An assessment of the costs and benefits of using *Acacia saligna* (Port Jackson) and recycled thermoplastics for the production of wood polymer composites in the Western Cape province, South Africa

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Abstract

Acacia saligna *(Port Jackson) is one of the most pervasive IAPs in South Africa. The government's control efforts have by and large not been co-financed by the private sector due to a lack of incentives. Here we develop a system dynamics model to assess the costs and benefits of using the invasive* Acacia saligna *for the production of wood polymer composites (WPCs). The cumulative net present value for clearing* Acacia saligna *and making WPCs amounts to approximately ZAR122.1 million for the baseline scenario (no WPC production), and is estimated to be ZAR144.4 million for Scenario 2 (WPC production with 20% co-financing), ZAR172.7 million for Scenario 3 (50% co-financing) and ZAR211.2 million for Scenario 4 (100% co-financing). In addition to these direct financial benefits, the control of* Acacia saligna *also offers benefits with respect to employment, an increase in the state's tax revenue base, and an increase in the contribution to GDP.*

Key words: *Acacia saligna* (Port Jackson); cost-benefit analysis; system dynamics modelling; wood polymer composites; recycled thermoplastics; invasive alien plants

1. Introduction

1.1 Background

Invasive alien plants (IAPs) and municipal solid waste pose environmental concerns both in South Africa and internationally (Williamson 1996; Richardson & Van Wilgen 2004; Reinhart *et al*. 2010; Couth & Trois 2012; Department of Environmental Affairs [DEA] 2012; Republic of South Africa 2014; Friedrich & Trois 2016). The government of South Africa, through its Department of Environmental Affairs: Natural Resource Management programme (DEA: NRM), has allocated substantial resources for the control of IAPs. Approximately ZAR3 billion (US$457 million) is spent annually by the DEA: NRM on the control of IAPs within the country. More than 50% of this amount has been spent on the control of *Acacia* species, *Pinus* species, *Eucalyptus* species and *Prosopis* species, which are the major invaders in most of the country's biomes (Van Wilgen *et al*. 2012). Various IAPs are invasive within the Western Cape province, among others *Pinus* species, *Acacia cyclops* (Rooikrans), *Acacia saligna* (Port Jackson), *Eucalyptus* species, *Prosopis* species and *Acacia mearnsii* (Versfeld *et al*. 1998; Kotzé *et al*. 2010). This study investigates the feasibility of using *Acacia saligna*, which does not offer much commercial opportunity in the form of timber, as an input material in the production of wood polymer composites (WPCs).

The production of WPCs can be augmented by thermoplastics sourced from municipal waste. Municipal solid waste is defined as any kind of waste material and includes durable goods (such as car tyres and office desks), non-durable goods (such as newspapers, disposable cups and plates, plastic cutlery), containers and packaging (such as plastic bottles and wrapping materials) and other waste material (such as food and yard waste) (Environmental Protection Agency [EPA] 2015; Center for Sustainable Systems 2016). Najafi (2013) states that waste thermoplastics comprises a major part of municipal solid waste from a global perspective – this presents a potential raw material source for the manufacture of WPCs. It is estimated that approximately 108 million tonnes of municipal solid waste was generated in South Africa in 2011 (DEA 2012; Godfrey *et al*. 2015), with 98 million tonnes being disposed at landfill sites. Approximately 6% of the waste generated was reported to be plastic waste (DEA 2012; Godfrey *et al*. 2015). In the Western Cape province, approximately 3.8 million tonnes of municipal solid waste is generated per annum, with 70% of this being generated by the City of Cape Town (Western Cape Department of Environmental Affairs and Development Planning [WC-DEA&DP] 2012). As a result, the City of Cape Town spends approximately ZAR2.1 billion (US$150 million) on operations, and between ZAR200 million (US$14.285 million) and ZAR250 million (US$17.857 million) on capital expenditure, in managing solid waste (Western Cape Provincial Treasury 2013).

Both IAPs and municipal solid waste are characterised by undesirable environmental concerns and the resulting costs. Both, however, can also be used to make WPC. In producing WPCs, value is created from IAPs and thermoplastic waste that can contribute toward management costs. The rate of recycling of municipal solid waste is very low, with the national rate for South Africa at 9.8% and that for the Western Cape specifically being at 14% (WC-DEA&DP 2013). Therefore, there is much scope to improve the use of thermoplastics. Likewise, *Acacia saligna* that have been cleared are largely abandoned at the clearing sites.

