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Integrating Microalgae into the Brazilian Programme for Biodiesel Production and Use

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Abstract

Brazil's "Programme for Production and Use of Biodiesel" is a novel programme, aimed at improving the sustainability of biodiesel by promoting social inclusion, whilst simultaneously increasing food security, diversifying feedstocks and producing a lower carbon fuel. The aims of the programme have been evaluated by conducting a qualitative analysis of the system. The existing system is then compared with the introduction of microalgae as a feedstock. This research shows that revisions to the programme are needed in order to address economic, social and environmental sustainability. Particular attention must be given to more thorough environmental criteria for land use and agricultural techniques. Family farmers need stronger support in order for biodiesel to become a sustainable product for them to grow. Microalgae could be included into a biodiesel programme, provided sufficient incentives are given, and this could improve the overall sustainability of biodiesel production and use.

Key Terms:

Social Fuel Seal – Certification granted to biofuel producers who meet a certain criteria aimed at integrating smallholder farmers into the biodiesel supply chain.

Technical fitness for purpose – functionality of a process in terms of physical capability

Social goals – Expectations of how a process will impact on people's lives

Economic viability – A process which can sustain itself financially, with or without government funding, and compete with alternative products in the same market

Environmental Impact – The effect a process and product will have on its surrounding biospheres during its lifecycle

Abbreviations

PNPB	Programme for Production and Use of Biodiesel
ANP	National Petroleum Agency
SFS	Social Fuel Seal
CFPP	Cold Filter Plugging Point
ASTM	American Society for Testing and Materials
EN	European Standards
FAME	Fatty Acid Methyl Ester
PM	Particulate Matter

1 Introduction

As the demand for road transport fuel increases, so does the desire of governments to find alternative sources of fuel. Typically, this desire is driven primarily by concerns over carbon reduction and/or energy security. The transport sector accounts for 43% of carbon emissions from energy use in Brazil and around 50% of the fleet uses diesel, so the biodiesel sector is key in the emissions reduction [1]. The Brazilian government has taken a novel approach by using biodiesel as a tool for social development as well as an opportunity for fuel security, technology development and environmental protection. Given the natural comparative advantage Brazil has in terms of land area and climate, the Brazilian government has developed a plan to exploit these resources for biofuel production, in this case biodiesel. This opportunity was incorporated into policy by President Luiz Inácio Lula da Silva through the National Programme for Biodiesel Production and Use (PNPB in Portuguese), with a subsequent range of laws and creation of governmental institutes to manage and direct development [2]. The PNPB was implemented in 2005, and has been analysed many times from a policy based perspective and also in terms of the social impact [3–11]. Brazil has a range of policies within which the biodiesel programme must sit. These rules and regulations include forestry and land tenure, social inclusion and labour, foreign direct investment and direction of technology development. The Brazilian Agroenergy Plan (2006-2011) focused on ensuring a long term energy supply, cheaper process for energy, local energy competitiveness and climate change and environmental commitments [12]. It included development of agricultural and industrial technology in order to improve Brazils' position globally as a competitor in the biofuel market [13]. Figure 1 show the design of the PNPB, from how it is driven, to obstacles it faces and the expected outcomes.

