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Research paper

Balancing growing global bioenergy resource demands - Brazil's biomass potential and the availability of resource for trade

Andrew Welfle

Tyndall Centre for Climate Change Research, School of Mechanical Aerospace & Civil Engineering, University of Manchester, Pariser Building, Sackville Street, Manchester, M13 9PL, United Kingdom

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ABSTRACT

Based on the general acceptance that greenhouse gases from biomass can provide a low carbon energy source, bioenergy pathways are being increasingly included in many countries renewable energy and emission reduction strategies. As a result demand for biomass is rising fast with several regions forecast to encounter major resource stresses over the coming decades. The bioenergy strategies of many countries rely heavily on future imported resource to balance their bioenergy resource demands. Applying a Biomass Resource Model to evaluate and forecast the types and potential availability of different categories of biomass resources from Brazil – a case study of a country with extensive biomass resources and export potential. This research evaluates Brazil's biomass potential to 2030, and analyses the levels of resource that may be available to export. The research finds that Brazil has extensive biomass resources that are potentially sufficient to both balance Brazilian total primary energy demand by 2030 and for Brazil to increasingly become a major exporter of resource for energy end uses. The paper also discusses the potential impact for global biomass trade, if countries such as Brazil were to adopt energy strategies that resulted in greater domestic use of their available biomass. The research's analysis shows that if the Brazilian Government were to adopt strategies to utilise a greater proportion of its resource for domestic energy, Brazil could export up to >25.8% less biomass by 2030 compared to forecast export levels based on Brazil's current policy framework.

1. Introduction

Energy from biomass currently contributes approximately 10% of global energy supply, two thirds of this bioenergy is generated in developing countries, and the remaining in the industrialised world [1]. Bioenergy is such an attractive energy option for all stages of development due to its flexibility and potential for integration with all stages of development strategies [2], and the general acceptance that bioenergy can deliver energy with less greenhouse gas emissions than from fossil fuel energy pathways [3].

The IEA/IRENA Global Renewable Energy Policies and Measures Database [4] confirms that more than 60 countries currently have national targets or policies supporting renewable energy. In countries such as those in Europe, biomass is expected to play a major role in contributing over 50% towards their renewable energy targets [5].

Despite widespread global demand, biomass is unevenly distributed with some of the regions with the greatest demand having comparatively low resource availability [6–9]. Trade has an important role to play, with biomass being described as the most important renewable energy carrier worldwide [10]. The short-term trend is that countries and regions with strong economies and development will increase their use of imported biomass resource, whilst less developed countries will continue their development largely reliant on fossil fuels [11].

As a result of recent energy policies Europe has become the prime market for the trade of biomass for energy [12]. More than 30% of biomass resources currently consumed in Europe are imported [13], and demand is forecast to rise by almost 50% between 2010 and 2020 [14]. Demands for biofuels are expected to rise sharply driven by Europe's ambitious biofuel mandates, and the demand for fuels such as wood pellets are forecast to increase three-fold by 2020 as Governments offer renewable energy subsides [15].

In summary developed countries and regions are set on a journey of increasing reliance on bioenergy pathways to meet their energy demands. As their renewable energy policies are implemented and targets met, more and more of the biomass resource

E-mail address: andrew.welfle@manchester.ac.uk.

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required to generate this energy will have to be imported.

Undertaking analysis using a Biomass Resource Model, this paper sets out to analyse the potential availability of biomass resources from Brazil - a key biomass exporting country. The paper also explores what may happen if scenarios arise where 'biomass rich' countries or regions start to adopt policies to use a greater extent of their biomass resource to meet domestic demands rather than exporting to the international market.

2. Global trade of biomass

The following section provides further details of the current major flows of biomass resource around the world and explores how this trade may further develop.

2.1. Supply & demand regions

The key forces driving the global trade of biomass resources for the bioenergy sector are the prices of fossil fuels (especially oil), the implementation of policy mandates aimed at reducing greenhouse gas emissions and increasing policy and financial mechanisms supporting bioenergy pathways [16].

Fig. 1 highlights the major biomass trade flows around the world. Brazil is the major exporter of bioethanol, predominately to Europe, the United States and Japan [17]. The United States, Argentina, Indonesia and Malaysia are the largest exporters of biodiesel, mainly to Europe [17]. The major exporters of wood pellets are Canada, the United States, Russia and the Balkan States, with Europe once again being the largest importing region [18–20].

2.2. Trade hub Europe

Driven by the renewable energy and greenhouse gas reduction targets of EU States, Europe is the key trading hub and demand region for each of the major categories of traded biomass resources. With all major biomass trade flows headed towards Europe, this may present both positive and negative issues for the bioenergy sectors of specific European States. Being part of the central hub of biomass trade with increasingly established trade routes will likely present resource opportunities for the growth of the bioenergy sector. However the competition for resource throughout Europe is only likely to intensify, with European countries having to increasingly compete with their neighbours who each have their own equally large(r) and growing demands for resources.

2.3. Key trade flows – biofuels

By 2030 global demand of biofuels are forecast to rise by 2.1 EJ and 1 EJ respectfully for bioethanol and biodiesel based on 2000 levels. Driven by biofuel mandates Europe is forecast to represent 74% of the total global biodiesel demand in 2030 and 13% of the bioethanol demand [15].

The United States and Brazil are the two leading producers of bioethanol – these dominating by representing over 85% of the global market [21]. Brazil is the largest exporting country with the United States and Europe being the greatest importers followed by Canada and Japan [16]. The UK and Sweden are amongst the largest importers of bioethanol in Europe, of which 32% (in 2009) was estimated to be utilised to power the transport sector [16].

Driven by the biofuels mandates the Europe has the world's most developed biodiesel industry producing two thirds of global production [16]. Germany, France, Spain and Italy are the leading producers [22], with rapeseed oil produced in Europe being the major feedstock that represents two thirds of total demand for production. Imported feedstocks such as soybean oil, palm oil and to a lesser extent further rapeseed oil representing the final third [23]. Other major biodiesel producers include the United States, Argentina, and Brazil. With more than 95% of global biodiesel exports being directed toward Europe [24], Germany and France consuming almost half of this amount [21].

2.4. Key trade flows – wood pellets

The global wood pellet market has also been growing exponentially, with levels currently comparable to that of both bioethanol and biodiesel in terms of traded volumes [16].