Najafi (2013) states that the literature on the use of recycled thermoplastics to make WPCs is limited; it furthermore is focused largely on a single type of thermoplastic waste (Yam *et al*. 1990; Youngquist *et al*. 1994; Selke & Wichman 2004; Lei *et al*. 2007) and a combination of recycled thermoplastics waste and virgin thermoplastics (Ha *et al*. 1999; Tzankova Dintcheva & La Mantia 1999; Sellers *et al*. 2000; Kamdem *et al*. 2004; Kazemi-Najafi *et al*. 2006; Ashori & Nourbakhsh 2009; Kiaeifar *et al*. 2011), with a few studies focusing on recycled thermoplastic waste blends (Ha *et al*. 1999;

Jayaraman & Halliwell 2009; Kiaeifar *et al.* 2011). Moreover, little has been reported on the use of wood flour obtained from IAPs as a raw material for WPCs, with only cases of *Pinus* species having been mentioned (Sellers *et al.* 2000; Jayaraman & Bhattacharyya 2004). Furthermore, all these studies have been greatly limited to the effect of recycled thermoplastics on the tensile strength, hygroscopic properties and impact strength of WPCs. No studies to date have been conducted to determine the costs and benefits of using biomass from IAPs and recycled thermoplastic waste regarding the feasibility of such value-adding activities.

1.2 Wood polymer composites

A composite material is made by combining two or more materials to give a unique combination of properties (Kim & Pal 2011). WPCs can be defined as a group of materials that are manufactured from mainly wood and thermoplastic polymers, and occasionally a marginal amount of additives (Teuber *et al.* 2016). In most cases, renewable resources, such as wood and/or waste, are used to manufacture WPCs (Teuber *et al.* 2016). The most widespread uses of WPCs are outdoor decks, park benches, indoor furniture, and window and door frames (Kim & Pal 2011). According to Klyosov (2007), the amount of wood used in the manufacture of WPC varies, with up to more than 80% of both soft and hard wood being used, subject to the region of manufacture and availability of a particular type of wood. In terms of the thermoplastic polymers, polyolefin polymers such as polyethylene (PE) and polypropylene (PP) are the most used polymers in the production of WPC products (Ashori 2008; Carus *et al.* 2014). Using waste resources such as IAPs and recycled thermoplastic waste can potentially lead to a more responsible and efficient method of resource use. Moreover, such an innovative approach is in line with the principle of cascading use and resource efficiency. Cascading use promotes the use of resources and by-products from production processes multiple times before considering their conversion to thermal energy (Eshun *et al.* 2012).

1.3 Objectives of the study

This study aims to determine the costs and benefits of using IAPs (specifically *Acacia saligna*) and recycled thermoplastic waste for the production of WPCs in the Western Cape province of South Africa. Externality costs (i.e. potential loss of carbon sequestration) and benefits (i.e. water savings), as well as the private costs and benefits incurred in the production of WPCs, are also included. It is important for integrated reporting purposes to show both private and social costs (and benefits) emanating from the production of WPCs from the aforementioned raw materials (i.e. *Acacia saligna* biomass and recycled thermoplastic waste). *Acacia saligna* was considered because it is a low-value species that has been mostly abandoned at cleared sites. It is therefore important to assess the economic feasibility of this value-adding opportunity. Also, the study seeks to assess the dynamic behaviour of environmental, social and economic systems over time for several scenarios. This is imperative, as it helps decision makers and other relevant stakeholders to foresee opportunities and threats, adapt to change and be well prepared for any possible adverse consequences.

2. Material and methods

2.1 Scope of assessment and study sites

We investigated the clearing of *Acacia saligna* within three study sites in the Western Cape province of South Africa, namely the Citrusdal quaternary catchment plot(s) (E10F), the Berg River quaternary catchment plot(s) (G10A-J), and the De Hoop quaternary catchment plot(s) (G50J & G50K) (see Figure 1). The *Acacia saligna* biomass cleared within these sites is used as a feedstock for wood flour production, and combined with recycled thermoplastic waste to produce WPCs. We augmented the wood flour with recycled thermoplastics sourced from various industries in the country.

For the purposes of this study, it was assumed that the WPC factory would be set up within the City of Cape Town. The Citrusdal quaternary catchment lies 175 km north-west of the Cape Town, and the Berg River quaternary catchment about 70 km north of it. The De Hoop quaternary catchment lies 230 km south-east of the City of Cape Town. All the study sites are within the Fynbos biome and have a Mediterranean climate, receiving rain in the winter and experiencing dry and hot summers (Mucina & Rutherford 2006).

