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# Wasteland energy-scapes: a comparative energy flow analysis of India's biofuel and biomass economies

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1 **Wasteland energy-scapes: A comparative energy flow analysis of India's biofuel**  
2 **and biomass economies**

3

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21

22 **1. Introduction**

23

24 In 2009, after nearly a decade of debate, the Government of India enacted a National

25 Policy on Biofuels (Government of India, 2009). The policy restricts biofuel

26 cultivation to 'wastelands', an official government term for marginal lands, but

27 provides no guidance as to how wastelands will be identified for biofuel production.

28 Despite a lack of consensus as to what wastelands are (Baka, 2013, 2014), earlier

29 biofuel policy documents suggested that at least 17.4 million hectares (Mha) of

30 wastelands exist – roughly 4% of India's geographic area -- and are available for

31 establishing Jatropha curcas (hereafter Jatropha) plantations (Government of India,

32 2003). This paper examines the impacts, in terms of energy service provision, of

33 locating Jatropha plantations on lands that are ambiguously defined yet seemingly

34 abundant.

35

36 India's biofuel policy is not unique. Calls to locate biofuels on marginal lands have

37 increased over the past decade out of concern over the potential food security and

1 land use change impacts of growing biofuels on arable lands (Fargione et al., 2008;  
2 Searchinger et al., 2008; Tilman et al., 2009). Aided by numerous remote sensing  
3 analyses estimating the extent of marginal lands ‘available’ globally for biofuel  
4 production (Cai et al., 2010; Campbell et al., 2008; Nijsen et al., 2012), this strategy  
5 has been incorporated into biofuel sustainability criteria and various government  
6 biofuel policies across the global North and South (Bailis and Baka, 2011). Recent  
7 remote sensing analyses have downgraded initial estimates of the extent of marginal  
8 lands after ground truthing (Fritz et al., 2012) and in recognition that marginal lands  
9 are often used as grazing lands (Gelfand et al., 2013). However, these adjustments do  
10 not address the political relations shaping lands or the politics of land classification  
11 processes.

12  
13 Social scientists have long argued that labels such as wastelands are not neutral,  
14 unbiased assessments of landscapes, but are social constructions reflecting, and often  
15 reinforcing, the (prior) perceptions of dominant stakeholders (c.f. Fairhead and Leach,  
16 1996; Robbins, 2001a; Robbins, 2004). As such, land classification processes often  
17 simplify complex land use practices on the ground (Scott, 1998). Other scholars have  
18 questioned estimates of ‘spare’ lands arguing that such figures often overestimate the  
19 availability of cultivable lands by failing to adequately consider the full range of  
20 services lands provide (Young, 1999). Lands classified as wastelands by the state are  
21 often common property lands used by the rural poor for fuelwood and fodder  
22 gathering (Ostrom, 1990). For these reasons, critical scholars of biofuels have  
23 challenged calls to locate biofuels on marginal lands arguing that such policies fail to  
24 adequately consider the livelihood significance of such lands (Ariza-Montobbio et al.,  
25 2010; Borrás et al., 2010; Franco et al., 2010).

1

2 Yet, to date, little empirical evidence has been offered assessing the livelihood  
3 significance of marginal lands in the context of biofuel development. Through the  
4 lens of social metabolism, this paper provides such an assessment in a subregion of  
5 rural India. We find that India's wastelands are dynamic energy landscapes servicing  
6 a range of household and industrial consumers in both rural and urban settings. This  
7 existing economy, centered on Prosopis juliflora (hereafter Prosopis), is currently  
8 being uprooted to establish a Jatropha biodiesel economy. We compare the changes in  
9 useful energy this transition would engender through a comparative energy flow  
10 analysis (EFA) of the Prosopis and Jatropha economies. Drawing on political ecology  
11 theory, we extend social metabolism literature by analyzing how this transition could  
12 re-shape human-environment relations in rural India.

13

14 In the next section, we review theories of social metabolism and its intersection with  
15 political ecology. We introduce the field site and EFA method in section 3 and present  
16 results in section 4. We discuss the implications of our findings in section 5.

