Biofuel Development in the Lao PDR:
Baseline Assessment and Policy Evaluation

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Since 2006, the government of the Lao PDR has strongly promoted biofuel development, on the basis of national energy security concerns, and interests for rural development. As a result, many farmers were encouraged to cultivate jatropha as a biofuel feedstock through government campaigns and private sector investment. For most, the return on their investment has been woefully low; a domestic biofuel sector has failed to materialise, largely due to (i) negligible feedstock supply and poor yields, (ii) inadequate market development, and (iii) a lack of investment in biofuel processing capacity. Despite these limitations, the Lao government has set an ambitious target of offsetting 10% of petroleum fuel consumption with biofuel by the year 2020. In order to address the likelihood and requirements of reaching such a goal, this paper presents a baseline assessment of the embryonic biofuel sector in the Lao PDR, and formulates a comparison between national expectations and targets with the current scale of investment by public and private sectors. A simple analysis of market chains for domestic biofuel production and consumption in the Lao PDR is established as a basis to evaluate the merits of biofuel for the Lao PDR, in the context of national development goals.

Keywords *- biofuel, Jatropha, Lao PDR, market chain, policy.*

1. INTRODUCTION

At 0.32 tons of oil equivalent (toe) per capita in 2006, energy demand in the Lao PDR was amongst the lowest in the world [1]. Burning of woody biomass, mostly for domestic heating and cooking, dominated consumption and accounted for 69% of energy use in rural areas. Petroleum fuel followed, all of which was imported from neighbouring countries.

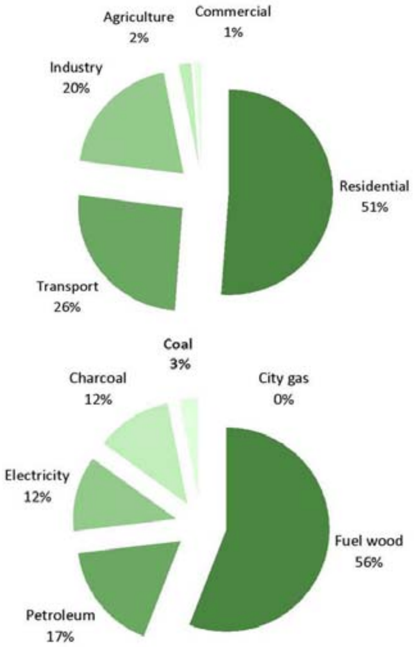

Fig. 1: Energy consumption by sector (left) and by resources (right) [1]

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Nationwide energy consumption is presented by sector and energy source in Figure 1. The urban and rural energy contexts strongly differ, partly as a consequence of limited electrification (50% of the population was connected to the national electricity grid in 2008): urban consumption of diesel is largely for transportation, whereas rural populations also rely on the fuel for lighting, electricity generation, and productive uses (rice mills, pumps, etc). The rural poor are most dependent upon diesel for lighting, for whom it also tends to be more expensive.

Of the energy sources listed in Figure 1, petroleum is unique since it is wholly imported. Concerned by the implicit vulnerability to external market fluctuations, and compounded by growth in demand for petroleum fuels, in 2006 the Government of the Lao PDR (GoL) began promoting biofuel development with the hope of substituting demand with a local resource. At that time, domestic experience of biofuel production was negligible, although several possible feedstock crops had been extensively cultivated for other purposes, most notably Jatropha Curcas, which has been used as living fences throughout Laos for generations.

The attraction to foreign investment of biofuel was strong, as global interest in feedstock production was similarly high due to rising fossil fuel prices. This resulted in substantial government and privately-lead promotion of biofuel cultivation to small-holder farmers, albeit with neither a regulatory framework, nor safeguards to ensure development towards the goals of the GoL. Following unprecedented rises in the global market price of crude oil in 2008, the GoL established an ad-hoc committee to facilitate the development and formulation of a national strategy and policy on biofuels. Such a policy would be required to complement the national growth and poverty eradication strategy (NGPES), and support economic growth, socio-cultural development and environmental preservation.

The principle aims and corresponding structure of this paper are as follows:

- To present the status of the Lao biofuel sector, as observed in late 2009, and make a statement with regard to current trends and the level of correspondence with a government target to achieve 10% substitution of petroleum fuel with biofuels by 2020 (Chapter 3);
- To review potential biofuel market chains that could contribute to substantial domestic biofuel production within 10 years (Chapter 4);
- To discuss the opportunities and potential impact of these chains upon the Lao PDR, and merits of future biofuel promotion in the country (Chapter 5);

The remainder of this chapter comprises a brief overview of the local context, in terms of the most relevant socio-economic indicators, land resources, and fossil fuel statistics in the Lao PDR. The methodology employed, including a review of data sources and the simple analytical approach taken to present the data, is presented in Chapter 2.

1.1. Socio-Economic Indicators

The population of the Lao PDR was approximately 6.2 million in 2007, and is predicted to grow by 2.1% per year to reach 7.3 million by 2020 growth rate 2.1% [2]. Approximately 50% of the population is below the age of 20, with 80% living in rural areas. Being one of the Least Developed Countries (LDC), the gross domestic product (GDP) per capita for The Lao PDR was US$491 in 2005, but growing at a rate of 7%. In 2008 the GDP was estimated to be US$577, somewhat less than the GoL target of US$827 to be reached by 2010 [3]. Food security is a significant concern in the Lao PDR: about 37% of children under 5 years of age are underweight [4].

Agriculture accounts for 78.5% of the labour force, and contributes to 50% of the country's GDP. Moreover, the Ministry of Agriculture and Forestry (MAF) estimated that 60% of farms practised subsistence agriculture in 2005. In order to achieve partial fulfilment of milleunium development goals (MDG), the GoL is working towards the target of full and productive employment by 2020. This will require the creation of 1.5 to 1.6 million jobs over the next 10 years**.** The nation's trade balance remains negative for two reasons: the economic development gap between the partnering countries of the ASEAN Free Trade Agreement (AFTA), and low market access caused by geographic hurdles and poor infrastructure which raises transportation costs and limits the competitiveness of Lao goods [2].