Driven by mandates and incentives to increase renewable energy generation and reduce carbon emissions, Europe is the world's

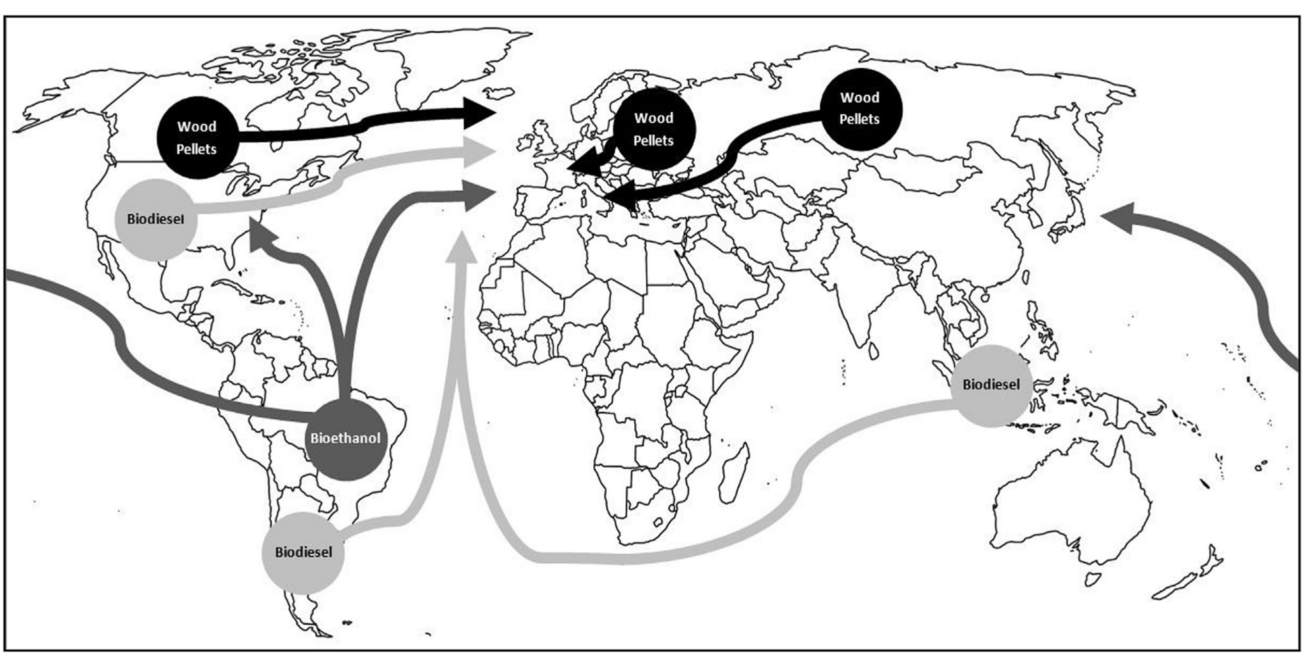

Fig. 1. Major global trade flows of biomass resources for energy end uses.

largest wood pellet market [23]. Wood pellets replacing or being co-fired with coal to either generate electricity [15] or to produce heating or cooling with reduced greenhouse gas emissions [23]. To balance growing demand, Europe is the largest importer of pellets with about 3.4 Mt imported in 2010, of which about half can be assumed to have been intra-traded inside the EU [25].

North America is the largest exporter of pellets, the majority of these going to Europe. Canada is the dominant exporter who also supply pellets to the United States. In Scandinavian countries despite there being significant domestic pellet production, large increases in demand are outpacing production leading to them also increasingly importing large volumes of pellets from the Baltic Regions and Russia [23]. Further minor biomass pellet trade flows to the Europe are also taking place and growing from Australia, Argentina and South Africa [5].

The European Biomass Association (AEBIOM) [5] forecasts that Europe's consumption of wood pellets will continue its steep rise, estimating increases from the 105 PJ in 2008 to as much as 837–1340 PJ in 2020. North American exports are targeted by Europe to provide the majority share of these near and mid-term demands [16].

2.5. Key trade flows – wood chips

Over most of the past decade Japan has been largest importer of wood chips, attracting over 50% of the global traded resource. Although China's growing demand is expected to see it take over as the predominant importer within the next few years [26].

The largest wood chip producing nations (based on 2013 data) are Canada (25%), China (13%), South Africa (5%), Sweden (5%) and the USA (5%) [27]. Each of these countries incidentally and relevantly having large pulp and paper production industries. Thus potential trends of the future trade of wood chips may be influenced by the on-going shift in the production of pulp and paper industries moving from the Northern to Southern hemispheres [12].

As a consequence of recent energy policies, price competitiveness and a strong forestry sector, Europe is becoming an increasingly major market for the wood chip trade [28]. The EU is a net importer of wood chips but also demonstrates many dynamics of EU State intra-trading. Sweden, Finland, Austria and Italy are major importers and Germany, Latvia and Estonia are major exporters [29]. From outside Europe wood chips are increasingly being sourced from Russia, Uruguay, Brazil and Canada [29].

3. Biomass and bioenergy in Brazil

The following section provides an overview of Brazil's energy and bioenergy policy landscape, and provides an introduction to the key categories of biomass resource that may be typically be used within bioenergy pathways. The future extents and potential availability of these resources in Brazil for the bioenergy sector are also discussed.

3.1. Brazilian energy policy, strategy & targets

The Brazilian Government have set renewable energy targets and policies [30–32] that will see the increased contribution from a broad range of renewable technologies. Brazilian States such as Sao Paulo have also set further targets [33] requiring greater contribution of renewables. Energy from Brazilian biomass will make a major contribution towards these, meaning Brazil will need to sustain its current increasing rate of biomass production if it is to meet increasing domestic demand as well as maintain its export share [34].

Brazil's 'National Climate Change Plan' [35], '2030 National Energy Plan' [36] and 'Decennial Plan' [37] sets strong targets for greenhouse gas emission reductions and the phasing-out of fossil fuels through increased renewable energy generation - with particular focus on bioenergy and large scale hydro-power power. Brazil also has key energy mandates [6,38–43] specifically focused on enhancing the role of biofuels within the transport sector.

Brazil has large resources and favourable conditions to match its strong aspirations for increased hydro-power and biofuels. Brazil can be categorised as a global giant in terms of its productivity of biofuel feedstocks, and has great potential to vastly increase its productivity levels further. Brazil may also be a potential sleeping giant in relation to future wood based biomass resources, especially pellet production, and has large existing [44] and vast potential hydro-power opportunities [36].

However further reports [45,46] highlight that regardless of Brazil's various energy strategies, the majority of near-term major developments within the Brazilian energy sector are/have focused on the development of the fossil fuel sectors, specifically natural gas plants. Much of this development linked to Brazil's large events, the 2014 Football World Cup and 2016 Olympics. Szklo et al. (2013) [46] forecast that the proportional contribution of renewable energy to Brazil's energy mix will be much diminished by 2030 compared to current levels unless the pace of renewable technology development keeps up with that of conventional fuels. As such the current ambitions, targets and aspirations for Brazil's energy sector could be described as modest at best, in comparison to some of the targets of countries with less fortunate resource backing.

3.2. Brazil's biomass resources

Brazil is highly important for the global biomass market due to its vast production of plantation crops such as sugarcane, the predominant feedstock for the bioethanol industry [21]. Brazil is well placed for increased production of these feedstocks as it has vast areas of arable savannas that could potentially be utilised to produce crops without risk of deforestation [34]. Brazil's Ministry of Agriculture, Livestock & Food Supply estimate potential scope for crop expansion at 1,190,000 km^2, from savannas (690,000 km^2) and conversion of pastureland (500,000 km^2) [47]. Brazil's large agricultural sector represents a further major potential source of waste and residue feedstocks for the bioenergy sector [48].