17

## 18 **2. Theoretical review**

19

20

21 Grounded in ecological metaphors, social metabolism, or its synonym, socioeconomic  
22 metabolism, analyzes the biophysical exchange processes mediating human-  
23 environment relations (Fischer-Kowalski, 1997). This involves studying the material  
24 and energy throughputs and associated land use changes required to sustain  
25 socioeconomic systems. Interdisciplinary in nature and influenced by a diversity of  
26 fields including cultural anthropology, land-change science and industrial ecology,  
27 amongst others (Singh et al., 2013), this approach "provides a framework to

1 distinguish cultures, societies or regions according to their characteristic exchange  
2 relations with nature” (Fischer-Kowalski and Haberl, 1998: 574).

3

4 Many social metabolism studies analyze socioecological transitions, the changes in  
5 metabolic profiles accompanying broad economic transformations, such as  
6 transformations from agrarian to industrial societies (Fischer-Kowalski and Haberl,  
7 2007). While most such studies have analyzed national or multi-national transitions  
8 (e.g. Krausmann et al., 2004; Schandl and Krausmann, 2007; Singh et al., 2012; West  
9 and Schandl, 2013), a subsection of studies have analyzed transitions in island or  
10 small village settings (Gruenbuehel et al., 2003; Singh et al., 2001).

11

12 To date, most of these studies have focused on the biophysical dimensions of  
13 socioecological transitions with limited research on the associated socio-political  
14 factors shaping and shaped by these transitions. An emerging strand of literature has  
15 combined ecological economics and political ecology to analyze how a changing  
16 global social metabolism can lead to conflicts (Martinez-Alier et al., 2010; Muradian  
17 et al., 2012). This literature posits that a fundamental transformation in the extraction  
18 and provision of natural resources is underway, engendered, in part, by rising food  
19 and energy prices and continued population growth. Conflicts can and have been  
20 occurring along commodity frontiers as actors seek out new territories for resource  
21 provision.

22

23 The new bioeconomy (ETC, 2010), the emerging industrial economy centered on bio-  
24 based materials and premised on replacing fossil fuels with biomass, represents a

1 fundamental transformation in social metabolism. Many recent studies of the new  
2 bioeconomy have focused on the political-economic dynamics of the transformation.  
3  
4 Smolker (2008) argues that substituting biomass for fossil fuels is facilitating a  
5 fundamental restructuring of the global agricultural system as it interlocks agriculture,  
6 energy, land use, climate change, transportation, trade and human rights policies.  
7 McMichael (2012) asserts that the global ‘land grab’ (c.f. Borras et al., 2011; Fairhead  
8 et al., 2012; White et al., 2012; Wolford et al., 2013) marks the beginning stages of  
9 this restructuring as it “anticipates the rising value of living biomass” (687). The land  
10 conflicts that have resulted, documented extensively by the Environmental Justice  
11 Organizations, Liabilities and Trade project (EJOLT, 2011), presage what may result  
12 as the new bioeconomy advances. Overall, Birch, et al (2010) argue that the new  
13 bioeconomy continues the neoliberalization of nature and knowledge as new  
14 innovations and requisite markets and property rights are developed to unlock (and  
15 adequately value) the potential of biomass in today’s society.  
16  
17 Biofuel production, a component of the bioeconomy, has been a key focus of the  
18 social metabolism and political ecology literatures. However, similar to the above, the  
19 core of this research has focused on the political dimensions (c.f. Borras et al., 2010)  
20 and associated conflicts (c.f. Martinez-Alier et al., 2010; Muradian et al., 2012) of  
21 biofuel promotion. Fundamentally, the low energy density and spatial requirements of  
22 biofuel feedstocks compared to fossil fuels creates new land use pressures as land is  
23 now needed to service society’s food, fiber and fuel needs (Scheidel and Sorman,  
24 2012). While this literature is too vast to review in this paper, we review the section  
25 of this literature relevant to *Jatropha* promotion in Tamil Nadu, India.

1

2 In an analysis of Tamil Nadu's *Jatropha*-centered wasteland biofuels program, Ariza-

3 Montobbio, et al (2010) argues that the concept of 'wasteland' is a politically

4 malleable term applied to lands ranging from fallow lands to agroforestry lands.