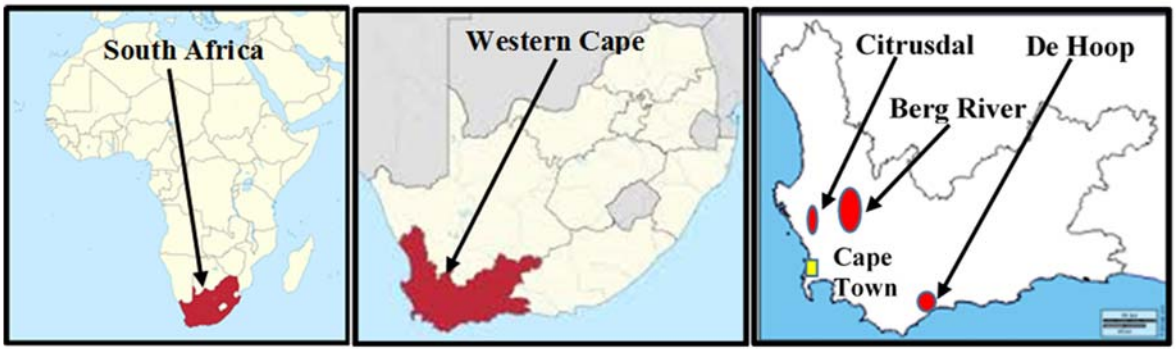

Figure 1: Location map for the study sites
Source: Own analysis

2.2 Data collection

The data on IAPs was collected from the DEA: NRM's central database. This includes data on the clearing costs, person days worked, and the hectares cleared over time. In addition, extensive literature surveys were conducted to obtain other published data relevant to the purposes of this study. Experts were consulted to validate the data and also to help define the assumptions. The area invaded by *Acacia saligna* was extracted from Kotzé *et al*. (2010). Focus group discussions were held with experts, Department of Environmental Affairs personnel and the agents implementing the clearing operations. This was done to aid the qualitative system dynamics model-building process (i.e. the causal loop diagram). Site visits and investigations were conducted as a form of ground-truthing in order to verify whether the species mapped by Kotzé *et al*. (2010) and the Department of environmental Affairs: NRM (2016) correspond to what is on the ground.

The data on recycled thermoplastic waste was sourced from the Western Cape Department of Environmental Affairs and Development Planning, as well as literature surveys. Data on the tensile strength of using wood flour from *Acacia saligna* for the production of WPCs was obtained from an experimental study and analysis conducted by Effah, Van Reenen and Meincken (2017, in press) (see Section B in the supplementary materials segment).

2.3 Data analysis

2.3.1 Method

A system dynamics model was constructed to conduct an analysis using the Vensim® PLP software. System dynamics modelling is normally used when the subject under study involves complex systems that change over time (Ford 2009). Coyle (1977:2) defines system dynamics as *that branch of control theory which deals with socio-economic systems and that branch of management science which deals with problems of controllability*. Biological invasions emanating from IAPs like *Acacia saligna*, and the environmental impacts caused by thermoplastic waste are characterised by various hidden dynamics and complexities. Moreover, the use of these two environmentally non-benign sources as raw materials for the production of WPCs, and the corresponding environmental, economic and social impacts, are difficult to assess as a result of the numerous complexities and dynamics of the subject matter. Thus, the system dynamics modelling approach was selected due to its versatility with regard to research problems that are non-linear in nature and characterised by complexities. The PORTTHERM-WPC model (i.e. the *Acacia saligna* (Port Jackson) Recycled Thermoplastic Waste-Wood Polymer Composites Model) was constructed for the purpose of this study and is described in greater detail in Section A in the supplementary materials segment.

2.3.2 Scenarios

Four scenarios were developed to assess the benefits and cost of using *Acacia saligna* and thermoplastic waste for the production of WPCs over a 23-year simulation period (2008 to 2030), namely:

Baseline scenario
The DEA: NRM continues its control of *Acacia saligna* based on historic figures for 2008 until 2015, with the budget for controlling *Acacia saligna* kept constant from 2016 onwards until 2030, based on the 2015 figures, with no value addition.

Scenario 2: Low co-finance
The control of *Acacia saligna* is done by the DEA: NRM based on historic figures from 2008 until 2015, with control efforts kept constant from 2016 onwards until 2030, based on the 2015 figures, but allowing for a 20% co-finance component from the private sector augmenting the DEA: NRM budget. In addition, a WPC factory is established in 2016 and production commences in 2017.

Scenario 3: Moderate co-finance
The control of *Acacia saligna* is done by the DEA: NRM based on historic figures from 2008 until 2015, with control efforts kept constant from 2016 onwards until 2030, based on the 2015 figures, but allowing for a 50% co-finance component from the private sector augmenting the DEA: NRM budget. In addition, a WPC factory is established in 2016 and production commences in 2017.