1.2. Land Resources

The Lao PDR is a landlocked country with a total area of 236,800 km^2. The country's mountainous terrain precludes expansive permanent agriculture, with 70% of the land area having a slope of more than 20 degrees. The area suitable for intensive agriculture, made up of permanent pasture, arable lands and permanent crops, is approximately 1.26 million hectares, or 8% of the total land area.

The Lao PDR is rich in forest resources, 43% of the land area is under permanent forest. Non-forest area, which covers 47% of total land area, includes bamboo forest, bush, rocky areas, fallow and land involved in upland farming. The country has established 20 natural protected areas (NPAs) covering 22% of total land area and two major road trade corridors, covering almost 3.4 million hectares, more than 14% of the country. Figure Fig 2 provides an overview of the land use in the Lao PDR.

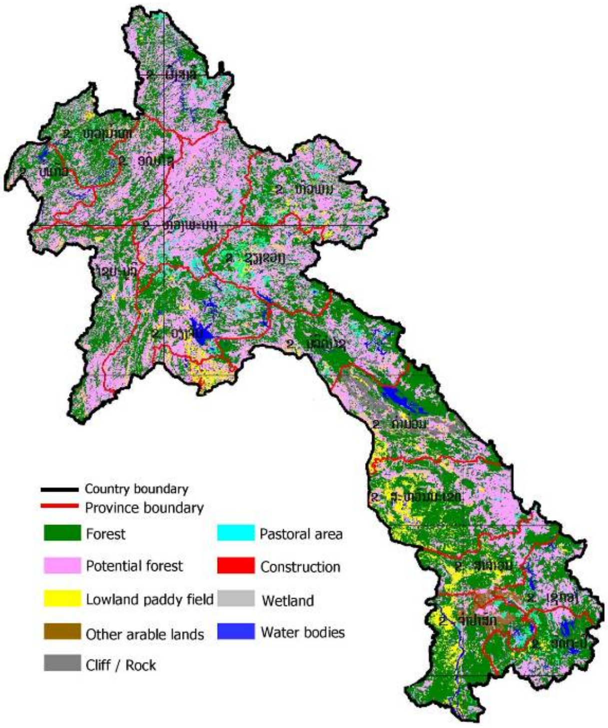

Fig 2: Land use in the Lao PDR [5]

1.3. Fossil Fuel Consumption

On a national level, fossil fuel import and consumption in the Lao PDR is rising rapidly: from 450 million litres in 2006 to 558 million litres in 2008. According to the Ministry of Energy and Mines (MEM) from 2000-2004, the number of vehicles increased tenfold from 51,000 to 557,000 [6]. The transport sector consumed 165 million litres of gasoline and 365 million litres of diesel in 2008. The share of consumption in the transport sector will also increase within the next decade as a result of greater electrification replacing diesel for light and electricity.

The MEM estimated that fuel consumption in 2010 will be 561 million litres, and it is expected to increase to 716 million litres by 2015. Imports are estimated to rise to 914 million litres by 2020. An alternative projection, based on fossil fuel imports of the Lao State Fuel Company (LSF), suggests future consumption could be much higher: from 831 million litres in 2015 to 1,166 million litres in 2020 [7].

2. METHODOLOGY

A compilation of relevant publications and other information was collected, and then used to formulate a baseline assessment of the potential for biofuel development and production in the Lao PDR. Key stakeholders in the Lao PDR, government institutions, the domestic and international private sector, and international NGOs, were consulted to develop an accurate description of current biofuel activities. An estimation of biofuel production from present until 2020 was made based on the current status and projections taking into account existing promotion activities of GoL.

The proposed biofuel cropping and refining modalities were reviewed and evaluated in terms of social, economic, and technical aspects, and the issue of sustainability. Case studies of other biofuel efforts in the region were integral to the analysis. Finally, any potentially adverse effects of government-supported biofuel production programs were identified in order to determine mitigation strategies.

2.1. Methodology Of The Model

LIRE has created a model forecasting biodiesel production and its impact on land use between 2010 and 2025. Impact variables were (i) jatropha, (ii) ethanol crops, (iii) agricultural land use and (iv) fossil fuel consumption and market prospects.

Furthermore, three scenarios of possible future biofuel development were developed, based on the data gained during the stakeholder consultation: a pessimistic, expected, and an optimistic scenario for the domestic biofuel market. These scenarios correspond with reaching 20%, 50% and 120% of the cultivation target from the private sector respectively. The scenarios are briefly described below:

Pessimistic scenario: It is assumed that claimed energy crop production will only achieve 20% of the cultivation target predicted for the private sector! Furthermore, it is assumed that 90% of the produced biofuel will be manufactured for export only, excluding the domestic market which was stated by the majority of the private sector.

Optimistic scenario: As another extreme, the study team designed a very optimistic scenario supposing an energy crop cultivation achievement of 120% and a domestic utilization of 75% of the produced biofuel.

Expected scenario: This model represents a mean between the pessimistic and optimistic scenario. Therefore is assumed that targeted energy crop production will achieve only 50% of the proposed target of the private sector. Furthermore, it is assumed that 70% of the produced biodiesel and bioethanol are produced for export only.

Furthermore, a number of broad assumptions were made in order to allow the predictions to be made, these are detailed below.

- No war
- Consistent national economic policy
- No tangible impact of climate change

2.2. Methodology On Chain Selection

Domestic biofuel market chains includes (i) different varieties of feedstock such as oil, starch and sugar crops, (ii) operational models utilized by private companies or associations and (iii) processing facilities and marketing. Each component was considered for viability separately, before performing a global analysis of complete chains.