Sugarcane production rates have realised typical annual increases of 9.7% in recent years, with continuous improvements in productivity, high domestic and international demand for sugar and increasing bioethanol exports being the key driving factors [49]. Even in the most favourable production years, Brazilian exports of bioethanol have never represented more than 15% of total productivity – highlighting the importance of the domestic market. Although investment in Brazil's sugarcane production industry has increasingly focused on producing resource for the export market, although perspectives continue to predict only gradual growth over the near-term [21].

Brazil is also a large consumer of biodiesel of which 100% is produced domestically [50]. There is little or no data describing Brazilian biodiesel exports so this is taken to be negligible [21,51].

Brazil also has large but predominately domestic market for woody biomass that is utilised for charcoal and wood briquette production [52]. This market is considered by some to be one of Europe's most promising trade opportunities due to its proximity, but much debate is still required whether wood-based fuels exported from Brazil could meet stringent European sustainability criteria [53]. There are a growing number of Brazilian companies developing information about the European markets with a view to establishing wood pellet trade links. This is widely regarded as being a good opportunity for Brazil but is still in early phases and far from widespread deployment [21]. The Brazilian Association Industry Biomass & Renewable Energy confirmed [51] that Brazil currently has 10 plants producing wood pellets predominantly using pine and eucalyptus residues, these have a reported capacity of about 320,000 tonnes per year [51]. Although more pellet plants are currently under development which will increase pellet production to over 3 million tonnes; with a series of further plants following by 2018–19. The realisation of these plans would place Brazil as a major future producer and exporter of pellets, the majority expected to go to Europe [54].

3.3. Key categories of biomass resource & potential availability for the bioenergy sector

3.3.1. Resource from forestry systems

The extent (area and standing volume) and characteristics (types and uses) of Brazil's forests are described by many studies [55,56]. Current forestry systems are accounted inline with FAO categories [56], in 2010 Brazil's forests were categorised as follows: for wood resource production (>534,000 km^2); to protect soil and water systems (>425,000 km^2); for conversation & biodiversity (>560,000 km^2); for social services (>1,191,000 km^2); with multiple uses (>243,000 km^2); and with no/unknown use (2,118,000 km^2) [56]. Brazil's overall forested area and ‘forest use categories’ are expected to greatly evolve in the future, with multiple studies and reports developing forecast scenarios [55,57,58], each predicting different potential levels of resource availability for the bioenergy sector.

3.3.2. Forestry residues

Residues from forests are utilised extensively throughout Brazil, albeit predominantly as wood fuel for small scale and domestic uses [57]. Although by 2050 it is forecast that upto 45% of total available forestry residues may be harvested from managed forests [57,59,60]. Future availability for bioenergy will likely reflect the area of managed and plantation forests, and the implemented harvest and utilisation strategies.

3.3.3. Wood-based industry residues

Current residues produced by Brazilian wood-based industries are not well documented, despite Brazil having extensive industries reliant on forestry resource [57,58]. The future availability of these resources and their potential use for bioenergy will be dependent on the growth of industries, future trade dynamics and the extent that residues are utilised by competing uses [55].

3.3.4. Agricultural residues – crop

It is estimated that up to 10% of all agricultural residues such as straws are harvested in Brazil [47], where they are then predominantly reutilised within agricultural processes [61]. It has been forecast that by 2050 up to 40% of all crop residues may be harvestable through technological advances [57], the availability of this resource for bioenergy being much restricted by the resource demands of competing uses.

3.3.5. Agricultural residues – animal

The availability of animal waste resources such as slurry and manures is dependent on the number of livestock [62], the levels of manure produced (manure factor) [63], and the farming practices determining the extent that the resource may be collected [64,65]. Future availability will correlate with forecasts of the number of livestock farmed and changing farming practices, whilst the resource potential for bioenergy will be restricted by the resource demands of competing uses [64,66–68].

3.3.6. Arboriculture residues

There is little reporting of arboricultural residues in Brazil aside from that from large municipal areas, the majority of which are sent to landfill [69,70]. Future resource levels will likely expand in correlation with urban growth [71]. The resource availability for bioenergy will be largely reliant on the focus of future waste management strategies and specifically the extent that resource is diverted from landfill.

3.3.7. Wastes

Official statistics [72] provide a summary of the predominant categories and extents of waste within Brazil - in 2010 > 1.3 Mt of waste was identified as being potential available/suitable for the bioenergy sector, largely from the organic waste/food and paper/cardboard waste categories. Brazil's economy is still expanding, and therefore it has been forecast that ‘peak waste generation’ is still to come [73]. Waste generation and management practices in Brazil are typically poorly developed, with the majority of Brazil's waste currently disposed through landfill. Although the Brazilian Government has ambitions for increased energy recovery from wastes [74,75].

3.3.8. Sewage waste

The extent of sewage resource is dependent on the population and the design and coverage of sewage infrastructure. In 2012 50% of the Brazilian population was connected to sewage grid systems, 28% of these had treatment infrastructure [76–78]. Therefore future availability of this resource for bioenergy will be highly dependent on Brazil's progress towards implementing its sewage and sanitation infrastructure roadmap [79]. At the current/planned investment rate full coverage may take 60 years [80].

3.3.9. Plantation crops for energy end uses

The extent of crop plantations for energy are well documented for Brazil [23,58,81–88]. In 2010 significant land was dedicated to: soya (>283,000 km^2); and sugarcane (>77,000 km^2) [62]. The future resource potential and availability for the bioenergy sector are forecast within many reports and scenarios [23,58,81,83–90]. Key plantation crops for energy include poplar, palm, sugarcane, soya, eucalyptus, pine and jatropha.

4. Research methodology

4.1. Modelling Brazil's biomass resource supply chains

This research utilises the Biomass Resource Model (BRM), a resource focused modelling tool developed to analyse the practical potential of indigenous biomass resources, in this case within Brazil. The BRM's analysis methodology progresses in three distinct analysis stages as demonstrated in Fig. 2 and described below:

- Stage One Analyses – analysis focuses on evaluating the area of Brazilian land currently utilised to meet various demands, including; food production, further urban development and forestry. The remaining land area potentially suitable for crop production is then analysed to determine its potential availability for biomass and energy crop growth dedicated for the bioenergy sector.
- Stage Two Analyses – this analysis phase aims to quantify and forecasts the extent, availability and competing markets for different biomass resources indigenous to Brazil. This takes into consideration factors such as the potential for resource