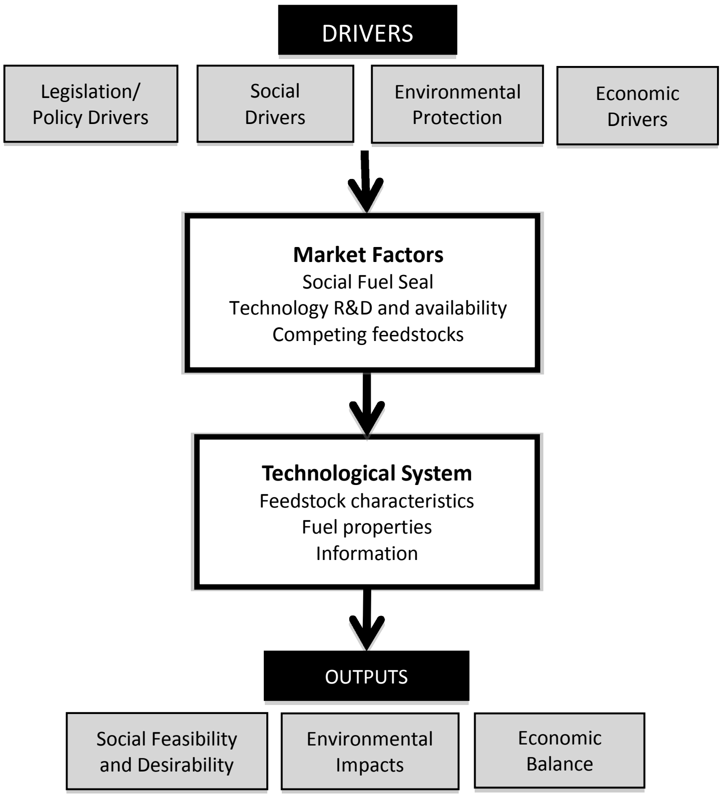

Figure 1 Brazilian biodiesel programme design

There were two federal laws introduced to support the programme, described in detail by [4], [6], [10]. These laws introduced a 2% mandatory blend of biodiesel from 2008 (No. 11.097-05) and established a tax structure for the programme (No. 11.116-05). The price of biodiesel is kept competitive through biodiesel auctions, administered by the ANP [5], [8], [14]. This combination of policies has led to the Brazilian government being able to control biodiesel production without expenditure of public funds. The government has set up other policies and ministries to stimulate the production and use of biodiesel, the main tool being the Social Fuel Seal (SFS). The SFS is part of Law 11.097/05. It is a set of incentives granted by the Ministry of Agrarian Development to industrial biodiesel producers to purchase raw materials from family farmers (Act 11326, 24/7/2006). The aim of the SFS is to promote social inclusion through job creation and technical assistance to family farmers, by providing federal tax relief [15].

Tax reduction	Any feedstock, any region	Castor or palm feedstock North/North-east region
With Social Fuel Seal	80%	100%
Without Social Fuel Seal	67%	77.5%

Table 1 Examples of tax breaks under the Social Fuel Seal Scheme

There are advantages to using biodiesel in a standard engine, particularly in Brazil where there is low turnover of vehicles, the average age of a truck being 18 years [16]. Biodiesel has a high flash point, a good lubricity, a high cetane number and potentially lower toxicity than mineral fuels which can reduce engine wear [17]. But there are issues too, depending on the type of oil feedstock, such as viscosity, cold filter plugging point (CFPP) and oxidative stability [18]. Soybean is the most common feedstock for biodiesel in Brazil. It is more stable than castor oil, a feedstock promoted by the PNPB for family farmers to grow. However, castor oil has good properties for operation in cold climates because of its low CFPP, due to the majority of the oil being monounsaturated. This would be important if Brazil was to decide in future to focus on fuel export rather than their internal market production [19], [20]. It also has a high cetane number for this reason. However, there are problems with the kinematic viscosity and cetane number being too high for it to be used without blending. Palm oil, a growing feedstock in Brazil, has over 85% saturated and monounsaturated fatty acids, making it a stable fuel. However, a high CFPP makes it unsuitable without additives or blending. Based on these features, a biodiesel blend from these feedstocks appears a good technical choice for end application in Brazil's warm climate.

Whilst producing biodiesel from different feedstocks is an important aspect of environmental protection, fuel security and social involvement, this does result in technical issues with quality control. Whilst biodiesel can be incorporated into any blend with mineral diesel (i.e. up to 100%) each type of oil has different physiochemical characteristics, leading to different quality biodiesels being produced. While some types of biodiesel (e.g. soya and palm) have national and international quality standards already available, such as ASTM D-6751 in the US or EN14213 in the EU, biodiesel from other feedstocks such as castor oil still require the development of standard test methods for quality assurance and control [21], [22]. The Brazilian National Petroleum Agency is responsible for setting quality standards (i.e. Resolution ANP 42/2004), but in their case they focus on performance based parameters in the specification, classifying properties relating to the "quality of the process" instead of "nature of raw materials" as is measured in the EU and US. The aim of that approach is to comply with end market use requirements, mainly as a blend component and so as not to limit the diversity of biodiesel sources (Goosen et al., 2007). This works to complement the PNPB which aims to increase diversification of feedstocks in order to promote regional development and fuel security.

2 Aims and Methods

A systematic analysis was performed in order to characterise the PNPB as an integrated technological, social, political and economic system, with the intent of identifying in which respects the PNPB is "fit for purpose" and to evaluate how plausible modifications to the PNBP are. The purpose of this paper is to develop a way to identify existing positive and negative impacts of the system, and use them to explore the potential impact of introducing a new feedstock into the biodiesel supply chain. The authors have assessed the literature and information obtained from interviews to make an informed judgement of the system, based on the criteria set out as follows. We look at both the technological robustness of the system, the social fuel programme, the political and economic landscape and the environmental impacts. We then assess the extent to which the PNPB has addressed each of them with regards to the goals set in the policy. This study is qualitative and is intended to provide a sense of the various impacts of the programme, both in its present form and where a new feedstock, i.e. microalgae is introduced. The outcome provides an indication of fitness for purpose of different design features within the Brazilian biodiesel programme. The aim is to represent where the programme has had positive impacts, identify where production processes can be improved in order to make it cleaner and create an opportunity to compare the existing programme with a new microalgae feedstock scenario.