5 Extending this analysis, Baka (2014) finds a lack of consensus amongst biofuel

6 stakeholders as to what constitutes wastelands in India. Yet, economic incentives

7 motivate the dominant perception of wastelands appearing in biofuel policy

8 documents as 'empty', 'unproductive' spaces. Baka (2013) also finds that this

9 ambiguity has helped to facilitate biofuel-related land grabs of wastelands in Tamil

10 Nadu, which are dispossessing rural farmers. For these reasons, in addition to lower

11 than anticipated seed yields and higher than anticipated water requirements, Ariza-

12 Montobbio and Lele (2010) characterize *Jatropha* promotion in northern Tamil Nadu

13 as a latent conflict between farmers and the state.

14

15 Overall, the social metabolism literature on biofuels has primarily focused on the

16 political-economic drivers and potential for ecological conflicts stemming from

17 biofuel promotion. Limited empirical research has examined the biophysical

18 dynamics underlying this energy transition. This study fills this research gap. We

19 analyze the metabolic transition underway in southern Tamil Nadu by characterizing

20 the changes in the quantity and quality of energy resulting from replacing biomass

21 with biofuels. We also examine the resultant socio-political transformations stemming

22 from this transition.

23

24 Collectively, this study contributes to the emergent "new geographies of energy"

25 literature (Zimmerer, 2011), which seeks to analyze the multiple political, economic

1 and biophysical processes shaping and shaped by society's current quest for a low  
2 carbon, environmentally benign energy future.

3

### 4 **3. Field site and methods**

5

6 Fieldwork took place between December 2010 and February 2011 in Sattur taluk,  
7 Virudhunagar District, Tamil Nadu (Figure 1). This region was selected because of  
8 the history of *Jatropha* promotion in the area as well as the prevalence of *Prosopis* in  
9 the region. While rainfed cultivation of corn, cotton and pulses farming are currently  
10 the main forms of production in the Taluk, Sattur is in the midst of an industrial  
11 transition with an increasing number of fireworks and match factories moving into the  
12 area (Virudhunagar District Collector, 2009). Average rainfall for the district is  
13 approximately 830 millimetres per year and black soil is the predominant soil class  
14 (Virudhunagar District Collector, 2009).

15

16 Data was gathered by surveying 158 users/producers of *Prosopis*: fuelwood users  
17 (n=114), a 10 MW biomass power plant (n=1), charcoal makers (n=4), brick makers  
18 (n=5), match factories (n=7), restaurants (n=11), paper mills (n=3), oil mills (n=2),  
19 wood traders (n=11) and 2 *Jatropha* companies: plantation (n=1), biodiesel  
20 manufacturer (n=1) in 39 randomly sampled villages of Sattur (Figure 2). Calorific  
21 analyses of various *Prosopis* and *Jatropha* products were conducted to evaluate energy  
22 contents (Appendices A-C).<sup>1</sup> Energetic contents for all other parameters were  
23 obtained from the literature and from Ecoinvent, a common lifecycle analysis (LCA)  
24 database (Appendices A-C).

25

---

<sup>1</sup> The products analyzed were: *Prosopis* charcoal, roots, stems and *Jatropha* oil and seedcake. *Jatropha* biodiesel was not available, so values were obtained from the literature.



1 The area of Prosopis in Sattur was estimated through a supervised classification of  
2 three seasonal LANDSAT images of Sattur between 2009-2011.<sup>2</sup> We estimate the  
3 average Prosopis area in Sattur to be 16,573 ha (36.2% of Sattur's geographic area).

4 [Figure 1]

5 [Figure 2]

6

7

8 We conducted the EFAs following the methodology developed by Haberl (2001,

9 2002). EFA distinguishes between three categories of energy (Haberl, 2001, 2002): 1)

10 primary energy, the energy content of feedstocks at the time of extraction (i.e. wood);

11 2) final energy, the energy content of feedstocks after conversion (i.e. charcoal); 3)

12 useful energy, energy that performs work (i.e. cooking). For this study, EFA offers

13 insights into the possible land use change impacts of biofuels by characterizing and

14 comparing the useful energy of Sattur's wastelands under a biomass and biofuel

15 energy system. Further, EFA provides insights into how lands would be transformed

16 to establish Jatropha plantations, particularly in terms of fertilizer and irrigation

17 requirements. As will be demonstrated, the existing Prosopis economy provides

18 significantly more useful energy than would a Jatropha economy.

