interest in the project. Ensuring groups or individuals approach developers rather than the other way around ensures empowerment. A clear and extensive division of labour, and a democratic and transparent governance regime, retains trust and empowerment.

There are two models of collective business management currently operating successfully in PNG. The Investment Promotion Authority's 'group business' model is in practice in over 500 enterprises throughout PNG. It ensures the retention of ownership for shareholders and members, whilst providing tax and promotion incentives which individual producers would not be able to receive. It can be applied at both a provincial and national level, however as the business increases in size and/or the number of clans increases instability and inefficiencies can occur at the association (i.e. local group business entity) and market outlet levels. For these reasons, a regional application of this model is suggested.

A more appropriate model could be the typical recommended structured used by the co-operative society's registration and regulatory department, currently with over 5000 examples in PNG. It is applicable to a wider range of business enterprises and fits well within the traditional structures of power. It is a widely practised model of group business operation in PNG because of its simplicity and applicability; it does however have a high failure rate. Like the business group model, it retains ownership with the membership and decisions are facilitated through the committee. Without a high number of decision-making checks, and especially without representation or management levels, businesses are at risk of instability and failure. This is an area on which improvements could be made in future models.

Successful charcoal business structures in practice

Armed with the knowledge from those who have gone before us, we facilitated the establishment of nine charcoal producer–vendor groups, comprising about 100 individuals. We were careful not to be too prescriptive about how the various groups organised themselves. We provided training in charcoal production using the Tongan Kiln method, and training in the construction of portable charcoal stoves made from a steel bucket lined with concrete and a simple grate on top (details in Nuberg & Mitir 2013). After training in basic business principles and developing their own charcoal business plans, we allowed the groups to develop their own structures.

Interestingly, this revealed that there is no one-size-fits-all structure for establishing charcoal producer groups. The social and cultural differences between highlands Mt Hagen and coastal Lae are such that different approaches are necessary in the different locations.

In Mt Hagen we found that broad social groups are unstable and are prone to disintegrating when desired goals are not forthcoming. A business model using the extended family system and further targeting individual households is more appropriate (Fig. 2). These groups determined that a household-level Lead Charcoal Producer (LCP) as the best way to facilitate successful charcoal businesses. The LCP is given the technical and financial support via microcredit loans to establish the business. The LCP then identifies other households in the community to produce charcoal and sell to the lead charcoal producer, who acts both as a wholesaler and as a retailer in the charcoal business.

The limitation of this model with respect to its promulgation throughout the highlands is that the selection of LCPs and further incorporation of other charcoal producers will always be within the same clan group as the local NGO facilitating the process. Also, illiteracy and the low formal education of some members result in poor or no record maintenance, and a culture of dependency on the facilitating NGO. At the end of the project, most of the charcoal was still being sold from the office of the NGO.

In Lae, the experience was quite different. The seven groups that finally emerged represented a broad range of social and cultural characteristics. Lae is a port city with a more diverse social and cultural structure than Mt Hagen. Also, in contrast to Mt Hagen, some of the participants did not even have land to collect or grow their own fuelwood. Despite this they managed to come together under a successful 'Charcoal Wantok Group' structure similar to the IPA model that emerged from the parallel interview survey (Fig. 3). The groups differed in their emphases on charcoal and stove production, wood and charcoal sales, and charcoal

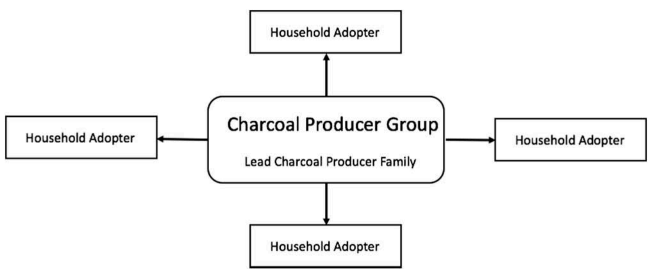

Figure 2. Lead charcoal producer structure that emerged in the Mt Hagen groups
Source: Nuberg et al. (2013)