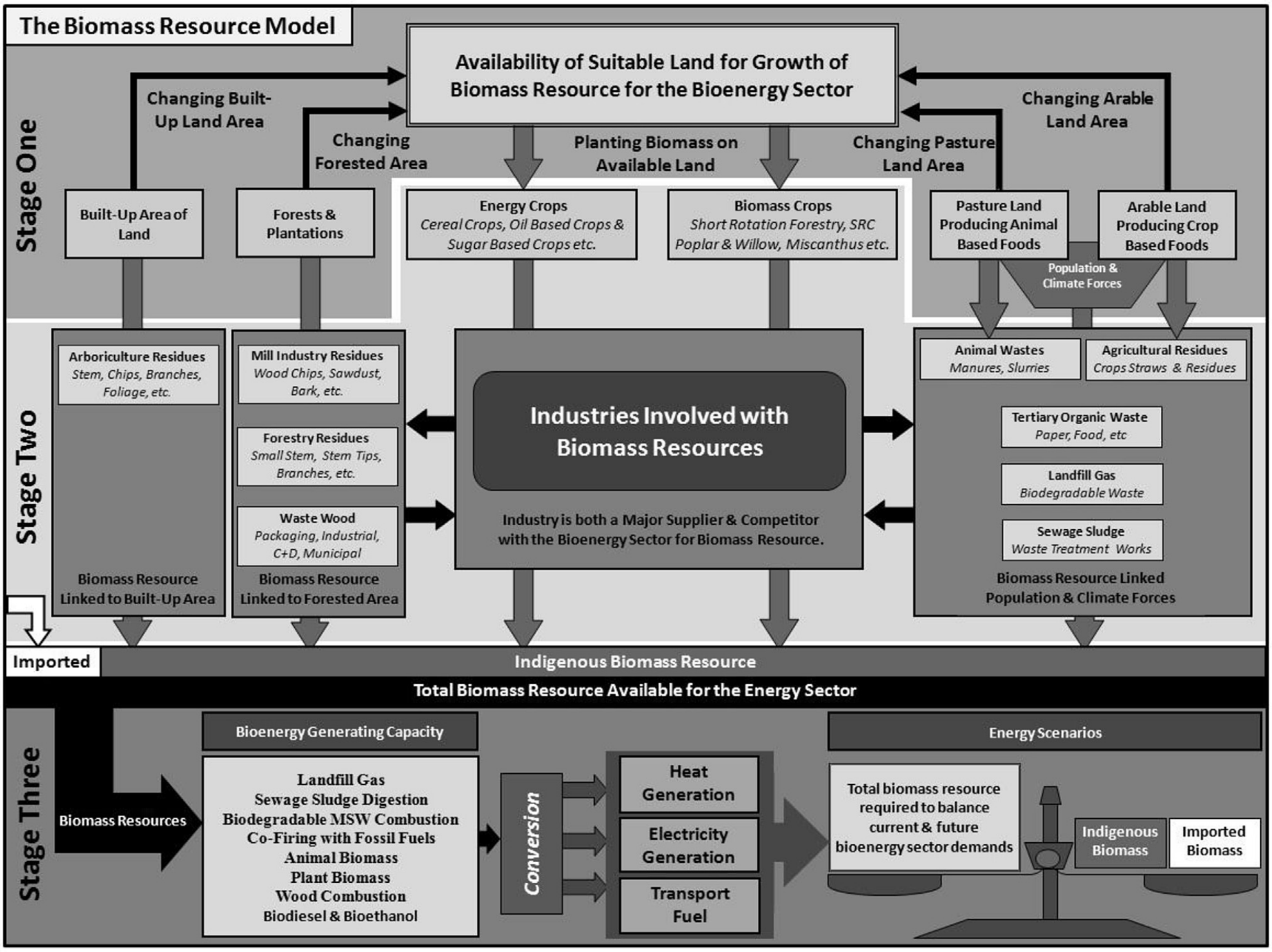

Fig. 2. The biomass resource Model's high level modelling architecture.

collection/harvest, changes in the levels of arisings linked to industrial activity and agricultural residue utilisation.

- Stage Three Analyses – evaluation of the extent and forms of bioenergy that may potentially be generated from the specific resource quantities calculated within Stage Two. The range of pre-treatment and energy conversion pathways applicable to different types of biomass are considered. Resource bioenergy potentials are calculated taking account of the resource and energy efficiencies reflective of each bioenergy generation pathway. Once the energy potentials of the available resources have been calculated, they are then compared against Brazil's respective renewable energy and bioenergy targets.

Important features of the BRM to highlight are that the analysis takes account of both agricultural and industrial systems. The BRM taking into consideration competition for land and resource, for both food and industry productivity – the biomass resource forecasts for bioenergy are in addition to continued food and industrial productivity at prescribed levels.

4.2. The BRM's modelling mechanics and assumptions for Brazil

The value of the BRM is that the drivers that control the model can be calibrated to collectively mirror the variances and dynamics of different country's biomass supply chains. The key drivers and assumptions for modelling the supply chains of Brazil's predominant categories of biomass resource are presented Table 1. These assumptions reflect a 'literature informed' mean or 'baseline scenario' of Brazil's current biomass availability and supply chains, and how these may evolve to 2030. Calibrating the BRM to produce this baseline scenario allows analysis of the availability and bioenergy potential of each category of indigenous resource to 2030. The majority of studies and literature reviewed when developing the Brazil baseline scenario assumptions, were based on the general premise that there would be a progressive trend towards increased production and mobilisation of biomass resources. As such the outputs from this research should be likewise regarded as reflecting an outlook of potential resource availability if Brazil were to follow a pathway with increasing focus on bioenergy.

Modelling assumptions for the full range of biomass resources analysed in this research are presented in Appendix A1 of the Supplementary Materials. The key equations that drive the BRM are presented in Appendix A2 of the Supplementary Materials. The BRM's full methodology, modelling assumptions, calculations, datasets and references are reported externally [91], and other studies [92,93] document application of the BRM in previous research applications.

4.3. Modelling Brazil bioenergy scenarios

The next step within the research's methodology focuses on analysing the extent of Brazil's available biomass resource will be

Table 1
Key assumptions applied in modelling Brazil's biomass resource supply chains.

Theme	Base year (2012)	Modelling forecast assumptions (to 2030)
Population	- 195.2 m [93]	- Population increasing to: 203.7 m by 2015; 211.1 m by 2020; and 222.7 m by 2030 [93].
Built-Up Land Area	- 54,600 km^2 [61]	- Urban land area increasing to: 68,800 km^2 by 2015; 83,200 km^2 by 2020; and 97,800 km^2 by 2030 [70].
Crop & Agriculture Yields	- Literature review undertaken to develop a database of typical crop and agricultural yields in Brazil [61,94–103]. The assumed base year yields (Mg ha^{-1}) for selected key crops: Wheat: 2.7 *(2.1-3.3)*; Barley: 2.9 *(2.6-3.6)*; Oats: 2.1 *(1.9-2.5)*; Maize: 4.4 *(3.7-5.0)*; Poplar: 7.7 *(5.6-10.0)*; Eucalyptus: 14.6 *(9.0-19.2)*; Jatropha: 6.2 *(4.5-9.0)*; Soya: 2.8 *(2.1-4.0)*; Sugarcane: 81.4 *(74.3-100.4)*. *(ranges in brackets reflect those provided by literature)*	- Reflecting values from a range of sources [95,96,99,101,104–120], assumed yield change over that in the base year of: +18% by 2015; +40% by 2020; and +60% by 2030 [70].
Crop Residues	- Total resource potentially harvestable: 50% [47]. - Residue resource harvested in base year: 10% [47]. - Competing uses for harvested resources: 40% [60]. - Proportion of harvested resource available for Bioenergy: 10% [56].	- Reflecting values from a range of sources [47,56,60,121–123], assumed change in proportion of total resource harvested: +15% by 2015; +25% by 2020; and +30% by 2030.
Forestry	Managed Forests Area: - Expanse of forests dedicated to wood resource production (>534,000 km^2) [55]. Productivity of Managed Forests: - Wood resource output (green tonnes): 390 Mt [55]. Woodfuel from Managed Forests: - Proportion of total wood resource output dedicated for wood-fuel/energy: 53% [55]. Wood-Based Industry Residues: - Generation of wood based industry residues (kg residue per green tonnes of total wood resource output): 6.1 kg of wood chip resource; 0.3 kg bark resource;	Managed Forests Area: - Managed forest area producing wood resource will change compared to the base year: +11% by 2015; +16% by 2020; and +36% by 2030 [54]. Productivity of Managed Forests: - Growth of forest productivity will change: +7% from base year to 2015; +7% from 2015 to 20; and +6% from 2020 to 30 [57]. Woodfuel from Managed Forests: - Propoportion of total wood resource output dedicated for wood-fuel/ energy: +65% by 2015; +68% by 2020;