3 Assessment of the Current Process

The study presented in this section depicts the compromise that is made between the social and environmental impact and the technical and economic viability. Each design feature has been in terms of the PNPB's design having a positive impact, negative impact, split/uncertain impact or there being insufficient information to permit analysis. The measurement of overall "success" as perceived by participants in the PNBP, is subjective depending on where a participant is in the system. A summary of the results of this analysis are given in Table 3, and have been rated according to the key in Table 2.

Table 2 Key to assessment study

Positive Impact	Negative Impact	Split/Uncertain Impact	Insufficient Data

Table 3 Assessment of impacts from the current process

Criteria for "Success"	Design features				
	Biodiesel Feedstock	**Agricultural Producers (Family farms)**	**Production Processes**	**Distribution**	**End Use**
Technical fitness for purpose	Able to produce biodiesel from feedstock oil	Capacity and yield low	Technically mature method for biodiesel production.	Logistical issues	Fuel properties meet standards for diesel fuel
Compatible with social goals	Cultivation of fuel crops does not compromise cultivation of food crops.	Income increasing to family farmers. Lack of cooperation and resources to provide for all participants.	Some job creation Restrictions on participation for small businesses	Data required on distributors and their participation with family farmers	Positive health impacts locally and globally from lower CO_2 and PM emissions
Economic viability	Only with financial incentive	Only with financial incentive	Technique depends on feedstock. Capacity exceeds supply.	Can use existing infrastructure	Subsidises distort cost comparison but remain competitive
Environmental Impact	Multi-cropping allows biodiversity and resilience	Fewer agrochemicals, lower carbon intensity	Chemical use Energy input Water consumption	Emissions associated with distribution by road	Lower CO_2 and particulates. Higher NO_x

The programme is making progress towards social inclusion and reducing negative environmental impacts, but this analysis reveals agricultural producers can not comply with the technical demand of biodiesel feedstock needed and the programme is only economically viable with financial incentives that are provided through the legislation described above. The literature explains that social goals are being met to some extent, but the impact varies from region to region [5], [12], [15], [23–25]. Some areas studied saw incomes rise and provision of access to education, plus multiplier effects into local communities where incomes have also risen (see case study in Box 1). However, problems with the existing PNPB system include insufficient resources in terms of technical assistance and a lack of government intervention where this is the case, and restriction of access to parts of the supply chain where value is added to the crop.

Box 1 - Case Study of the Petrobras Biodiesel Facility in Quixada

The town of Quixadá in the north-east state of Ceará saw a Petrobras owned biodiesel plant open in 2008. The plant has a capacity of 96,000t/yr and uses predominantly soya feedstock, with palm and cotton oil in addition. 37% of the fuel purchased by Petrobras qualified for social fuel label status in 2010.
As a result of the project, local residents have seen a rise in income for both farmers and those in the wider local economy. In 2010 63,034 families and 15 co-operatives were under contract with Petrobras covering an area of 165,430 hectares. Acquisition from the family farms reached R$78million (US$38million) in 2010. 650 technicians were employed to provide technical assistance to farms, with an investment of R$24.2million (US$12million) from Petrobras. Employment was generated during construction for 1,200 people directly and a further 400 indirectly. Currently there are 104 people employed as operational staff although these roles generally require specialist knowledge that does not exist at present in the local labour force.
Petrobras is also involved with education schemes that see farmers visiting local education centres to talk to students about their experience and encourage young people to become involved in agriculture. This is, in part, an attempt to stem the flow of young people to cities such as Fortaleza in Ceará.