3. BASELINE ASSESSMENT OF THE LAO BIOFUEL SECTOR

A total of 16 private companies and 12 public sector bodies, including government organisations, local authorities, universities, non-profit associations and NGOs, provided information about their current and future activities. The GoL has played a key role in the promotion of biofuel in the Lao PDR. The development plan for industrial sectors at the VIII General Congress of the Lao Revolutionary Party in 2006 [8] included the promotion of biofuel feedstock. In the same year, MEM released a draft policy for energy saving and biofuel production in the Lao PDR, which explicitly stated targets for domestic consumption [9]. In response, the Prime Minister's Office (PMO) and the National Authority for Science and Technology (NAST) have been actively involved in supporting biofuel initiatives with a focus given to jatropha. Small state and private biofuel research programmes have been pursued, mostly on the cultivation and processing of jatropha. The largest of these was a 20 ha trial plantation managed by NAST and a private enterprise.

Substantial investment in feedstock cultivation has been made in parallel with and independently of the above studies. Foreign private sector development has dominated, with almost exclusive attention given to jatropha. Table 1 summarises the cultivation statistics obtained by the stakeholder consultation.

Table 1: Summary of known current and planned private investment in jatropha cultivation for biofuel feedstock in The Lao PDR in 2009

Parameter	Provided information from stakeholders
Investment [US$]	49,991,800
Area recorded in 2009 [ha]	26,057
Area planned in 2020 [ha]	334,750
Plantation age [years]	1-3
Total yield up to 2009 [tons]	1,478
Farm gate price [US$/kg]	0.087
Contract farming 2+3 model [%]	86.1
Contract farming 1+4 model [%]	13.5
Plantation model [%]	< 1

Until 2009, approximately US$50 million have been invested in biofuel development. Stakeholders reported an area of 26,057 hectares of land having been assigned for jatropha cultivation. Although the same or a higher order of magnitude of land was being used to cultivate other oil crops such as ground nuts, and starch or sugar crops such as cassava, sugar cane, and maize concurrently in the Lao PDR [10], this was entirely used for food or fodder production and none was designated for biofuel. The majority of jatropha cultivation was either immature or not productive due to unforeseen operational difficulties, as reflected by a low reported integrated seed yield of only 1,478 t. This equates to a marginal average harvest of 57kg/ha of seed, significantly lower than the typical target of 2 t [11]. Almost all of the reported jatropha cultivation was by either ‘2+3’ or ‘4+1’ contract farming, with a mean farm gate price of US$0.087/kg.

Importantly, almost all planned biofuel feedstock production was intended for the external market. Although private companies generally expressed an interest in supplying to a domestic market, if attractive conditions exist, it was apparent that several companies already had export commitments. Thus, without market interventions on the part of the GoL, an export-oriented biofuel sector is likely to remain.

It should be noted that, in addition to contract farming, an undetermined but small amount of independent jatropha harvesting was taking place in 2009. Seed and other plant material were available from this source via the informal market in small quantities, usually at considerably higher rates than the farm gate price given above. Independent farming may increase in future, although without improvements in cultivation practices, jatropha is likely to remain a marginal source of income in most cases.

The total installed capacity for biofuel processing in the Lao PDR was approximately 2,257 kg/hr of dry seed in 2009. Most facilities were for demonstration and research purposes; none were reported in areas of cultivation. Actual production of jatropha oil was marginal, largely due to limited feedstock. For the production of biodiesel, a few small batch-systems existed, but only one unit was in fairly regular operation: a demonstration unit belonging to the Technical Research Institute (TRI), which produced biodiesel using waste-cooking oil from restaurants. Small quantities of waste-cooking oil was also exported to Thailand for biodiesel processing.

3.1. Estimation Of Model Parameters For Biofuel Production

Based on the trend of biofuel development perceived from the stakeholder consultation, pessimistic, optimistic and expected scenarios were defined as summarized in table 2. The scenarios were primarily distinguished by the level of exportation and cultivated land use, with some other parameters intentionally fixed in order to enhance the sensitivity of scenario variation on exportation and land use. In particular, jatropha seed yield at maturity was set constant for all three scenarios. Uncertainty in this parameter was treated as a systematic error. Gradual attainment of plantation targets was simulated by introducing a factor to describe the proportion of mature plantations. A small variation in extraction efficiency was introduced between scenarios, attributed to the different scales of processing likely to be present.

In terms of plant oil and biodiesel production, the pessimistic scenario describes the combination of a poor rate of success on existing cultivation investments, and a strongly export-oriented market. Indeed this would represent a direct extrapolation from the current situation of contract farming in the Lao PDR, without significant improvements to agricultural productivity. The expected scenario assumes somewhat fewer failed plantations and a lower proportion of export than in the pessimistic scenario, as may be the case if domestic biofuel is moderately incentivized by the GoL. Finally, in the optimistic scenario, a large domestic biofuel market is modelled, with a minority of biofuel being exported and an increase beyond the currently planned cultivation levels. This scenario may describe the outcome of a subsidized domestic biofuel sector.

The three scenarios exhibit large discreet advances in bioethanol feedstock cultivation, attributed to the limitations of processing facilities, which are necessarily large and involve considerable direct investments. Further discussion is provided in chapter 4.

Table 2: Variable parameters for each scenario

Parameters	**Scenarios**		
	Pessi-mistic	**Expec-ted**	**Opti-mistic**
Consumption and market variables			
Proportion of biodiesel that is exported	90%	70%	25%
Proportion of bioethanol that is exported	90%	70%	25%
Jatropha variables			
Proportion of predicted jatropha area achieved	20%	50%	120%
Seed yield at maturity	2	2	2
Oil extraction ratio	90%	85%	80%
Proportion of sugarcane/cassava used for BE			
2010	0%	0%	0%
2015	0%	10%	25%
2020	0%	20%	25%
2025	0%	25%	25%

3.2. Model Parameters For Future Petroleum Fuel Consumption

The model was designed to present forecasts of biofuel production, as a proportion of petroleum fuel demand. This enabled forecasts to be directed compared to the existing GoL target of 10% diesel substitution by 2020, albeit by making predictions dependent upon fossil fuel projections.