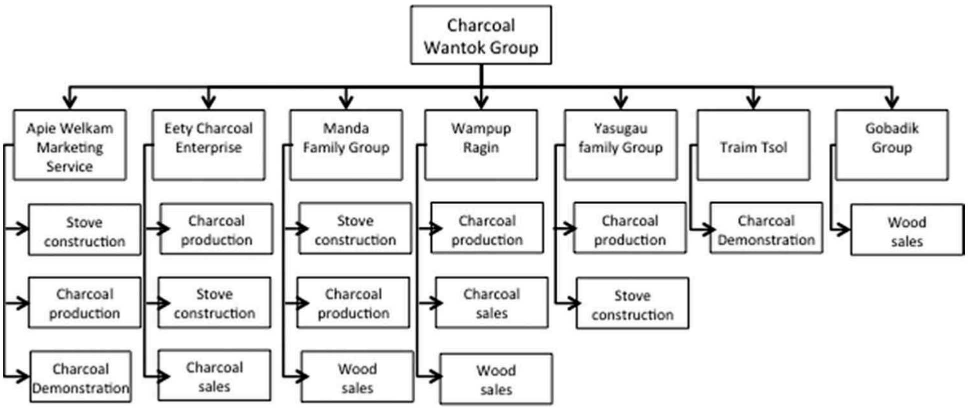

Figure 3. Charcoal Wantok Group structure, Lae, Morobe Province
Source: Nuberg et al. (2013)

demonstration (with hot food sales) activities. They also agreed on charcoal prices, as well as their local market spots, to minimise competition that might stifle the development of the charcoal market. The Lae groups needed microfinance facilities to enter the charcoal business, but the project did not need to facilitate these loans as such a service already exists in Lae. At the end of the project, the groups were successfully selling charcoal in the Lae market, independent of the project facilitator.

Environment for a flourishing fuelwood sector

Across the full arc of this research—from characterising the fuelwood economy, to evaluating SRC species, to facilitating charcoal producer–vendor groups—there is much to encourage the aspirations for a charcoal industry that provides opportunities for small-business development without degrading forest resources. The charcoal producer–vendor groups are a proof-of-concept, but the concept will not flourish without wider policy and institutional changes that create the appropriate enabling environment.

There needs to be a National Fuelwood Policy in PNG that recognises the crucial role of fuelwood and charcoal in providing renewable energy for domestic, commercial and industrial users. Such a policy will be multi-sectoral across energy, forestry, agriculture, public health and small-business and community development. This policy would lead to institutions that encourage the private sector to invest in fuelwood trade and create economies of scale; would protect smaller actors in the informal market; would incentivise the use of SRC over wild-collected fuelwood; would encourage the use of clean-burning charcoal in public places (e.g. markets); and would provide business development support for charcoal producer–vendor groups.

Conclusions

This paper describes six years of socioeconomic survey, field trial research and participatory extension work. It shows that fuelwood is a crucial component of the domestic economy of PNG and is likely to remain so for the foreseeable future. Fuelwood is also a very simple market (in terms of woodflows and value chains) and many people sell fuelwood on a part-time and full-time basis. Even more people use fuelwood in the generation of their incomes. There appear to be many opportunities for small business development in creating a more sophisticated fuelwood supply chain delivering sustainably harvested and value-added fuelwood to consumers, especially in urban areas and the commercial sector.

The short-rotation coppice fuelwood production trials determined the key species that could be used, and yielded favourable estimates of fuelwood production within 2–3 year rotations, at least in the highland site. Growing fuelwood gives better return to labour than conventional highland cash crops of sweet potato and coffee. As there may be some resistance to selling SRC-grown fuelwood because of its appearance, it will be better to add value to it as charcoal, which still has relatively good returns to labour.

There are early signs that it is possible to successfully facilitate the establishment of producer–vendor groups for SRC-grown charcoal even in a market where charcoal is not yet commonly in use. It is important that these groups be allowed to develop their own business and membership structures. Regional differences in culture will determine the nature of these groups. The enabling environment to encourage the flourishing of a SRC fuelwood industry requires multi-sectoral policies, and creation of institutions to foster private sector investment.

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ORCID

I. K. Nuberg http://orcid.org/0000-0003-1942-1190
B. Robinson http://orcid.org/0000-0002-1857-2117

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