The farmers providing biodiesel feedstocks were formerly engaged in subsistence farming and the importance remains of not impairing their ability to continue to grow food for their own use. Farmers frequently have more land than they have the manpower and tools to farm for food crops and so energy crops can be grown on land not used hitherto for food production. This is applicable for small farmers, as per the rules of the programme, where to be eligible for the programme the land cannot exceed 100ha but with no limit on productivity within this area. The current scale of the PNPB programme does not lead to competition of land between production of biodiesel crops and production of food, although this could be an issue if scaled-up production causes a shortage of cultivatable land. Also, certain plants can be grown together such as tall plants for biodiesel production (e.g. sunflowers or castor) combined with low growing food plants (e.g. beans). This may have further benefits such as reduction of soil erosion which is particularly relevant to castor bean cultivation where soil loss can be high [26]. However some crops do not allow this technique, such as palm which casts too much shade after reaching maturity [27]. Therefore, Table 3 shows the compatibility of growing a biodiesel feedstock with the social goals as having a positive impact (at least at present).

The greatest environmental benefits are realised by the small farmers because they use low levels of agrichemicals and intercropping (admittedly at the expensive of higher yields). There are also benefits from diversifying crops as opposed to mono-culture in terms of biodiversity, maintaining soil quality and increasing resilience to crop failure, hence the positive rating given to environmental impacts in Table 3.

Once the feedstock reaches the production process, use of chemicals and production of GHG emissions increases threatening cleaner production of biofuels. However, the use phase sees positive environmental impacts through the reduction of GHGs. Land use change is an important component regarding the environmental impact of biodiesel feedstock production. The type of land use change will affect the overall carbon balance of biodiesel production, as well as other emissions (e.g. N_2O) and biodiversity changes. However, the inclusion of land use change is beyond the scope of this project at this point, except to point out that increasing the volume of feedstock produced will certainly have an impact on the area of land under cultivation. A key problem with the system is the distribution of materials. Due to a poor road infrastructure and an ageing fleet (i.e., average 18 years per vehicle) the emissions associated with transporting of feedstock and the end product remains high. In the study, the capacity to supply feedstock and the distribution are linked and improvements in the distribution network would lead to a higher number of participants in the family farming scheme.

4 Microalgae as a biodiesel feedstock and as part of the PNPB

Developing microalgae as an alternative, more sustainable feedstock presents many opportunities. With high biomass production rate and low water demand, in a country with suitable climate, water availability and large land area, microalgae could contribute to Brazil's future road fuel needs, with much lower environmental impact than scaling up the existing processes. Whilst there is no commercial scale production of microalgae biodiesel at time of writing, the potential oil yield is confirmed as being much higher than terrestrial crops by a number of sources. Microalgae can produce over 1000 times more oil per year than soybean for example [28], [29] due to the fact it has a fast growth rate and can be harvested many times throughout the year. Following cell rupture, the lipid fraction is extracted using solvent extraction. In a similar fashion to vegetable oil derived biodiesel, the microalgal oil can be trans-esterified to fatty acid methyl esters (FAME), the primary constituents of biodiesel, using methanol and either an acidic or alkaline catalyst [30].

Table 4: Microalgae as a feedstock for biodiesel as part of the PNPB

Criteria for "Success"	Design features				
	Biodiesel Feedstock	**Agricultural Producers (family farms)**	**Production Processes**	**Distribution**	**End Use**
Technical fitness for purpose	Promising, although still problems to overcome.	Can be grown at any scale.	Extraction technology needs developing. Can potentially use existing infrastructure in places.	Use existing infrastructure.	Research to be done on combustion characteristics and comparison with international standards.
Compatible with social goals	Growth in wastewater provides water treatment.	Infrastructure and knowledge needs make small scale cultivation unlikely. Jobs will be created elsewhere.	May be more jobs created in harvesting and drying.	Data required on distributors and their participation with family farmers	Reduces emission during combustion. Cleaner water has health benefits Lower land demand eases land disputes
Economic viability	Depends on cultivation method and nutrient/water sources.	High costs for small scale cultivation.	Requires investment in infrastructure. Use existing facilities for transesterification.	Use existing infrastructure.	Current estimate are higher than diesel, but potential for costs to be reduced dramatically.
Environmental Impact	Water treatment. CO_2 sequestration.	Reduce loss of vegetation/ biodiversity due to lower land area demand.	High energy input into harvesting. Alternative methods in research phase.	Logistical issues leading to high levels of emissions during distribution	Uncertain of emission composition at this point.

If microalgae are to be considered as eligible for the social fuel seal it needs to be cultivated by family farmers. While it is possible to cultivate algae at any scale, growing microalgae at small scale for a large scale production process will be a technical challenge, and could be subject to the same or worse economies of scale that apply to small farms of terrestrial crops. The biggest challenge is the set up costs and infrastructure. Therefore it would be necessary to create an incentive, potentially in the form of an addition to the social fuel seal which allows tax breaks for algae cultivated at larger scale sites.