Table 3: Forecasted fuel consumption in the Lao PDR [7]

Year	**2010**	**2015**	**2020**
Fossil fuel	592,490,000	830,997,875	1,165,517,508
Diesel	325,869,500	457,048,831	641,034,629
Gasoline	266,620,500	373,949,044	524,482,878

Two sources of data were considered for projected fossil fuel demand: fuel import statistics and vehicle registration records. The former was judged to be more accurate, as it also accounted for unregistered vehicles, and non transport demands. Additionally the high growth rate in the number of vehicles was unlikely to be sustained for the next ten years. National statistics indicated a 10% increase in registered vehicles from January to October 2009 [12]. In anticipation of decreasing growth towards the latter half of the decade, the model approximated fossil fuel demand to grow linearly by 7% annually (as estimated by LSF), with a fixed proportion of 55% diesel to 45% gasoline. Predicted fossil fuel demand is summarized in Table 3.

3.3. Forecast Biofuel Production

The predicted development of jatropha and derived fuels are summarised in table 4, by 2020, for the three considered scenarios. The scenarios illustrate the impact of actual cultivation achieved, the proportion of biodiesel that is exported and designated biodiesel for domestic consumption by 2020.

Table 4: Predicted biodiesel development by 2020

Scenario	Pessi-mistic	Expec-ted	Opti-mistic
Companies' expectation in jatropha [x1000ha]	335	335	335
Mature jatropha plantation [%]	75	75	75
Calculated jatropha area [x1000ha]	67	167	402
Total jatropha seed production [x1000t]	100	251	604
Crude oil production [x1000t]	30	79	169
Crude oil Exported [x1000l]	3,247	8,596	18,338
Crude oil for Domestic Use [x1000l]	29,227	77,365	165,046
Biodiesel production [x1000l]	20,605	54,542	116,357
Biodiesel for domestic market [x1000l]	2,061	16,363	87,268
Percentage of diesel substitution [%]	0.321	2.55	13.61

Ignoring other important factors such as political and economic conditions, the scenarios show that current private sector investment, although considerable, is not adequate to significantly offset expected diesel demand in 2020 unless both cultivation targets are exceeded, and most biofuel feedstock is utilized for domestic demand.

For the expected scenario, model forecasts are displayed in figure Fig 3. Projected fossil fuel and biofuel consumption is shown as a histogram for 2010, 2015, 2020, and 2025. Overlaid are model predictions of the proportion of fossil fuel substituted by biofuel. The figure illustrates the dramatic increase in petroleum fuel demand predicted over this period.

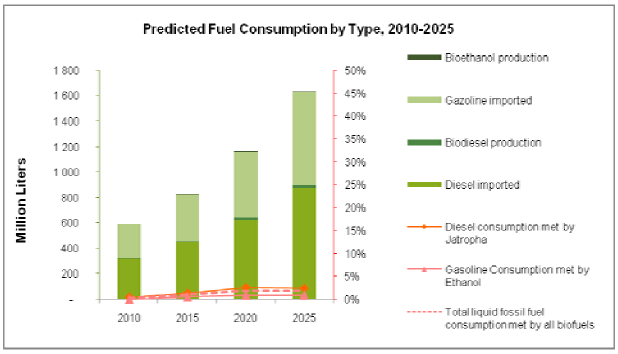

Fig 3: Model projections for national fossil fuel consumption and predicted biofuel production

Bioethanol development scenarios are similarly presented in table 5. According to MAF [13], 19,470 ha of sugar cane and cassava plantation would exist in 2010, increasing annually by 2%. From this baseline figure, the scenarios demonstrate possible shifts in use from food and fodder to bioethanol production.

Table 5: Predicted bioethanol development by 2020

Scenario	Pessi-mistic	Expec-ted	Opti-mistic
Cassava area [x1000ha]	14.0	14.0	14.0
Cassava area used for bioethanol [x1000ha]	0	2.76	3.45
Cassava produced for bioethanol [x1000t]	0	58.03	72.54
Bioethanol from cassava [x1000l]	0	10,445	13,057
Sugar cane area [x1000ha]	10.61	10.61	10.61
Sugar cane area used for bioethanol [x1000ha]	0	2.12	2.65
Sugar cane produced for bioethanol [x1000t]	0	80.61	100.76
Bioethanol from sugar cane [x1000l]	0	5,642	7,053
Total bioethanol Production [x1000l]	0	16,088	20,110
Bioethanol for domestic use [x1000l]	0	4,826	15,083
Percentage of gasoline substitution [%]	0.00	0.92	2.88

The optimistic scenario illustrates that, if large bioethanol facilities are implemented in Laos within 10 years, capable of processing 72,540 t and 100,757 t of cassava and sugar cane feedstock respectively and representing 25% of expected national production, then almost 3% of the gasoline demand in 2020 could be offset by bioethanol. Jatropha, cassava and sugar cultivation for biofuel are distinctly different in several ways. Most important to interpreting the above results are as follows: firstly, due to the technical requirements of bioethanol processing facilities, it is favourable to locate a majority of cultivation in the immediate vicinity of the biofuel facility. Since these feedstock crops already represent important sources of food and fodder, cultivation specifically of fuel may necessarily require new plantations. Secondly, there is a major difference in the productivity of the crops: Jatropha requires considerably more land than the other crops, producing on average 2 t/ha compared to 1 t/ha, and 38 t/ha respectively for cassava and sugarcane. These differences will be summarized in the next chapter, along with other possible crops. First though, the model forecasts are used to show land use change required for each scenario.

3.4. *Predicted Land Use Change*

The mean annual increase of agricultural area in the Lao PDR was 8% between 1997 and 2007 [14]. As the government program of land allocation reaches its end, it is likely that the expansion will slow down. As such a 2% annual increase of agricultural land was used in the model. Rice area was assumed to increase by 1% annually. A larger increase in rice production is expected and indeed required, but given GoL land policy, a large component of this rise will be through improved agricultural practices**.** Figure Fig 4 shows that in the expected scenario biofuel crops start using a significant proportion of available agricultural land.