Table 1 (*continued*)

Theme	Base year (2012)	Modelling forecast assumptions (to 2030)
	1.5 kg sawdust resource [55]. - 9% of total industry residues available for bioenergy [54]. Forestry Residues: - Generation of forestry residues (odt residue per km2 managed forest area): 7.9 [55]. - Proportion on total residue resource collected for bioenergy: 9% [56].	and +76% by 2030 [55]. Wood-Based Industry Residues: - Propoportion of total industry residues available for bionergy: +9% by 2015; +20% by 2020; and +30% by 2030 [54,57]. Forestry Residues: - Propoportion of total residue resource collected for bionergy: +9% by 2015; +20% by 2020; and +30% by 2030 [6,7,56,58,59].
Energy Crop Plantations	- Reflecting Official data and reports [57,80–87,89,94], 484,811 km^2 of land dedicated to plantation crops. - Land is predominantly dedicated to the production of the following key crops: Eucalyptus: 9.7%; Pine: 3.8%; Jatropha: 2.8%; Soya: 60.6%; Sugarcane: 22.2%.	- Forecast assumptions based on reports and scenarios [23,57,61,80,82–89], the area of land (thousand km^2) dedicated to plantation crops for bioenergy: >52.8 by 2015; >61.5 by 2020; >79.0 by 2030. - Proportion of land dedicated to key crops dedicated to different crops by 2030: Eucalyptus: 8.1%; Pine: 3.2%; Jatropha: 2.3%; Soya: 50.8%; Sugarcane: 34.8%.

required to balance indigenous demands, and the levels that may be available for export to the global trade markets. Three Brazil Bioenergy Scenarios are developed to evaluate how Brazil may utilise its available biomass resources in reflection of varying future ambition of Brazilian energy policy, strategy and targets. These scenarios represent a series of balances, analysing the difference between the domestic utilisation of available biomass resources and the surplus potentially available for export.

A strong assumption of the methodology is that available biomass resources will first be dedicated to meet domestic demands, and then all remaining resource may then be potentially available for export. This clearly won't resemble a real world scenario as Brazil is not a centrally planned economy and as such the total prioritisation of resource for domestic use over export is not plausible. However this methodology and the generated results may be used to provide an indication of trends and wider lessons based on the assumption that greater utilisation od resource to meet domestic demands will have an impact on the levels of resource that may be available for export.

4.3.1. Developing Brazil bioenergy scenarios

The developed Bioenergy Scenarios represent a series of trajectories each with varying contributions of energy from different energy technologies. This methodology mirrors other research [125–129] where energy modelling scenarios have been applied to provide instruments to inform policy makers on decisions relating to greenhouse gas reduction and renewable energy targets.

Global energy scenarios have been developed by numerous studies, and many organisations publish annual reports forecasting how global energy systems may evolve based on changing drivers such as; population, GDP, technologies, policy, available resources etc [130]. The Bioenergy Scenarios developed in this research utilise a forecast framework based on the International Energy Agency's (IEA) 'World Energy Outlook' Scenarios [30] to inform a baseline of trends for how the Brazilian energy sector may evolve. The outputs from this research must therefore be taken in context of the IEA's approach to forecasting future global energy systems. The IEA's Scenarios are chosen as they provide a medium to long-term projections of energy systems and detailed sector-by-sector and region-by-region energy demands. The Scenarios are also developed in reflection of constantly evolving energy and climate change mitigation policies, providing an insight into future energy systems assuming current targets and policies are fully realised [131].

The key characteristics of the IEA Scenarios are:

- IEA 'Current Policies Scenarios' – forecast how the energy systems of different countries may evolve, assuming that all currently adopted energy strategies and polices will be realised through to maturity.
- IEA '450 Scenarios' - forecast how the energy systems of different countries may evolve, assuming the implementation of the high-end National pledges and strong policies beyond 2020. The overarching aims of the 450 Scenarios includes the near-universal reduction of fossil-fuel subsidies to achieve the