Scenario 4: High co-finance
The control of *Acacia saligna* is done by the DEA: NRM based on historic figures from 2008 until 2015, with control efforts kept constant from 2016 onwards until 2030, based on the 2015 figures, but allowing for a 100% co-finance component from the private sector augmenting the DEA: NRM budget. In addition, a WPC factory is established in 2016 and production commences in 2017.

2.3.3 Model validation

The PORTTHERM-WPC model was tested through a three-stage validation process, namely model debugging, model verification and model validation. In the model debugging stage, all errors were traced and corrected to allow the PORTTHERM-WPC model to simulate the various scenarios properly. During the model verification stage, the model was checked for any obvious errors present within it, for example errors relating to unit consistency and numerical accuracy. Lastly, the model validation process was two-pronged, consisting of a direct structural test to assess the validity of the model structure compared to the reference mode, based on prior knowledge of the real-world system, and an extreme condition test to gauge how sensitive it was to alteration in some of the variables, as recommended by Sterman (2000).

3. Results

3.1 Total area invaded by *Acacia saligna*

The results from the PORTTHERM-WPC model show a decreasing trend in the area invaded by *Acacia saligna* from 2008 to 2014 for all the scenarios (Figure 2, see graph at the bottom right). During the initial simulation period, the total invaded area for all the sites was approximately 1 614 ha for all the scenarios. In 2014, it had reduced to 1 186 ha (baseline scenario), 850 ha (Scenario 2), 845 ha (Scenario 3) and 911 ha (Scenario 4). As from the year 2015, the total area under invasion began to increase, with the biggest increase noted in the baseline scenario, followed by Scenario 2 (with 20% co-finance), Scenario 3 (with 50% co-finance) and, lastly, Scenario 4 (with 100% co-finance). At the end of the simulation period, the total area under invasion from *Acacia saligna* was reported to be 5 840 ha, 3 617 ha, 2 768 ha and 2 257 ha for the baseline scenario and scenarios 2, 3 and 4 respectively. As illustrated in Figure 2, most of the invasion emanates from the Citrusdal site, which shows an exponential dynamic behaviour pattern over time (Figure 2, see graph at the bottom left) for all scenarios, in contrast with the Berg River (except for the baseline scenario) and De Hoop sites, which show a decline in invasion under all scenarios, with invasion being almost zero from 2010 until the end of the model simulation (as shown in the two top graphs in Figure 2). According to CapeNature (2016), *Acacia saligna* is reported as the second IAP that is causing problems in the De Hoop Nature Reserve. In contrast to the aforementioned, our simulation results show that the area invaded by *Acacia saligna* in De Hoop (top left graph in Figure 2) is almost zero as from 2012 onwards. Given our model assumptions and the historical clearing costs incurred by Working for Water, this can possibly be attributed to a rebound effect. The current norm is that Working for Water clears an area of IAPs in anticipation that the area will restore itself to its natural, pre-invasion state. Since we focused only on the quaternary catchment plots G50J and G50K in our case, the DEA: NRM needs to check whether or not the areas cleared have been reinvaded, given the recent report published by CapeNature (2016). The De Hoop Nature Reserve is a large site with quaternary catchment plots ranging from G50A to G50K. In this study, only quaternary catchment plots G50J and G50K were considered, since these are the sites that the DEA: NRM has been working on and which have available data on clearing costs and for which the invasion densities have been mapped (Kotzé *et al*. 2010; Moerat, personal communication 2015; Pitseng, personal communication 2015; Van Staden, personal communication 2015). The two quaternary catchment plots are invaded mainly by *Acacia cyclops*, followed by *Pinus* spp., *Acacia saligna* and *Eucalyptus* spp. to a lesser extent (Kotzé *et al*. 2010).

3.2 Private benefits and costs of WPC production

3.2.1 Total WPC production output per annum

The results from the PORTTHERM-WPC model show that the total production output from converting *Acacia saligna* wood flour and recycled thermoplastics (in a 50:50 ratio) amounts to 1 354 tons (Scenario 2), 1 628 tons (Scenario 3) and 2 041 tons (Scenario 4) per annum from the year 2017 until the end of the model simulation. During the period 2008 to 2016, the total production output is zero for Scenarios 2, 3 and 4 because of the assumption that the WPC extrusion-moulding production line is set up in 2016 and that production commences in 2017, allowing for a one-year lag time. However, for the baseline scenario, the production output amounts to zero for the entire simulation period due to the "do nothing" assumption. As a result, there is an opportunity cost of not transforming the harvested biomass into value-added products, such as WPCs as considered in this study. The annual total production output of WPCs is presented in Table 1. This annual production output is then apportioned on a pro rata basis to the production of solid WPC decking planks (150 x 18 x 580 mm) and solid WPC wall cladding decking planks (145 x 12 x 580 mm) in a 50% proportion for each WPC product typology.