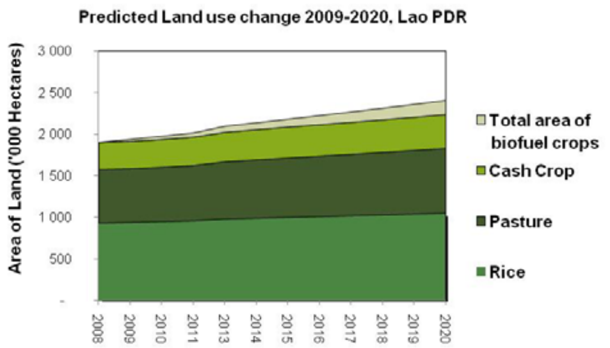

Fig 4: Model projection for land use change from 2008 to 2020 for expected scenario

The optimistic scenario would present a more dramatic change of land use. The model forecasts that in 2020 more than 407,000 ha of agricultural land would be covered by energy crops which accounts for 17% of the total arable area which is achieved to the detriment of pasture and cash crop land area.

Despite sacrificing enormous fractions of land area for energy crop cultivation, the resulted biofuel substitution would only reach approximately 8.8% in 2020 in this scenario.

4. SUITABLE MARKET CHAINS FOR BIOFUEL PRODUCTION IN THE LAO PDR

In contrast to the uniform, large-scale orientation of sector development currently observed in the Lao PDR, this chapter reviews suitable market chains considering appropriate feedstock, available resources, processing technologies and operational models. Elementary items of each market chain have been assessed in regards to their feasibility in the local context. Furthermore market chains have been shortlisted according to their ability to play an important role in future biofuel development before 2020.

4.1. *Potential Energy Crops For Biofuel Feedstock Production*

Table Table 6 presents an evaluation matrix devised to assess and identify the most feasible crops for biofuel development in the Lao PDR within ten years.

For simplification, each parameter received a rating ranging from good (G) to moderate (M), or poor (P), or in some cases, not available (N). Data sources are provided as footnotes to table column headers. It has to be considered that the evaluation was designed to identify the most feasible crops likely to be developed in the next 10 years in the Lao PDR, rather than selecting the most favourable energy crop in terms of NGPES goals. Note that crop demand refers to water, nutrient and pesticide demand. The investment ranking was based on input cost and time before maturity. Biofuel price was based on national market price (or neighbour if not available) [16] and stakeholder consultation for jatropha, plus recommendations from [15].

Table 6: Evaluation matrix for potential energy crops

Feedstock	Crop demand	Suitable area	Land use, biodiversity [15]	Energy balance and GHG[15],[16]	Labour pressure	Employment generation [15]	Biofuel Yield [15],[16]	Yield improvement potent.	Investment	Biofuel price	Overall National Potential
Oil crops reviewed for biofuel production											
Jatropha	G	G	M	G	G	G	M	G	M	G	G
Castor oil	G	M	M	N	M	G	P	G	G	P	M
Soybean	M	G	P	N	G	P	P	G	M	P	P
Palm oil	P	P	P	G	M	M	G	M	P	M	P
Coconut	G	G	M	G	M	G	G	M	P	M	M
Sunflower	M	M	P	N	M	G	P	G	M	M	M
Stone Jatropha	G	M	G	N	M	M	M	N	P	N	N
Camelina	G	G	M	N	P	G	P	N	G	N	N
Sugar and Starch crops reviewed for bioethanol production											
Sugarcane	P	G	P	G	G	M	G	G	M	P	G
Cassava	M	G	M	G	G	M	G	M	G	G	G
Corn	P	M	P	M	G	P	G	M	M	G	P
Sweet Sorghum	M	M	M	G	M	M	M	G	G	G	M
Sugar beet	P	M	M	M	P	P	G	M	M	M	P
Rice	P	G	P	P	G	M	G	M	M	G	P

Other critical parameters to feedstock selection are land and labour resource availability. Feedstock for biofuel development can be obtained from different land types that may lead to direct or indirect land use changes. Direct land use change occurs when designated biofuel feedstock displace a prior land use (e.g. forest), thereby generating impacts on that land. Indirect land use change occurs when pressure on agriculture due to the displacement of previous activity or use of the biomass induces land use changes on other lands. Table 7 presents the evaluation criteria considered. In the Lao PDR, the months with the most intensive labour force employment for farming are July, August, and November and might collide with labour requirements for energy crop cultivation [17].

According to the assessment jatropha, sugarcane and cassava have been identified and classified with 'good' potential for biofuel development. Despite historically being cultivated as living fencing and not for its fruit, the relatively widespread knowledge of Jatropha was a key factor in its selection as the most suitable oil crop for the next decade in the Lao PDR, combined with the opportunity to minimise land use change and conflict with food security. Stone Jatropha is interesting particularly for northern provinces, but insufficient data was available to evaluate this crop. Cassava and sugarcane are the preferred energy crops for bioethanol production, either using sugar or molasses. Both energy crops are already cultivated in the Lao PDR, although more intensive production and indeed mechanisation may be required to achieve suitable economic conditions for biofuel production.

4.2. Operational Models For Biofuel Production

The cultivation of energy crops for biofuel production can be progressed within different operational models, which can, to some extent already be found in the Lao PDR. Three main operating models used in Laos have been investigated: farmer association, contract farming and plantation model. One example of the former model for Jatropha in S.E. Asia is the Viengsa Agricultural Cooperative, Thailand. Contract and plantation models have been extensively used in Malaysia and Indonesia.

Advantages of farmer associations include the provision of key services for members, including credit, input supplies, access to market, information, and training. These can in principle be provided under contract models as well, although market guarantees alone are more common. The plantation model avoids capacity building needs by importing capacity.

Both farmer associations and contract farming models are vulnerable to a lack of legal framework and enforcement, as is the case in the Lao PDR. The main disadvantage of plantation models is the large environmental impact due to intensive monoculture cultivation, and social impact of population displacement. Compensation and alternative livelihoods may not be assured.

4.3. Processing And Utilisation Of Biofuel

The technologies associated to the extraction, refinement and utilisation of biofuels are varied and complex, and it is not possible to review these in detail within the scope of this paper. However, it is useful to review the opportunities and challenges associated to the different scales at which biofuel is produced and used.