The feedstock cultivation can still meet a social development goal - although not necessarily the one the PNPB had in mind as it is unlikely microalgae could feasibly be grown by smallholder farmers. This is due to technical capability and resources including capital, construction and maintenance including fertilisers. The social development goal would be in using microalgae as a wastewater treatment technique. If algae are cultivated in wastewater the microalgae can absorb nutrients from the water leading to a cleaner water product and a free source of nutrients for the microalgae. This will lead to health benefits from cleaner water and also environmental benefits, as this method will reduce impact of water discharge into open waterways by reducing nutrient content, therefore reducing toxic/uncontrolled algal blooms. Microalgae also lowers costs and greenhouse gas emissions associated with manmade fertilisers, making the overall production process cleaner [31–34]. If ponds are constructed on marginal lands, this could reduce the pressure for land and thus be beneficial in easing land conflicts in sensitive regions. Job creation would occur at the algae farms through jobs in cultivation, harvesting, and drying plus further work in engineering, consultancy or contingency for example. However, the algae would not be grown together with other crops, and therefore it would take labour resources away from the land which may be detrimental to subsidence farming practices. There will be health risks associated with cultivating algae in waste water, as there will be pathogens present, which is why this item is given a split impact.

The environmental impacts of microalgae biodiesel could be far reaching. Initially, the demand for land use will be reduced; therefore more natural habitat could be retained. Microalgae also sequesters CO_2 at a higher rate than terrestrial crops reducing GHG CO_2 emissions further [35], [36]. However, there may be N_2O production during the growth phase which would severely reduce the benefits gained in CO_2 reduction in terms of total greenhouse gases [37], [38]. Another alternative is to grow microalgae heterotrophically, i.e. without light. Heterotrophic cultivation of microalgae could utilise waste streams such as sugar cane waste or waste glycerol from the biodiesel process as a carbon source [39–41]. This is still difficult on a small scale, but this process would remove the need for large amounts of land availability and has the potential to significantly increase lipid yields [42].

The production step still requires chemical use but there is scope for cleaner production and integration with existing industry. The energy use for harvest and drying is also high at the moment, compromising the overall energy balance of the energy contained in the final product compared with the energy put in to produce the final product [34], [43], [44]. Distribution of the product can use existing infrastructure which means exhaust emissions will remain high. However, if co-location of wastewater treatment, microalgae cultivation and refineries was included into the planning phase of a microalgae biodiesel project, this has the potential to reduce transportation and provide jobs locally. The fuel quality and emission from microalgae need to meet or improve upon other biodiesel feedstock, So far, research has shown this is possible [45]. The technological challenge of producing microalgae biodiesel still exists as the characteristics of microalgae oil differ to that of terrestrial crops and varies by strain, and much research is still needed into the combustion characteristics to ensure investment is really leading to a sustainable.

The economic feasibility of microalgae as a feedstock is a major hurdle. Using data from algae farms in the USA, estimates have shown algae biomass is the most expensive component of the biodiesel production process. However, there are optimistic projections for microalgae production of as low as \$1.44/litre [46]. This could reduce further if lower costs for CO_2 input were found and nutrients could be recycled instead of buying virgin fertilisers. This is a promising finding, and particularly if algae can be processed in the existing facilities.

5 Combining the changes

The PNPB has provided a unique opportunity for family farmers to access the biodiesel feedstock market. However, more needs to be done to make sure this contribution can continue and grow, and allowances be made for these producers to access more of the production value chain. The contributions of different feedstocks contribute both to a more environmentally sustainable fuel and a technically superior fuel, making it fit for its purpose. However, it is unlikely the volume of existing feedstocks can be expanded without causing detrimental effects on the environment or on local communities who may either be displaced themselves or see their food crops displaced by crops for fuel.

Whilst increasing the level of government intervention seems like an ideal solution to increase social inclusion, financially it is not a real world option. There are refinery managers who show the cost of providing technical assistance to farmers exceeds the tax rebates gained under the current system [11]. The cost of including either higher levels of terrestrial biodiesel or microalgae in the program are a key part of whether the program can continue to be successful as an increase in costs will have an impact on both the biodiesel producer and the customers. The majority of freight transporters are diesel vehicles, therefore a rise in the cost of fuel will lead to inflation of food and other consumable goods.

Mandating an increase in biodiesel volume through the PNPB would not help small farmers who do not currently have the capacity to produce more. The increase would also place more strain on the environment in terms of land use, land quality and biodiversity as the production would lead to further large scale cultivation, the associated problems are discussed above.