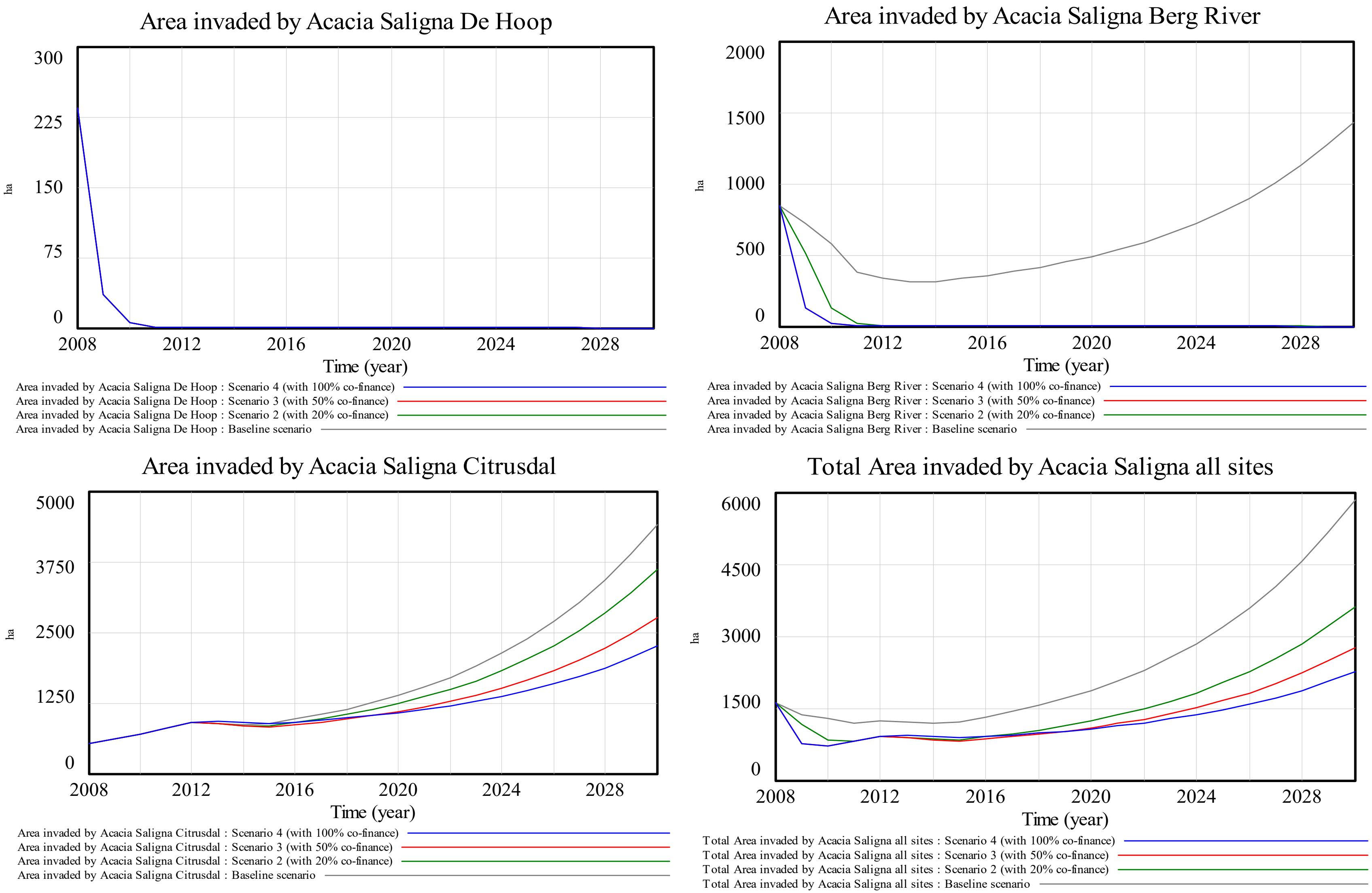

Figure 2: Dynamic pattern over time of the total area invaded by *Acacia saligna* for all sites