Although the eventual price of biofuel is largely dictated by feedstock cost [18], the production scale impacts significantly on utilisation and sector development. This is even more important for a country with areas of poor accessibility, such as the Lao PDR.

Table 7: Evaluation criteria for land resource availability

Parameter	Evaluation criteria
Crop demand	Requirement of temperature, rainfall, soil, nutrients and sensitivity to diseases
Suitable area	Range of suitable agro-ecosystems for crop, as an indicator of potential land area
Land use and biodiversity	Suitable agro-ecosystem for the feedstock, taking into consideration biodiversity and land pressure, crop requirements, biofuel yield/ha and area needed for production
Energy balance and GHG	Environmental evaluation as a substitute to fossil fuel
Labour pressure	Feasibility based on production, status of current production and labour force needed related to the labour force calendar of rice
Employment	Opportunity for job creation
Biofuel yield	Efficiency as a feedstock, based on biofuel conversion factor, national yield (S.E. Asia mean yield if unavailable)
Investment	Expected level of investment, based on development period until full productivity, and cost of management
Biofuel price	National market price, (or price in neighbouring country if unavailable)
Potential to meet 2020 target	Combined rating based on above criteria, plus the level of readiness for production within a ten-year timeframe

Bioethanol production [19] is only conceivable on a large scale, due to the need to produce anhydrous ethanol [20], whereas plant oil extraction [21] and biodiesel transesterification is feasible at scales as low as 25,000 l/yr [15]. For comparison, in 2009, individual site production facility capacities for bioethanol and biodiesel in Thailand ranged from 25,000-200,000 l/day and 50,000-1,200,000 l/day respectively [22].

Blends of up to 20% biofuel with petroleum fuels can be used in vehicles without the need for modification [23], and hence blended fuels are easier to introduce than pure biofuel. Plant oil can be used directly in low speed compression-ignition engines, such as those used in small tractors and steady load motors in rural parts of the Lao PDR, but may reduce the engine lifetime due to high viscosity and contaminants [24]. Quality control is also easier for biodiesel as the transesterification process effectively removes unwanted ingredients such as sediment, and hence small scale biodiesel may be more suitable than plant oil, despite a larger investment in processing facilities. In summary, large scale bioethanol and biodiesel production is suitable for national distribution of biofuel in the Lao PDR, whilst small scale production and use of biodiesel is also technical viable.

Table 8 Impact analysis of biofuel market chains

	Chain	Environment	Social	Economic	Technical
Jatropha	**Contract 2+3, Large scale**	+ Energy balance + Erosion buffer - Land pressure, biodiversity	+ Market access + Employment - Contract legacy - Food price/security	+ Biodiesel price +/- energy security/ export - Food price	+ Suitable area + Existing company -Energetic demand -Land availability
	Farmer association, small scale	+ Energy balance + Erosion buffer + Low crop demand - Land use change	+ Market access + Knowledge transfer - Toxicity - Maintenance	+ By product + Local market + Crop requirement -Facility cost	+ Suitable area + Oil press - Skills - Engine modification
Sugarcane	**Plantation large scale**	+ Energy balance - Land degradation - Loss of biodiversity - Water pollution	+ Farmer skills + Employment - Food price/security - Land/water conflict	+ Bioethanol yield/price +/- energy security/ export - Food price - High maintenance	+ Thai knowledge + Sugar market chain - Complex process - Land availability
	Contract 2+3, Large scale	+ Energy balance - Land degradation - Loss of biodiversity - Water pollution	+ Employment + Fix price - Contract legacy - Food price/security	+ Bioethanol yield/cost +/- energy security/ export - Food price - Logistic cost	+ Thai knowledge + Sugar market chain - Complex process - Land availability
Cassava	**Farmer association, Large scale**	+ Energy balance + Low crop demand + Intercropping - Land erosion	+ Market access + Employment	+ Bioethanol Yield/price +/- energy security/ export - Logistic cost	+ Farmer skills + Suitable area + Thai example - Complex process
	Contract 2+3, Large scale	+ Energy balance + Intercropping + Low crop demand - Land erosion	+ Market access + Knowledge transfer - Contract legacy	+ Bioethanol Yield/price +/- energy security/ export - Production control	+ Farmer skills + Suitable area + Thai example - Complex process

4.4. Short List Of Suitable Market Chains

After considering each component in possible biofuel market chains, the following six combinations were found to be more suitable for development in the Lao PDR.

Jatropha contract farming 2+3; large scale:
Primary model currently employed by the private sector in The Lao PDR: 80% of the companies consulted use this model.

Jatropha farmer association; small/medium scale:
Potential for local substitution of diesel on community level by simple processing of oil suitable for modified diesel engines, or by small-scale batch biodiesel production. Farmer associations already exist in the Lao PDR for cash crops such as tea or coffee.

Sugarcane plantation / contract; large scale:
The plantation model offers a high biofuel yield/ha, and is partly employed in the Lao PDR for the production of sugar. The complexity of processing demands large scale processing facilities.

Cassava farmer association; large scale:
Existing cultivation model utilized similar to other cash crops. Farmers are already highly skilled, and would not require extensive technical support. Farmer groups can strengthen farmers bargaining and organisational position. Current production in the Lao PDR is large high (Cassava is 3rd most important crop in the Lao PDR), and thus access to sufficient feedstock for large-scale production appears promising.

Cassava contract farming; large scale:
Scale is justified by the process complexity. The low market price of cassava implies good economic feasibility for a processing company, which could allow a fixed farm gate price to be introduced.

4.5. Potential Impact Evaluation And Selection Of Most Viable Market Chains

Although the above six chains were all found to be compatible with conditions currently present in the Lao PDR, the specific potential contribution of each to development would likely differ. Moreover, each chain would require a tailored set of mitigation strategies in order to minimise the different possible negative impacts associated to each. This is expressed in **Error! Reference source not found.** below, which presents opportunities (+) and threats (-) according to environmental, social, economic and technical features of each chain. In order to further clarify which chain, or combination of chains should be pursued in the Lao PDR, it is necessary to review which national development targets are more valuable to GoL. This discussion shall be initiated in the following chapter.