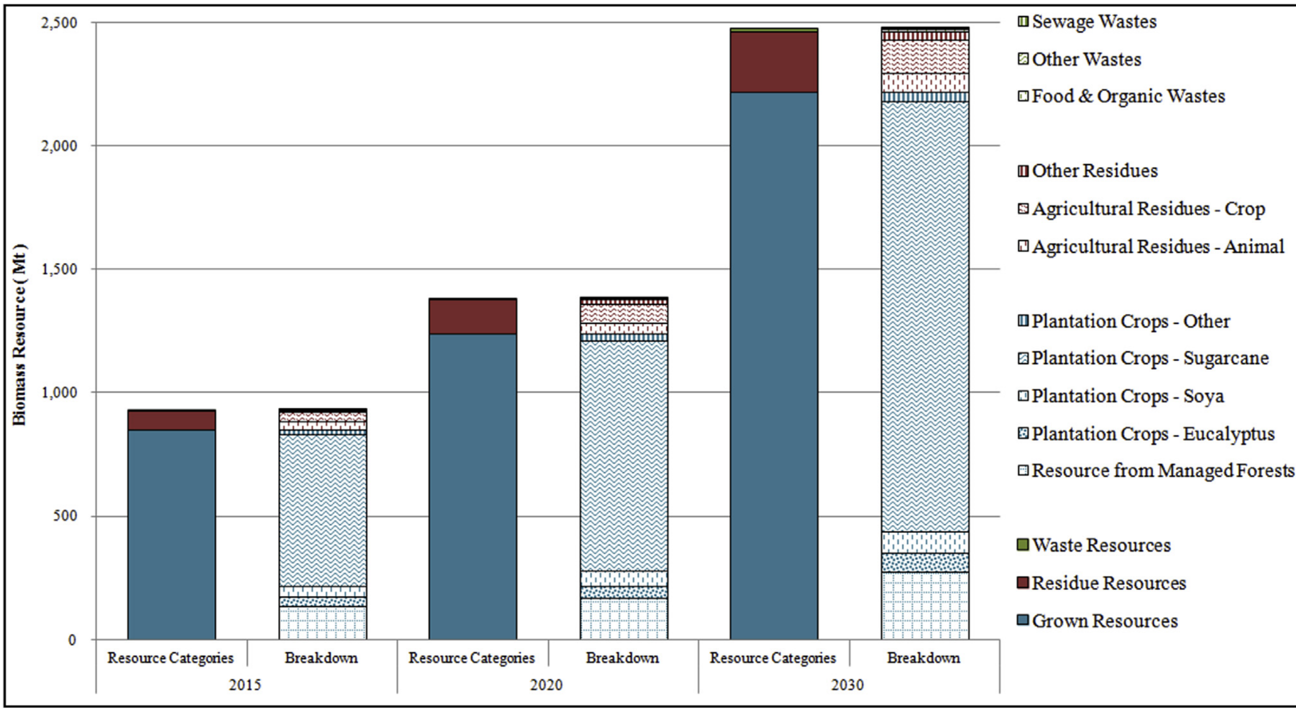

Fig. 3. Brazilian biomass resource availability forecast to 2030.

Table 2
Forecast availability of biomass resource in Brazil to 2030.

Biomass resource categories		Resource availability (Mt)		
		2015	2020	2030
Grown Resources	Resource from Managed Forests	129.89	162.06	268.94
	Biomass Crops	54.73	69.68	104.03
	Plantation Crops for Energy (*sugarcane*)	716.61 *(611.44)*	1072.34 *(931.73)*	1945.33 *(1742.90)*
Residue Resources	Agricultural Residues - Animal	34.06	44.66	75.56
	Agricultural Residues – Crop	35.48	76.38	137.52
	Industry Residues	2.59	2.77	2.93
	Forestry Residues	4.01	9.42	14.45
	Arboriculture Arisings	0.00	0.02	0.06
Waste Resources	Food & Organic Wastes	0.92	3.04	8.25
	Other Wastes	0.58	1.92	5.21
	Sewage Wastes	0.17	0.18	0.19

objective of restricting the global concentration of atmospheric greenhouse gas to limit global temperature increases to 2 °C.

4.3.2. *Brazil current policy scenario (CP-S)*

The CP-S is developed to show how the contribution of different energy technologies may evolve if current Brazilian energy targets and strategies are realised. The characteristics of this scenario correspond to those of the IEA's Current Policies Scenario for Brazil [30]. This scenario is important for the analysis as it provides a baseline indication of how Brazil's bioenergy sector may evolve, and what the Brazil's biomass resource requirements may be by 2030 without any policy changes.

4.3.3. *Brazil renewable focus scenario (RF-S)*

The RF-S has been developed to demonstrate a future Brazilian energy sector that places greater emphasis on renewable technologies over fossil fuels. The RF-S assumes that energy generation trends from bioenergy, hydro-power, nuclear power and other renewable technologies will increase in line with those within the IEA's 450 Scenario for Brazil [30].

4.3.4. *Brazil 100%/2050 scenario (100/50-S)*

The 100/50-S has been developed to demonstrate a future energy strategy where Brazil increasingly utilises its extensive renewable resources, on a roadmap towards a target 100% of its energy from renewable and low carbon technologies by 2050. Within this scenario the contribution of non-bioenergy renewables will increase inline within the IEA's Brazil 450 Scenario [30]. Whilst the contribution of fossil fuel technologies is assumed to gradually reduce on a linear trajectory that would see their contributions reduced to 0% by 2050. The contribution from bioenergy technologies are assumed to increase at rates required to balance the energy demands, thus largely taking over from the energy demands previously provided by fossil fuel technologies. This scenario is designed to show the potential upper limit of biomass resource demand in Brazil for energy end uses.

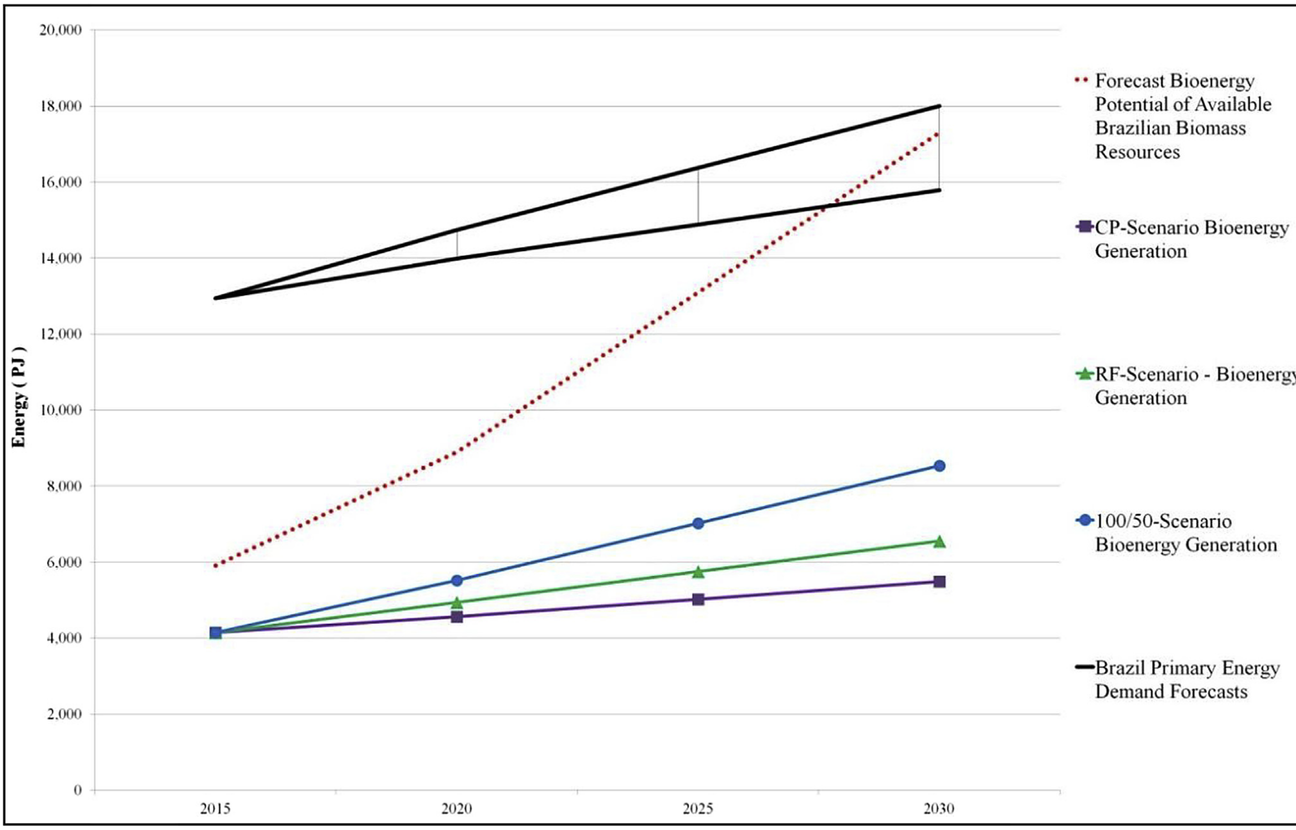

Fig. 4. Brazilian primary energy demand & bioenergy contribution forecasts to 2030.