The optimal solution is a combination of increased efficiency of resource distribution and use, and expanding the fuel matrix to include other feedstocks, such as microalgae, either as a blended product with soya or as an alternative given that it is technologically feasible. These analyses shows microalgae could be a suitable supplement to the biodiesel industry, being fit for use technically, and delivering social and environmental benefits. Inclusion could also meet a political agenda for development of sanitation, and expansion of biodiesel production without compromising land use. As a result, the Brazilian government will have allowed development of a biodiesel blend which is more sustainable, maximises clean production of biodiesel fuel and is economically sound and environmentally friendly.

Future Perspectives

The biodiesel industry will continue to grow as long as there is a political drive for expansion. Brazil is looking to export biodiesel, mainly to Europe as well as potentially increase the mix internally. This puts pressure on feedstock production and will demand alternatives or else run the risk of environmentally destructive practices. Now is an exciting time for microalgae as a feedstock as it is seeing increased interest from investors and developers. A number of plants have been scaled up to industrial scale production and the authors expect this will continue. However, the success of microalgae as a feedstock still depends on new technologies being developed and the right political intervention may be key to determining its success.

Executive Summary

Aims and Methods

- The Programme for Biodiesel Production and Use (PNPB) in Brazil has a range of technological, political, economic, social and environmental aims.
- This analysis examines the relative success of the existing system since it's' establishment in 2005.

Assessment of current situation

- The PNPB does not achieve success when rated against a set of designed features identified in the biodiesel production process; therefore microalgae are proposed as an alternative feedstock.
- Restructuring of the current PNPB is required to improve it sustainability; environmentally, economically and socially.

Additional feedstocks

- Additional feedstocks are required that do not compromise sustainability, in a way that extending terrestrial agriculture appears to. Microalgae could provide a high yielding feedstock with low environmental impacts.

Combining the changes

- Whilst microalgae would not be suitable for cultivation by small scale farmers, thus excluding it from the PNPB under current rules, it could be used as an additional feedstock within the biodiesel fuel matrix, being both technologically viable and providing social and environmental benefits.

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References

[1] C. F. Alvim, "Transport Sector in Brazil," in *New Energy Indicators for Transport: The Way Forward*, 2008.

[2] A. Harvey, M. and McMeekin, "Political Shaping of Transitions to Biofuels in Europe, Brazil and the USA," University of Essex: Colchester, 2010-02, 2010.

[3] Abramovay R. and Magalhães R., "Access of family farmers to biodiesel markets : Partnerships between large companies and social movements," University of Sao Paulo: Sao Paulo, 2007.

[4] A. D. Padula, M. S. Santos, L. Ferreira, and D. Borenstein, "The emergence of the biodiesel industry in Brazil: Current figures and future prospects," *Energy Policy*, vol. 44, pp. 395–405, May 2012.

**[5] D. S. Vianna, C. Aliana, and G. Garcez, "Brazilian Biodiesel Policy : Social and environmental considerations of sustainability," *Energy Policy*, vol. 34, no. 2009, pp. 645–654, 2011.

**Describes the PNPB in its initial stages with a detailed description of the programme.

[6] J. Hall, S. Matos, and L. Severino, "Brazilian biofuels and social exclusion : established and concentrated ethanol versus emerging and dispersed biodiesel," *Journal of Cleaner Production*, vol. 17, pp. S77–S85, 2009.

[7] E. Laabs and F. Gröteke, "The Brazilian biodiesel-program – a socially acceptable approach in biofuel production?," in *7th Pan-European IR Conference*, 2010, pp. 1–25.

*[8] E. F. De Almeida, J. V. Bomtempo, and C. M. De Souza E Silva, "The Performance of Brazilian Biofuels : An Economic, Environmental and Social Analysis," Joint Transport Research Centre: Rio de Janeiro, 2007-5, 2007.

*Investigates several factors influenced by biofuel production in Brazil

[9] M. Lima, M. Skutsch, and G. D. M. Costa, "Deforestation and the Social Impacts of Soy for Biodiesel: Perspectives of Farmers in the South Brazilian Amazon," *Ecology and Society*, vol. 16, no. 4, 2011.

[10] S. B. Schaffel and E. L. La Rovere, "The quest for eco-social efficiency in biofuels production in Brazil," *Journal of Cleaner Production*, vol. 18, no. 16–17, pp. 1663–1670, Nov. 2010.

[11] S. Matos and B. S. Silvestre, “Managing stakeholder relations when developing sustainable business models: the case of the Brazilian energy sector,” *Journal of Cleaner Production*, pp. 1–13, May 2012.