5. DISCUSSION

It is hoped that biofuels can contribute to the National Growth Poverty Eradication Strategy

(NGPES), improving energy security, rural development, and environmental protection. However, for the reasons outlined below, a single biofuel strategy is unlikely to meet all of these goals. Rather, multiple actions in parallel would be warranted, with careful inclusion of mitigation strategies.

Given a large degree of uncertainty a diversification of energy crops designated for biofuel production offers some advantages, especially since various plant types can be processed within the same manufacturing facility. In case one energy crop fails due to agronomical, social or technical factors, remaining energy crops could compensate this loss. Furthermore an increased consideration of starch and sugar crops is justified since resulting bioethanol yields per hectare are considerably higher than for biodiesel.

The following discussion is intended to place current biofuel development targets into a wider context, in order to ascertain whether the opportunities outweigh the costs.

5.1. Physical Requirement For Meeting 10% Biodiesel Offset

The calculation of forecasted biofuel production was modified to indicate cultivation requirements assuming a fixed production target, as was present in the Lao PDR in 2009. The expected scenario parameters predict 53 million litres of biodiesel are required for domestic consumption in 2020 to meet 10% substitution of diesel, equivalent to 517,669 ha of Jatropha plantation, or 15% of the total expected agricultural in 2020. The potential impact of such a considerable land use change is difficult to predict, but would almost certainly be dramatic.

Looking at the above naive calculation in greater detail, it is clear that there are two principle features leading to such a large demand for biodiesel: rapid growth in fossil fuel consumption, and continuation of an export-oriented sector. If significant advances can be made to slow growth in diesel demand, either by improved fuel efficiency or by greater use of alternative technologies to combustion, or if the development of a domestic biofuel market can be encouraged, then the requirements for biofuel production could be considerably relaxed.

With exclusive cultivation for domestic consumption, 132,782 ha of land are required for Jatropha production, or 4% of available agricultural land. However it is unlikely such a scenario would occur without large GoL investment. A challenge to the development of a domestic biofuel market is the lack of necessary infrastructure, which in turn is difficult to establish without a reliable supply. One mechanism to promote domestic demand in biofuel whilst supporting the development of the necessary infrastructure would be to import biofuel from neighbouring countries over a transition period. This could also allow for technology transfer with neighbouring nations.

5.2. Economic Viability And External Market

The import of fossil fuel represents a considerable expense to the Lao economy. In 2009 it is estimated that 1,955bn kip (US$231 million), equivalent to 6% of GDP, were spent on diesel (assuming a cost of 6,000 kip per litre). In additional petroleum fuels are subsidised, the cost of which to GoL was approximately 48bn kip for diesel in 2009. As such there is an opportunity to reduce or internalise some annual expense through domestic biofuel, although at least in the short to medium term the investment required to establish a reliable supply would likely exceed the potential savings.

To date, of greater interest to GoL have been the opportunities to improve energy security and generate revenue from the external biofuel market. However, the basis for these opportunities has not been evaluated. First considering energy security, it should be noted that the price movement of biofuel feedstock is likely to follow the global petroleum market if more than 10% of that crop is used for biofuel production [25]. As a result, large-scale production of biofuel would not protect consumers against high petroleum prices, because feedstock prices would rise and reduce the price gap between petroleum and biofuel. In this scenario the domestic production of jatropha would not insulate the Lao PDR from high global crude oil prices.

Considering the external market for biofuel, the Lao PDR would be competing with neighbouring nations that already well established biofuel industries, and also benefit from more efficient transportation infrastructures. Moreover, market constraints in the EU and US would likely limit exports to the Aisa region.

The estimated price per litre of Lao biofuel based on expected cultivation and processing costs offer an indication of competiveness with current biofuel market prices. Assuming reasonable estimates of oil content, extraction efficiency, density, and conversion efficiency from oil to biodiesel of 0.35, 0.9, 0.92 [26] and 0.94 respectively [15], and allowing for 25% further costs for processing, energy costs and margins [18],[15], the current farm-gate price for jatropha seed in the Lao PDR equates to US$0.40/l for biodiesel for 2009, or US$0.94/l in 2020, assuming 8% inflation. Thus the price would appear quite competitive compared to diesel. However, it should be noted that the current farm gate price of jatropha may not by sustainable for small holder farmers, as would represents an annual gross income of US$175/ha of mature plantation in 2009. A more attractive income of US$300/ha would result in a price of US$0.69/l in 2009.

Current market prices for sugar cane and cassava are not directly applicable to biofuel, because of the need to use different cultivation models (indeed current prices are prohibitively high). Taking these changes into account, indicative prices of Lao bioethanol in 2009 are found to be US$0.47/l for sugarcane, and US$0.54/l for cassava in 2009, assuming for sugarcane a yield of 38.3 t/ha [16], 70 l/t conversion factor [15], and farm gate price of US$0.03/kg, and assuming for cassava a yield of 21.2t/ha [16], 140 l/t conversion factor [15], and

US$0.06/kg farm gate price. In 2009, the Thai market price for bioethanol was US$0.6/l [27], which is comparable to the above estimates. Moreover, the Thai bioethanol industry was export oriented, with a surplus relative to domestic demand. Thus, the economic viability of Lao bioethanol for the external market appears low.

Considerable debate still exists related to the commercial viability, environmental cost and poverty alleviation benefits that biofuels offer. Biofuels are not currently commercially viable in any country in the world without significant support from the state. Industrial nations such as Brazil and the United States are able to produce biofuel very efficiently, but still require certain subsidies. National markets also tend to require government support in the form of trade protection policies. Research suggests that no biodiesel pathway and product combination can provide a low-risk and profitable investment without some kind of government fiscal support [28].