Source: Own analysis

3.2.2 Total output and value per annum of solid WPC decking planks

The PORTTHERM-WPC model shows that no production of solid WPC decking planks occurs in the period 2008 to 2016 for Scenarios 2, 3 and 4, due to the assumption that the production line is set up in 2016 and production commences in 2017. As for the baseline scenario, no production occurs due to the "do nothing" assumption made for this particular scenario. As from 2017 until the end of the simulation (i.e. 2030), the amount of solid WPC decking planks produced sums up to 43 674 planks, 52 518 planks and 65 834 planks per annum for Scenarios 2, 3 and 4 respectively. In addition, each solid decking plank weighs 0.0155 tons (or 15.5 kg) and is valued at ZAR675 per plank (or ZAR43.55 per kg). This equates to an approximate annual gross value of ZAR29.5 million, ZAR35.5 million and ZAR44.4 million per year for Scenarios 2, 3 and 4 respectively. The total annual solid WPC decking planks produced are presented in Table 1.

3.2.3 Total output and value per annum of solid wall cladding planks

The results emanating from the PORTTHERM-WPC model show that the quantity of solid WPC wall cladding planks produced sum up to approximately 67 770 planks, 81 494 planks and 102 156 planks per annum for Scenarios 2, 3 and 4 respectively, from 2017 until the end of the simulation period (i.e. 2030). Each solid wall cladding plank weighs 0.010 tons (or 10 kg) and is valued at ZAR505 per plank (or ZAR50.5 per kg). As for the baseline scenario, no production takes place for the entire simulation due to the "do nothing" assumption. Furthermore, zero production output is recorded during the period 2008 to 2016 for Scenarios 2, 3 and 4 due to the assumption that production only commences in 2017, after the installation of the production line in 2016. The gross value of the solid wall cladding planks amounts to approximately ZAR34.2 million, ZAR41.2 million and ZAR51.6 million per annum for Scenario 2, 3 and 4 respectively. The total solid WPC wall cladding planks produced per annum are also presented in Table 1.

3.2.4 Total WPC material and production costs

The total material and production costs incurred in the production of WPC products (i.e. solid WPC decking and wall cladding planks) are reported to be zero for all the scenarios for 2008 to 2016. This is because of the assumption (Scenarios 2, 3 and 4) that the production only commences in 2017, after the WPC extrusion production line is set up in 2016. As for the baseline scenario, the manufacturing and production costs are zero due to the "do nothing" assumption. From 2017 until the end of the simulation period, the total manufacturing and production cost for the WPC products were constant, at approximately ZAR4.8 million, ZAR5.8 million and ZAR7.3 million for Scenarios 2, 3 and 4 respectively. The total material and production costs for manufacturing WPC products are also presented in Table 1.

Table 1: Summary of annual production costs and potential revenue realised due to WPC production for the period 2017 to 2030

Variable (unit)	Baseline scenario	Scenario 2 (20% co-finance)	Scenario 3 (50% co-finance)	Scenario 4 (100% co-finance)
Total annual production output of WPC products (tons)	0	1 354	1 628	2 041
Total solid WPC decking planks produced (planks)	0	43 674	52 518	65 834
Total solid WPC wall cladding planks produced (planks)	0	67 770	81 493	102 156
Total sundry costs (ZAR)	0	230 661	277 369	347 698
Total WPC material and production costs (ZAR)	0	4 843 880	5 824 756	7 301 667
Total clearing and wood-processing costs (ZAR)	0	4 947 034	6 150 275	8 132 663
Net value of WPC products (ZAR)	0	53 913 276	64 629 008	80 593 240

Source: Own analysis

3.2.5 Total establishment costs for the WPC factory plant

The once-off establishment cost incurred to set up the WPC production plant in 2016 amounted to approximately ZAR31.2 million for all the scenarios (except for the baseline scenario, which is zero throughout the entire simulation period). It is zero for all the other years in the simulation since the machines in the factory would not have reached their lifespan (assumed to be 15 years in this case) to warrant a replacement cost for the WPC production line components. With regard to the baseline scenario, there was no WPC production plant establishment cost due to the absence of the manufacturing process as a result of the "do nothing" assumption.

3.3 Externality benefits and costs due to clearance of *Acacia saligna*

3.3.1 Water savings benefit and monetary value

The water savings emanating from the clearance of *Acacia saligna* from the study sites (combined) decrease over time from 2008 to 2011, followed by an increase until 2014 and another decline in 2015. From 2016 onwards, the water savings due to the clearing of *Acacia saligna* in the Berg River and Citrusdal sites become constant, at 54 431 m^3, 43 339 m^3, 52 114 m^3 and 54 327 m^3 for the baseline scenario and scenarios 2, 3 and 4 respectively. Using a unit price of water of ZAR2 per m^3, this translates into values of ZAR108 864, ZAR86 676, ZAR104 228 and ZAR130 655 for the baseline scenario and scenarios 2, 3 and 4 respectively. The De Hoop site is excluded, since all the water saved flows to the sea (Mudavanhu *et al*. 2016). The water savings per annum emanating from the clearance of *Acacia saligna* are shown in much greater detail in Section F of the supplementary material.