[12] R. Marson, T. De Andrade, and A. Miccolis, “Policies, institutional and legal framework in the expansion of Brazilian biofuels,” *Working paper 71*, vol. CIFOR, pp. 1–36, 2011.

[13] E. Sundfeld, “Bioenergy Technology Development in Brazil,” 2009.

[14] S. Munir Y., M. O. Pavan, C. Barufi, C. Bermann, and V. Parente, “The Brazilian Biodiesel Program,” in *Amsterdam Conference on the Human Dimensions of Global Environmental Change*, 2007.

[15] J. Van Den Berg and L. Rademakers, “An in-depth look at Brazil’s ‘Social Fuel Seal’,” *Biopact*, 2007. [Online]. Available: http://news.mongabay.com/bioenergy/2007/03/in-depth-look-at-brazils-social-fuel.html. [Accessed: 18-Apr-2012].

[16] America Latina Logistica, “Railroad and Trucking Industries,” 2012. [Online]. Available: http://ir.all-logistica.com/all/web/conteudo_en.asp?idioma=1&tipo=323&conta=44#2. [Accessed: 30-Aug-2012].

[17] J. A. Kinast, “Production of Biodiesels from Multiple Feedstocks and Properties of Biodiesels and Biodiesel,” NREL: Illinois, 2003.

[18] X. Lang, a K. Dalai, N. N. Bakhshi, M. J. Reaney, and P. B. Hertz, “Preparation and characterization of bio-diesels from various bio-oils.,” *Bioresource technology*, vol. 80, no. 1, pp. 53–62, Oct. 2001.

[19] A. Okullo, A. K. Temu, P. Ogwok, and J. W. Ntalikwa, “Physico-Chemical Properties of Biodiesel from Jatropha and Castor Oils,” *Renewable Energy Research*, vol. 2, no. 1, 2012.

[20] D. S. Ogunniyi, “Castor oil: a vital industrial raw material.,” *Bioresource technology*, vol. 97, no. 9, pp. 1086–91, Jun. 2006.

[21] P. T. De Sousa, E. L. Dall’Oglio, M. Sato, J. M. Marta, R. A. B. De Azevedo, and C. Spindola, “The Ethanol and Biodiesel Programmes in Brazil,” in *Making Choices About Hydrogen: Transport Issues for Developing Countries*, L. M. Krieger and G. Boyle, Eds. USA: United Nations University Press, 2008, pp. 118 – 140.

[22] I. Barabás and I. Todoruț, “Biodiesel Quality, Standards and Properties,” in *Biodiesel- Quality, Emissions and By-Products*, G. Montero and M. Stoytcheva, Eds. Online: CC BY, 2011.

[23] E. Talamini and H. Dewes, “The macro-environment for liquid Biofuels in Brazilian science and public policies,” *Science and Public Policy*, vol. 39, no. January, pp. 13–29, 2012.

[24] C. Magalhães Drouvot, H. Drouvot, and P. M. Perluss, “A coherent agri-energy policy to foster social inclusion for peasant families : the role of Petrobras on the João Câmara and Ceará-Mirim sites (state of Rio Grande do Norte),” in *Family farming under pressure. Reassessing options for liveability and permanence*, 2010, no. July, pp. 1025–1035.

[25] A. S. Ceasar and M. O. Batalha, “Biodiesel production from castor oil in Brazil : A difficult reality,” *Energy Policy*, vol. 38, pp. 4031–4039, 2010.

[26] V. Comar, D. Tilley, E. Felix, M. Turdera, and Matias Chagas Neto, “Comparative emergy evaluation of castorbean (ricinus,” in *IV Biennial International Workshop “Advances in Energy Studies”*, 2004, pp. 227–237.

*[27] S. Kilham, C. Camargo, and J. Willetts, “Biodiesel: Farmer’s Perspectives,” Sydney, 2010.

* Describes how biofuels can be selected to ensure environmental sustainability

[28] Y. Chisti, “Biodiesel from microalgae.,” *Biotechnology advances*, vol. 25, no. 3, pp. 294–306, 2007.

[29] M. J. Groom, E. M. Gray, and P. a Townsend, “Biofuels and biodiversity: principles for creating better policies for biofuel production.,” *Conservation biology : the journal of the Society for Conservation Biology*, vol. 22, no. 3, pp. 602–9, Jun. 2008.

[30] T. M. Mata, A. a. Martins, and N. S. Caetano, “Microalgae for biodiesel production and other applications: A review,” *Renewable and Sustainable Energy Reviews*, vol. 14, no. 1, pp. 217–232, Jan. 2010.

