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Research paper

A systems approach to risk and resilience analysis in the woody-biomass sector: A case study of the failure of the South African wood pellet industry☆

Rebecca Bowd[a,*], Nevil W. Quinn[b], Donovan C. Kotze[a], Michael J. Guilfoyle[c]

[a] University of KwaZulu-Natal, South Africa
[b] University of the West of England, United Kingdom
[c] SA Wood Pellets, South Africa

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ABSTRACT

Currently more than 600 million of the 800 million people in SSA are without electricity, and it is estimated that an additional 2500 GW of power is required by 2030. Although the woody-biomass market in the developed world is relatively mature, only four woody-biomass plants in SSA have been established, all of which were closed by 2013. With its affordable labour, favourable climate and well-established forestry and agricultural sectors, South Africa appears to have the potential for a successful woody-biomass industry. This paper documents a first attempt at analysing why these plants failed. It aims to contextualise the potential role of a sustainable woody-biomass sector in South Africa, through firstly developing a SES-based analytical framework and secondly, using this to undertake a retrospective resilience-based risk assessment of the four former woody-biomass pellet plants in order to identify strategies for increasing the resilience of the industry. The SES-based framework advances previous theory, which usually focuses on natural resources and their supply, by introducing a production process (with inputs and outputs), internal business dynamics and ecological variable interactions. The risk assessment can be used at a broad level to highlight important aspects which should be considered during feasibility assessments for new plants. Further work is proposed to focus on splitting the social-ecological system at different scales for further analysis, and to investigate the long-term ecological impacts of woody-biomass utilisation.

1. Introduction

1.1. Background

Energy provision in Sub-Saharan Africa (SSA) is fundamental to growth and diversification of industry and therefore economic development. Currently more than 600 million out of 800 million people in this region are without electricity, and it is estimated that an additional 2500 GW of power is required by 2030 [1]. The greatest proportion of power demand comes from South Africa [2] and demand is planned to be met by a mix of renewable and non-renewable solutions.

In the northern hemisphere, legislation promotes substitution of fossil fuels with renewables (e.g. the EU Renewable Energy Directive [3], the US Energy Policy Act 2005 and US Energy Independent and Security Act of 2007 [4]). However, although work on renewable policy has been undertaken in South Africa [5–7], no similar legislation has been forthcoming [8]. Although wind, solar and hydropower have been implemented in some areas in South Africa, their main limitation is dependence on weather conditions [9], most notably limiting industrial applications [10]. Biomass is the only renewable source of energy which is not weather-dependent, and has acknowledged additional ecological, social and economic benefits (refer to Supplement 1 in supplementary material). Despite woody-biomass being the most utilised source of energy across the globe [11], negative connotations in SSA persist, considered by some as an energy which 'engenders poverty', 'comes from the past', is 'dirty', 'inefficient' and a 'subsistence fuel' [12]. Contradictions between the significance of biomass for countries in SSA and the low profile it is given in national policies are noted [13], where it is argued that biomass energy initiatives are ignored by decision-makers who consider economic growth and poverty reduction dependent on continued use of fossil fuel. Despite job creation being a priority in SSA and that woody-biomass production has the potential to create two to three times [14], and even to up to 20 times [15] more jobs compared to coal production, policy-makers in SSA are still dismissive of biomass.

Woody-biomass is derived from a variety of sources (e.g. plantation

☆ European Union (EU), Natural resource-based enterprises (NRBEs), Social-ecological system (SES), Sub-Saharan Africa (SSA), United Kingdom (UK), United States (US).

* Corresponding author.
E-mail addresses: rebecca@greendoorgroup.co.za (R. Bowd), nevil.quinn@uwe.ac.uk (N.W. Quinn), kotzed@ukzn.ac.za (D.C. Kotze), michaelg@thewattgroup.co.za (M.J. Guilfoyle).

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Fig. 1. Woody-biomass production process.

and sawmilling operations, alien plant removal). Pelletisation prior to application is favoured over direct combustion as it has a higher calorific value [11], less harmful emissions (< 1% compared to ca. 65%) [16], creates greater job opportunities [17] and is more logistically favourable [18]. A simplified flow diagram of the pellet supply chain is presented in Fig. 1.

In many parts of Europe, South America and the US, biomass pellet use is increasing rapidly in domestic, commercial and industrial sectors supplying electricity, heat (e.g. domestic stoves [19], bakery ovens [20]), combined heat and power (CHP), and fuel for transportation [21]. Co-generation applications, where some coal is substituted with pellets, are also increasing rapidly in the US, Finland, Denmark, Germany and Belgium [15]. In Europe alone, wood fuel production increased from 125 hm^3 in 2001 to nearly 160 hm^3 in 2011 [22], and ca. 4.4 Mt of wood-pellets were imported across European Union (EU) borders in 2012 [23]. The European biomass sector has developed in response to the EU Renewable Energy Directive in which the 28 member states have agreed to a target of 20% of energy from renewables by 2020. In 2011 this was 10%, of which 4.8% was from the use of wood and wood-waste material [24]. It is projected that more than 10% of final energy consumption will be derived from biomass by 2020 [25] with forest biomass likely to be a significant component [26].