3.3.2 Potential loss and cost value of carbon sequestration

The carbon stock sequestered, stored and removed as a result of clearing *Acacia saligna* amounted to approximately 13 437 tons (baseline scenario), 19 405 tons (Scenario 2) and 30 495 tons (scenarios 3 and 4) at the beginning of the model simulation. This translates into ZAR1.6 million (baseline scenario), ZAR2.3 million (Scenario 2) and ZAR3.6 million (scenarios 3 and 4) in monetary terms. In 2011, for scenarios 3 and 4, and 2030 for the baseline scenario, the negative value shows that there is a carbon sequestration benefit due to the re-invasion by *Acacia saligna* outweighing the clearance. The annual carbon sequestered, stored and removed is presented in much greater detail in Section F of the supplementary material.

3.4 Cumulative net present value (NPV) for clearing *Acacia saligna* and making WPCs

The PORTTHERM-WPC model shows a positive NPV value for all the scenarios considered in this study, with the exception of the baseline scenario. The cumulative NPV for the simulation period was -ZAR122.1 million, ZAR144.4 million, ZAR172.7 million and ZAR211.2 million for the baseline scenario and scenarios 2, 3 and 4 respectively. The dynamic pattern of the results for output produced from the PORTTHERM-WPC model is presented in Figure 3.

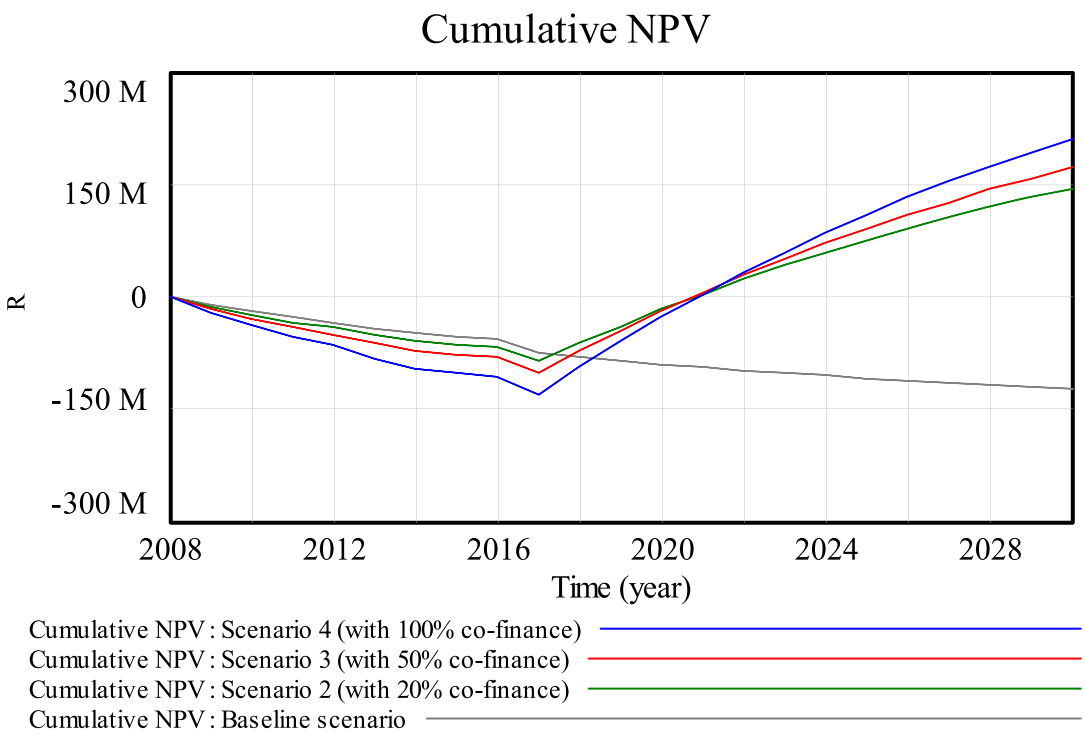

Figure 3: Cumulative NPV for clearing *Acacia saligna* and making WPC products
Source: Own analysis