Table 3
Bioenergy potential of Brazilian resources & bioenergy scenario resource demands.

		Bioenergy (PJ)		
		2015	2020	2030
Bioenergy Potential from Brazilian Resource		5909.4	8902.2	17,299.4
Bioenergy Demand	Current Polices Scenario	4144.9	4563.6	5484.7
	Renewable Focus Scenario	4144.9	4936.8	6558.9
	100%/2050 Scenario	4144.9	5518.9	8535.8

5. Research results

The following section provides the research results, presented in the form of tables and figures. This includes forecasts of Brazil's biomass resource availability to 2030, forecasts of the bioenergy potentially generated from these resources, and analysis of the extent that Brazilian biomass resource may be available for export.

5.1. Availability of Brazilian biomass resource

The types and extent of Brazilian biomass resources availability are forecast to 2030, this representing a mid-term timeframe where demands for bioenergy are currently predicted to potentially peak [30]. Beyond 2030 there is also increasingly greater uncertainty when forecasting how different supply chain dynamics may evolve. The base year for the analysis is 2012, as at the time of the modelling this represented the latest year where complete datasets were available. The results for the 2015, 2020 and 2030 time intervals presented in this paper are therefore forecasts extending from the base year.

Fig. 3 supported by the data in Table 2 presents the result of this analysis. The first stacked columns for each year provide a breakdown of resources availability in terms of category (grown/residue/waste) of resource. The second stacked columns for each year provide a further breakdown of resource availability, allowing identification of resources with particularly high or low availability. Fig. 3 shows that the availability of residue and waste resources are largely overshadowed by Brazil's grown resources. Resources from managed forests, and plantations of eucalyptus, soya and most notably sugarcane represent abundant resources in Brazil.

Agricultural Residues consisting straws and slurry resources are forecast to contribute >7.1% of resource total by 2015, rising to >8.3% by 2030. Forestry resource availability harvested directly from managed forestry systems are forecast to contribute >13.2% of the total resource by 2015, falling to 10.5% by 2030. Resources from plantations are forecast to contribute >78.8% of the resource total by 2015, rising to 80.0% by 2030, with sugarcane representing >68% of Brazil's total resource by 2030.

5.2. Bioenergy potential of Brazilian resources

Forecasts of Brazil's primary energy and bioenergy demands are documented in Fig. 4 supported by the data in Table 3. The forecast range for Brazil's total primary energy demand shows the potential demand scenarios developed for Brazil by the IEA [30]. The Brazil bioenergy potential forecast represents the total potential levels of bioenergy that may be generated if all Brazil's available resources (Fig. 3) were converted to bioenergy. The BRM carries out a calculation to convert the available resources into power, heat or transport fuels according to their most efficient or ‘preferred pathways’ as described further in Welfle et al. [91–93], with emphasis placed on transport fuels and heat bioenergy pathways to

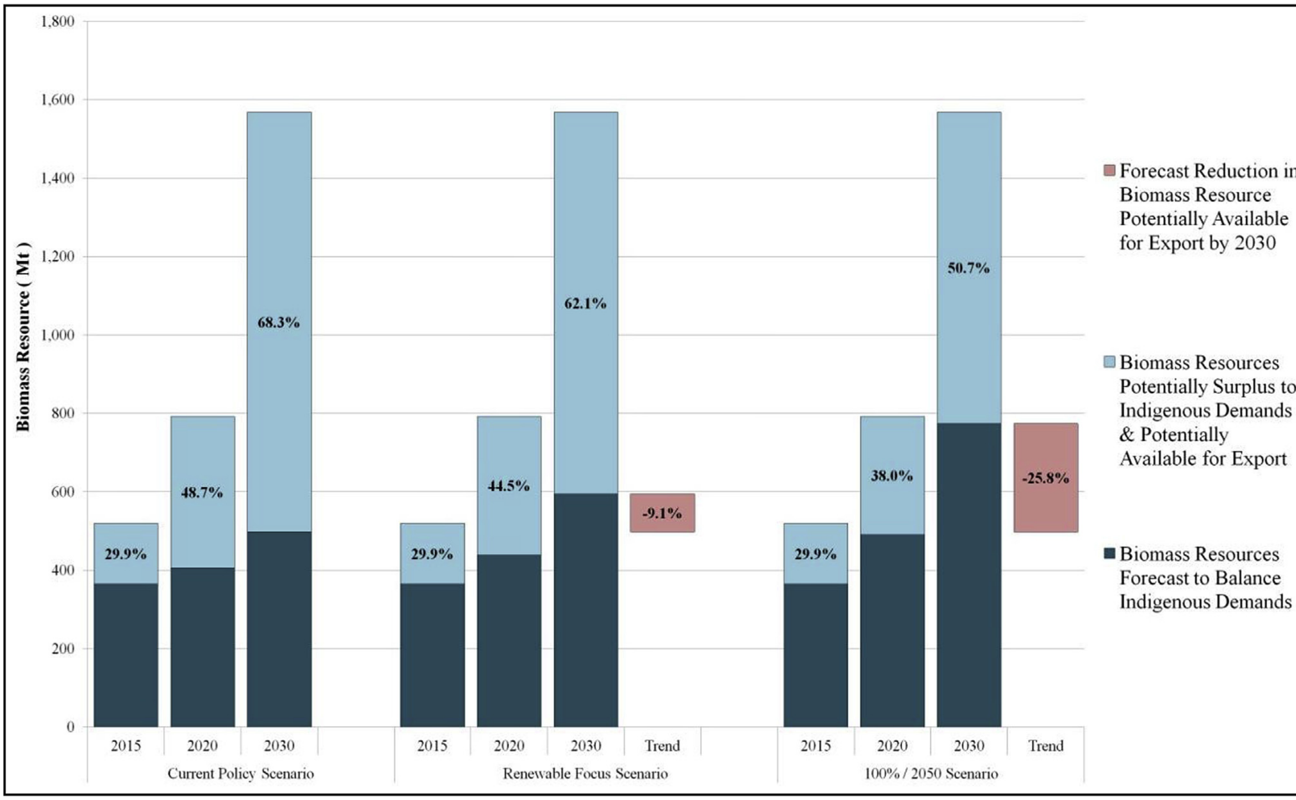

Fig. 5. Brazilian biomass resource balance analysis within future bioenergy scenarios.

Table 4
Forecast Brazilian bioenergy sector resource demands & surplus resources.

Resource balance	Current policy scenario			Renewable focus scenario			100%/2050 Scenario		
	2015	2020	2030	2015	2020	2030	2015	2020	2030
Resource Demand (Mt)	549.7	595.3	696.4	549.7	622.6	813.3	549.7	719.9	1083.8
Resource Surplus (Mt)	215.9	513.6	1360.7	215.9	488.8	1254.6	215.9	400.5	1009.3

correspondence of Brazil's future bioenergy demands [30].