There are an estimated 2.5 Mt of collectable biomass in South Africa, and significant areas of South Africa (predominantly located within a 200 km coastal buffer) are furthermore ideally suited to forestry [27]. Environmental conditions enable trees to reach maturity after ca. 15 yrs, whereas in Europe and North America trees need more than 50 yrs [28]. In South Africa, thinnings and plantation waste can be utilised as early as four years after planting, in contrast to much longer periods in the northern hemisphere (+10 yrs) [28]. SSA has the potential to substantially contribute to the supply of bioenergy [29], and there is a considerable surplus of biomass production compared to demand in the developing world [30].

With the pellet bioenergy market going from strength to strength in the US and Europe, some might assume that the US and European model could be directly transferred to South Africa. With ample affordable labour [27] and a productive timber sector, South Africa is potentially an ideal location for a pellet bioenergy industry. However, to date, only four pellet plants have been established in South Africa, all of which closed within six years of being commissioned (Table 1). Obviously unexpected events took place which the industry had neither anticipated nor prepared for.

A complex set of interacting factors, which occur at different scales, potentially affects the resilience of woody-biomass operations. The forest industry consists of a variety of interrelated and interconnected sectors within their respective supply chains and variations in one part of the supply chain generally propagate into other areas (e.g. the downturn of the housing market results in a reduced demand for timber, which in turn results in decreased availability of wood chips, and thus a reduced availability of raw material for bioenergy [31]). Other factors which make bioenergy complex include: optimal timber growing areas being spread over large areas which are challenging to access due to unreliable infrastructure (i.e. plantation companies usually only maintain access roads during harvesting); the need to optimize fluctuating transportation costs as the raw material is bulky with relatively low density; and the need to obtain and store raw material with a low moisture content in order to reduce costs associated with drying the material ready for processing [32]. These characteristics are known to contribute to the high cost and complexity of forest

Table 1
Details of the four former pellet plants in South Africa. Direct job creation - onsite jobs created. Indirect job creation - jobs created in the delivery of raw material to the plant and pellets to the harbour.

Plant	Details	Plant	Details
Plant A	Located within KwaZulu-Natal Midlands Built to produce 65 000 t yr^{-1} Operated at 98% capacity 325 000 t sold to Europe Date commissioned: 2008 Date closed: 2013 Operated for five years five months Direct job creation: 52 Indirect job creation (est.): 25	Plant C	Located within Mpumalanga Built to produce 75 000 t yr^{-1} Operated at 5% capacity 1000 t sold to Europe Date commissioned: 2010 Date closed: 2012 Operated for one year five months Direct job creation: 51 Indirect job creation (est.): 22
Plant B	Located within northern KwaZulu-Natal Built to produce 75 000 t yr^{-1} Operated at 10% capacity 800 t sold to Europe Date commissioned: 2008 Date closed: 2010 Operated for two years one month Direct job creation: 60 Indirect job creation (est.): 25	Plant D	Located within the Eastern Cape Built to produce 80 000 t yr^{-1} Operated at 20% capacity 10 000 t sold to Europe Date commissioned: 2009 Date closed: 2012 Operated for three years Direct job creation: 55 Indirect job creation (est.): 25

biomass logistics [33]. These dynamics interlink with the ecological systems generating the biomass, forming a complex social-ecological system (SES).

Social-ecological systems refer to social systems in which some of the interdependent relationships between humans are mediated through interactions with ecological units [34]. They are complex and adaptive [34], often functioning as a nested hierarchical structure, with processes occurring within different sub-systems at different rates and scales [35,36]. For example, within the woody-biomass SES interactions can occur at a local 'plantation' level, at a landscape level (geographical area which features favourable conditions for the growing of timber), and at a national/international level (area where pellets are sold, and groups have interest in policies associated with forestry practices).

Concerns around the environmental impacts of biomass harvesting have led to the development of sustainability criteria, indicators and certification as a way of monitoring the sector [37–41]. Although generally considered useful when applied to bioenergy production [38,41,42] and forest management [43], limitations associated with the use of criteria, indicators and certification have also been acknowledged [41] (refer to Supplement 2 in supplementary material). Alternative approaches for assessing the sustainability of the woody-biomass pellet sector are needed, and furthermore, such approaches must take into consideration the complex SESs which comprise and surround the woody-biomass industry. To date no investigation has taken place into the contributing factors undermining the resilience of the four failed South African pellets plants. This paper documents a first attempt at developing this understanding using a SESs theory approach. The paper also identifies the key risks to the establishment of a resilient woody-biomass sector in South Africa, and provides mitigation measures to