4. Discussion and concluding remarks

Given the empirical findings from the PORTTHERM-WPC model, the results indicate that the clearing of *Acacia saligna* and using the cleared biomass to make WPC value-added products is economically viable. However, clearing *Acacia saligna* without using the biomass to make WPCs yields a negative cumulative NPV for the baseline scenario. The rule of thumb in cost-benefit analysis using the NPV method is that all projects yielding a positive NPV are desirable and preferable, with the highest priority being assigned to the alternative yielding the highest NPV value. In this case, Scenario 4 is the most favourable, followed by Scenario 3 and, lastly, Scenario 2. The baseline scenario should be avoided at all costs. The annual net economic value from clearing *Acacia saligna* and making WPC value-added products (i.e. solid WPC decking and wall cladding planks) were discounted at a 6% discount rate, yielding the aforementioned total cumulative values for the respective scenarios. It is important to note that the negative cumulative NPV yielded in the baseline scenario presents an opportunity cost associated with not using the biomass for value-adding purposes. As a result, income and opportunities that would have arisen due to value-adding activities through the manufacture and sale of WPCs product are forgone in this case, and thus this scenario should be avoided by decision makers.

The results also show that augmenting the state budget through private sector co-finance can help reduce the area under invasion, with the biggest impact being realised with 100% co-finance, followed by the 50% co-finance and lastly the 20% co-finance options (see Figure 2). As shown in

Figure 2, the strategic importance of these dynamics is that they justify the importance of increasing the clearing budget in order to battle the problems of invasion by IAPs such as *Acacia saligna*. However, despite the increased funding due to co-finance from the private sector, the area under invasion gradually starts to increase again over time, but at a slower rate. This emphasises the strategic importance of follow-up clearing operations.

Figure 2 also shows how the effects of clearing IAPs differ from one site to another. It can be clearly observed that, for the Citrusdal site, the area under invasion maintains an almost constant (and stable) growth pattern from 2008 to 2015, and then eventually starts to increase for all the scenarios. As for the Berg River site, the area under invasion by *Acacia saligna* initially declines from the beginning of the simulation period, and then stabilises at almost zero from 2012 until the end of the simulation. Lastly, for the De Hoop site, the area under invasion by *Acacia saligna* gradually declines from the initial time of the model simulation to almost zero in the year 2012, and thereafter the same trend is maintained until the end of the model simulation, with invasion being almost zero. The general increase in the total area invaded by *Acacia saligna* for all sites combined can be attributed to the Citrusdal site (with the exception of the baseline scenario of the Berg river site). As a result, more control efforts should be focused on the Citrusdal site. This shows that site-specific case studies should not be treated with a “one size fits all” approach. The factors influencing invasion by IAPs vary on both a spatial and temporal scale, presenting a challenge for how we understand the behaviour of a system. For this reason, the system dynamics modelling approach is ideal, as it enables us to supplement and augment our models with more insights that we might otherwise have ignored.

The results produced by the PORTTHERM-WPC model also show that clearing *Acacia saligna* is a contentious issue. Despite it being an IAP that causes several harmful effects on the environment, economy and society at large, *Acacia saligna* also sequesters carbon dioxide from the atmosphere, thereby reducing the amount of greenhouse gasses. Furthermore, it can be used to create value-added industries that can create employment, add to the government’s tax revenue and also increase the country’s GDP and GNP, having multiplier effects on the downstream and mainstream economy.

Despite the regulations contained in the National Environmental Management: Biodiversity Act (No. 10 of 2004 (NEMBA) (Republic of South Africa 2014), there generally has been a lack of policy alignment and enforcement across various sectors affected by IAPs. As a result, a more robust legal framework that prohibits illegal planting of IAPs must be set up and enforced, through the help of environmental law enforcement agencies and the respective courts of law. As there is the potential of value adding and generating profit, there is also a risk of the incentive to grow these IAPs.

The results arising from this study show that there is great potential for using *Acacia saligna* biomass as a raw material in the manufacture of WPC products. Despite the negative impacts posed by *Acacia saligna*, benefits actually accrue as a result of its use in the production of WPC products. Thus, policy makers should view the use of *Acacia saligna* as an alternative way in which the private sector can be incentivised to help augment the current state budget, which is by far not enough to tackle the problem of IAPs.

It is recommended that this study be replicated at other sites to test and gauge if the same research findings can be obtained. Furthermore, a market research analysis (for both local and export markets) should be conducted before considering setting up a WPC plant in the City of Cape Town to produce the products assessed in this study. In conclusion, more research should be conducted to assess the feasibility of using *Acacia saligna* in comparison to other IAPs invading the sites under investigation, and also to test other value-added products such as timber, bioelectricity production, charcoal and firewood.

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