[31] L. F. Wu, P. C. Chen, A. P. Huang, and C. M. Lee, “The feasibility of biodiesel production by microalgae using industrial wastewater.,” *Bioresource technology*, pp. 1–5, Jan. 2012.

[32] L. Christenson and R. Sims, “Production and harvesting of microalgae for wastewater treatment, biofuels, and bioproducts.,” *Biotechnology advances*, vol. 29, no. 6, pp. 686–702, 2011.

[33] Y. Li, W. Zhou, B. Hu, M. Min, P. Chen, and R. R. Ruan, “Integration of algae cultivation as biodiesel production feedstock with municipal wastewater treatment: strains screening and significance evaluation of environmental factors.,” *Bioresource technology*, vol. 102, no. 23, pp. 10861–7, Dec. 2011.

[34] L. Lardon, A. Hélias, B. Sialve, J.-P. Steyer, and O. Bernard, “Life-Cycle Assessment of Biodiesel Production from Microalgae,” *Environmental Science & Technology*, vol. 43, no. 17, pp. 6475–6481, 2009.

[35] K. Sudhakar, S. Suresh, and M. Premalatha, “An Overview Of CO2 Mitigation Using Algae Cultivation Technology,” *International Journal of Chemical Research*, vol. 3, no. 3, pp. 110–117, 2011.

*[36] M. Koller, A. Salerno, P. Tuffner, M. Koinigg, H. Böchzelt, S. Schober, S. Pieber, H. Schnitzer, M. Mittelbach, and G. Braunegg, “Characteristics and potential of micro algal cultivation strategies: a review,” *Journal of Cleaner Production*, vol. 37, pp. 377–388, Dec. 2012.

*Summary of options for microalgae cultivation and use

[37] E. D. Frank, J. Han, I. Palou-Rivera, A. . Elgowainy, and M. Q. Wang, “Methane and nitrous oxide emissions affect the life-cycle analysis of algal biofuels,” *Environmental Research Letters*, vol. 7, no. 1, p. 014030, Mar. 2012.

[38] K. D. Fagerstone, J. C. Quinn, T. H. Bradley, S. K. De Long, and A. J. Marchese, “Quantitative measurement of direct nitrous oxide emissions from microalgae cultivation.,” *Environmental science & technology*, vol. 45, no. 21, pp. 9449–56, Nov. 2011.

[39] M. C. Cerón-García, M. D. Macías-Sánchez, A. Sánchez-Mirón, F. García-Camacho, and E. Molina-Grima, “A process for biodiesel production involving the heterotrophic fermentation of Chlorella protothecoides with glycerol as the carbon source,” *Applied Energy*, vol. 103, pp. 341–349, Mar. 2013.

[40] Y. H. Chen and T. H. Walker, “Biomass and lipid production of heterotrophic microalgae Chlorella protothecoides by using biodiesel-derived crude glycerol,” *Biotechnology Letters*, vol. 33, no. 10, pp. 1973–83, 2011.

[41] D. Mitra, J. (Hans) van Leeuwen, and B. Lamsal, “Heterotrophic/mixotrophic cultivation of oleaginous Chlorella vulgaris on industrial co-products,” *Algal Research*, vol. 1, no. 1, pp. 40–48, May 2012.

[42] Y. Liang, “Producing liquid transportation fuels from heterotrophic microalgae,” *Applied Energy*, vol. 104, pp. 860–868, Apr. 2013.

[43] E. D. Frank, J. Han, I. Palou-Rivera, A. . Elgowainy, and M. Q. Wang, “Life-Cycle Analysis of Algal Lipid Fuels with the GREET Model,” Energy System Division, 2011.

**[44] T. J. Lundquist, I. C. Woertz, N. W. T. Quinn, and J. R. Benemann, “A Realistic Technology and Engineering Assessment of Algae Biofuel Production,” Berkeley, 2010.

**Detailed study of energy flows involved in biofuel production from microalgae.

[45] H. Xu, X. Miao, and Q. Wu, “High quality biodiesel production from a microalga Chlorella protothecoides by heterotrophic growth in fermenters.,” *Journal of biotechnology*, vol. 126, no. 4, pp. 499–507, Dec. 2006.

[46] Y. Gao, C. Gregor, Y. Liang, D. Tang, and C. Tweed, “Algae biodiesel - a feasibility report.,” *Chemistry Central journal*, vol. 6 Suppl 1, no. S1, pp. 1–16, Jan. 2012.