5.3. *Environmental Costs*

There is concern about the environmental cost of widespread energy crop plantation development in the Lao PDR as other countries in Southeast Asia have experienced a rapid loss of biodiversity through reclamation of agriculture land from forested areas.

Furthermore, increased biofuel production based on current technologies will be limited by environmental factors such as the amount of unused land that can economically be brought into production and potential water shortages that may constrain expansion.

Feedstock production and biodiesel processing may also have environmental costs such water and air pollution, soil depletion, habitat loss, and potentially very large GHG emissions associated with the conversion of forests and grasslands to cropland. With this in mind, it should be noted that biodiesel subsidies in a number of countries in the past have exceeded the value of the environmental gains from fuel substitution [25].

5.4. *Poverty Alleviation*

The net effect of increased production of biofuels on a large scale will be higher food prices, which will benefit food producers but harm consumers. So in the Lao PDR, whilst some large landowners will benefit, evidence suggests that poor farming households in rural areas are often net buyers of food so will be worse off. Although small benefits will be gained from marginal fuel price reduction, the welfare of urban workers and net buyers of food will decline.

Small scale Jatropha cultivation and biodiesel production may in some areas be advantageous for rural development, local energy security and improving environmental protection and biodiversity. Although the likely impact upon national energy security is limited over a short time frame, this market chain represents a suitable opportunity to sustainably develop capacity, particularly for market mechanisms, technology, and spin-off enterprises. Of the three short-listed crops, cassava offers by far the best gross income for small holder farmers. Hence, although unable to exploit biofuel opportunities on a small scale, increased demand in this crop may be beneficial to rural communities.

5.5. *Mitigation Of External Factors*

In the context of national development, it is important to observe that the variables for biofuel production employed in the model are dominated by two external parameters: the projected food and energy demands of the country. Since the development of biofuel is being supported with the primary intention of improving the wealth of the Lao PDR, it should be noted that growth implies increasing food and energy demand [29]. Thus, given limited resources, especially land and labour, the development of biofuel must be undertaken within the wider context of efforts to improve the productivity and efficiency of the Lao economy. From an agricultural perspective, this entails increasing crop yields and improved management of food inventories. In terms of national energy demand, additional initiatives are required to improve energy efficiency, and reduce the demand for fossil fuels. Such initiatives should include the wider adoption of alternative (and locally available) energy sources.

6. CONCLUSIONS

At present biofuel development in the Lao PDR is focusing on export markets, with little consideration for the local context. Significant policy intervention is required in order to direct the sector to contribute to the improving energy security, rural development, and environmental protection. Indeed, it is difficult to achieve all of these goals with a single market chain, and hence a multifaceted approach appears necessary. With a simple evaluation of opportunities and costs associated to biofuel, this study has demonstrated that a domestic biofuel industry could contribute positively to the Lao economy. However, resources are inadequate to achieve both large exports and significant reduction in petroleum imports.

Over the short term, interested in energy security favour large scale production with strong limits to exports. In contrast, rural development targets favour small scale production. Over the longer term a well established infrastructure for small scale and diverse biofuel production could effectively contribute to national energy security. In order to raise the visibility of both approaches the GoL could consider introducing a new target that 10% of small holder farmers make use of biofuel technology by 2020. This may contribute to the NGPES more concretely than the 10% biodiesel substitution target. Finally, significant uncertainties remain regarding to the actual viability of small scale biofuel for rural parts of the Lao PDR, relative to existing and alternative rural development strategies. A detailed study focussed on this question would greatly contribute to the understanding of the value of biofuel for the Lao PDR.

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NOMENCLATURE

'2+3' model: Farmer provides land and labour (2); company supplies inputs, technical advice, and access to market (3). *'1+4' model*: Farmer provides land (1); company supplies inputs, technical knowledge, market access and hired farm workers (4).

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8. APPENDIX

Table A: Complete list of model parameter utilized for predicted biofuel development in The Lao PDR

Parameters	Scenarios: Pessi-mistic	Expec-ted	Opti-mistic
Consumption and market Variables			
Proportion of crude plant oil exported	10%	10%	10%
Proportion of remaining domestic plant oil process in biodiesel	75%	75%	75%
Proportion of biodiesel that is exported	90%	70%	25%
Proportion of bioethanol that is exported	90%	70%	25%
Predicted annual increase in fuel consumption	7%	7%	7%
Proportion of fuel consumption that is diesel	55%	55%	55%
Agricultural land use Variables			
Annual increase of total agricultural area	2%	2%	2%
Annual increase in rice area	1%	1%	1%
Proportion of bio-fuel area that supersedes cash crop	30%	30%	30%
Proportion of bio-fuel area that supersedes pastures	70%	70%	70%
Jatropha Variables			
Proportion of predicted Jatropha area achieved	20%	50%	120%
Seed yield at maturity (t/ha)	2	2	2
Seed oil content	35%	35%	35%
Oil extraction ratio	90%	85%	80%
Density of oil (kg/l)	0,92	0,92	0,92
Conversion factor, oil to biodiesel	94%	94%	94%
Ethanol Crop Variables			
Cassava yield (t/ha)	21	21	21
Annual increase in cassava area	12%	12%	12%
Cassava conversion factor in BE (litres/ton)	180	180	180
Sugarcane yield (t/ha)	38	38	38
Annual increase in sugarcane area	12%	12%	12%
Sugarcane conversion factor in BE (litres/ton)	70	70	70
Proportion of sugarcane/cassava used for BE			
2010	0%	0%	0%
2015	0%	10%	25%
2020	0%	20%	25%
2025	0%	25%	25%

8.1. About LIRE

LIRE is a non-profit association dedicated to the sustainable development of a self sufficient renewable energy sector in the Lao PDR. LIRE explores, develops and sustains efforts for making Laos develop its own energy sector with energy prices that are commercially viable and affordable to most of the Lao people. The Institute offers agronomical, technological and socio-economic research services, and provides information and advice on the use of renewable energy technologies. LIRE activities aims to support the development of the country by exploring commercially viable means to establish renewable energy technologies in remote areas without connection to the national grid and with little access to technical expertise.

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