Fig. 4 demonstrates that the availability of biomass resource in Brazil is sufficient to potentially allow the generation of bioenergy that could potentially exceed total Brazilian energy demand by 2030.

The CP-S bioenergy forecast highlights the levels of bioenergy that Brazil would generate if current energy policies and strategies were fully realised – representing >26.3% of Brazil's total primary energy demand by 2030. If policies with greater emphasis on renewable technologies were implemented such as those represented by the RF-S and 100/50-S scenarios, contribution from bioenergy to total demand by 2030 would increase to >35.8% and >42.5% respectively.

5.3. *Brazilian bioenergy sector resource demands & resource export potential*

The balance of Brazilian biomass resources required to meet domestic bioenergy sector demands within each of the developed bioenergy scenarios is documented by Fig. 5 and supported by the data in Table 4. The extent of available biomass resource beyond that required to meet domestic demands is highlighted as surplus resource within Fig. 5, and is assumed to be potentially available for export to the global trade markets. Fig. 5 also highlights the forecast reduction trend in surplus resource compared to baseline levels (CP-S) – demonstrating the assumed impact on potential exports as a result of utilising more resource for domestic bioenergy generation.

6. Analysis of Brazilian biomass resource scenarios

This section provides the analysis of the research results, placing them in the context of current global biomass trade trends. The potential consequences and policy ramifications of the results are also discussed.

6.1. *Availability of Brazilian biomass*

The availability of different categories of biomass resource as forecast by the BRM are shown to be significant, totally >2458 Mt by 2030. Grown resource and particularly plantation crops for energy end uses dominate this total, highlighting Brazil's focus on particularly sugarcane production and it standing as the world's second largest producer and largest exporter [23,57]. The forecast rate of increase in plantation crop production to 2030 highlights the Brazilian target to keep the rate of production in line with increasing domestic and international demand for both sugar and bioethanol. A further 'beneficiary' resource category of this rapid increase in energy crops are agricultural residues. The analysis shows the proportional contribution of agricultural residues and specifically straw resources are forecast to increase over the analysis timeframe.

Other plantation crops (excluding sugarcane) and resources direct from managed forestry systems are forecast to collectively contribute >28.1% of total resource by 2030. Agricultural residues collectively represent >8.3% of the resource total by 2030. The abundance of these resources demonstrate Brazil's strong position and the potential opportunities for generating different forms of bioenergy to meet future energy demands, with further opportunities also available for the global trade markets.

The availability and potential of other biomass resources such as wastes are shown to be largely negligible in comparison to that of the other resources. This characteristic is largely a result of the limitations of the focus and coverage of Brazilian waste management systems, although wastes may emerge as an increasing resource opportunity if greater emphasis were placed on energy recovery.

6.2. Potential contribution of bioenergy from Brazilian biomass

The standout observation of Fig. 4 is the forecast that Brazilian biomass resources could be utilised to generate sufficient bioenergy to satisfy total primary energy demand by 2030. This analysis not only reaffirms Brazil's status as being immensely 'biomass-rich', but it also suggests how modest Brazil's current bioenergy targets are – represented by the Current Policies Scenario analyses. Fig. 4 highlighting that if Brazil's current energy policies and strategies were to be realised as represented by the CP-S forecast, the contribution of bioenergy to Brazil's energy mix would remain relatively steady.

Brazil is unlikely to pursue energy policies exclusively reliant on bioenergy as the current and planned energy mix includes significant contributions from other renewable technologies, most notably hydro-power [44]. As the results from this research highlight, increased domestic use of bioenergy in Brazil does seem highly plausible, and something that Countries banking on the future use of Brazilian biomass exports should be aware of.

6.3. Brazil's future biomass resource export potential & implications for the global trade markets

The analysis documented within Fig. 5 demonstrates the potential consequences on resource exports as a result of Brazil utilising higher proportions of its available resource to balance domestic demands. The analysis highlights that within the framework of Brazil's current policies (CP-S), progressively more resource may be available to export up to 2030 – as higher levels of resource are produced/mobilised and there are modest increases in demand by the Brazilian bioenergy sector. Although the analysis also highlights that if Brazil adopted energy strategies that required increased contribution from bioenergy there would be a potential impact on the quantities of resource available for trade. The analysis finds that up to >25.8% less resource could be available for trade compared to the scenario where the current policies are maintained.

These analysis findings are highly significant as Brazil is currently the top global exporter of bioethanol and its exports of all categories of biomass resource for energy uses are forecast to increase. To add a comparator to this potential scenario, the IEA identify that a ≥7% fall in global supply of oil as a 'disruption' (crisis) [132–134].

Therefore with high demand resources such as biofuels being dominantly produced in a few key countries [34], if Brazil or any other large exporter were to reduce their exports by anywhere near >25.8%, there would likely be significant ramifications for the global biomass resource markets. These implications are most severe for the many countries around the world that will be increasingly reliant on imported resource to balance the demands of their energy and bioenergy strategies.

There is also a further implication of this research that is hidden by the choice of the Brazil as the case study for analysis. Brazil has extensive biomass resources and has the potential and plans to increase its production. The analysis highlights that Brazil has sufficient resources allowing for the potential adoption of enhanced bioenergy policies and targets whilst still having surplus resources that would likely be available for export. Repeating this analysis for other countries who are currently exporting biomass resource, albeit with less depth of resource compared to Brazil, may result in scenarios where countries shift from being net exporters of biomass to net importers if they were to adopt energy strategies reliant on bioenergy pathways.

Therefore this analysis should perhaps be flagged as potential caution for countries that are planning for increased reliance on the global biomass trade markets to balance their demands. Aside from taking on the multiple risks, limitations and impacts associated with trading all energy commodities, these countries are also highly reliant on major biomass exporting countries and regions to continue to export their resources.

7. Research conclusions - Brazil's large biomass potential & a global trade caution

The research finds that Brazil has vast biomass resources which are forecast to steadily increase over the analysis timeframe to 2030. Brazil's dominant category of biomass resources are plantation crops and feedstocks required to produce biofuels, whilst also having the potential to produce/mobilise large wood based biomass resources. Thus Brazil's is well placed to continue to be a dominant player in exporting resources for global trade in the future.

The research also concludes that Brazil's current energy strategies and targets were found to be relatively conservative and modest when placed in perspective of Brazil's renewable energy potential. The analysis finding that Brazil may have sufficient biomass resources to balance total primary energy demands, in addition to its already large hydro-power generation capacity. Therefore it was concluded that it would not be in realms of impossibility that a future Brazilian Government may decide to utilise a greater proportion its renewable resources for domestic energy demands.

The analysis found that Brazil could export up to >25.8% less biomass if it were to adopt and realise more ambitious energy strategies. This key conclusion represents a strong caution for countries developing bioenergy strategies that will require large biomass resource imports to balance their future demands.

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Appendix A. Supplementary data

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