19

20 EFA also examines the hidden flows of energy provision, energy mobilized in energy

21 production but not embodied in the energy feedstock (ie. diesel fuel for transporting

22 wood). In this study, hidden flows are the inputs of Jatropha production<sup>3</sup> and the

23 transport energy required to circulate Prosopis and Jatropha. This enables an energy

24 return on investment (EROI) analysis, the ratio of energy delivered (i.e. primary

---

<sup>2</sup> Researchers at the Centre for Ecological Sciences, IISc Bangalore assisted with this analysis.

<sup>3</sup> Prosopis is not actively managed and thus, transportation energy is the only input to the Prosopis system.

1 energy) to energy inputs (The Encyclopedia of Earth, 2013). An EROI less than 1  
2 indicates that an energy carrier requires more energy for its production than the  
3 resulting fuel provides. A high EROI can result from a low-input energy system  
4 and/or a high value energy carrier, such as fossil fuels (Hall et al., 1986). In this  
5 regard, EROI is both a measure of production efficiency and energy surplus  
6 (Cleveland et al., 2000).

7

8 Due to the different gestation periods of *Jatropha* (3 years<sup>4</sup>) and *Prosopis* (1 year<sup>5</sup>)  
9 and the uncertainty about *Prosopis* system performance over an extended lifespan, we  
10 modeled the current useful energy provided by *Prosopis* and the annual useful energy  
11 provided when *Jatropha* trees reach maturity. Thus, in contrast to previous EFA  
12 studies, our study is a one-year comparative study. At the time of fieldwork, *Jatropha*  
13 production was stalled in Sattur and across India. To model a *Jatropha* economy for  
14 Sattur, we surveyed a *Jatropha* company with a plantation in neighboring Ramnad  
15 District (Figure 1) and a biodiesel manufacturer in neighboring Aruppukkotai District  
16 (Figure 1).<sup>6</sup> Values were triangulated through a literature review of *Jatropha* life cycle  
17 analyses (LCAs), described below.

18

19 In addition to the uncertain gestation period of *Jatropha*, the spacing, irrigation,  
20 fertilizer, pesticide requirements and seed yield of *Jatropha* are also variable (Almeida

---

<sup>4</sup> The gestation period of *Jatropha* remains uncertain. Due to the breadth of their study, we used the gestation assumption of Almeida and colleagues (2011).

<sup>5</sup> According to interviews conducted during fieldwork, *Prosopis* trees can be harvested within the first year of growth. Additionally, trees are typically coppiced on a 3-4 year rotation.

<sup>6</sup> The company plans to convert its 121 ha *Jatropha* plantation to food production (interview with company manager, January 22, 2011). This conversion was not yet completed at the time of fieldwork and we observed a *Jatropha* harvest during our survey. At the time of our fieldwork, the biodiesel manufacturer was under repair.

1 et al., 2011; Whitaker and Heath, 2008). We assumed 1,600 trees per hectare (survey  
2 data) yielding 4.3 tonnes of seed per hectare per year starting in year 3, which is the  
3 reference scenario suggested by Almeida, et al (2010). We assumed continuous drip  
4 irrigation to deliver the difference between annual rainfall in Sattur and the optimal  
5 rainfall target for *Jatropha*, 1,500 mm per year (Trabucco et al., 2010). We assumed  
6 annual application of NPK chemical fertilizer and pesticide application following  
7 Almeida, et al (2011). All products are transported by lorry. Detailed model  
8 assumptions are included in Appendix A.

9

10 As van der Voet, et al's (2010) meta analysis of biofuel LCAs demonstrates, the use  
11 of by-products is a key component of the environmental footprint of biofuels. Thus,  
12 we estimate the potential useful energy of the by-products of the *Jatropha* system,  
13 which include the pruning biomass and seed husks resulting from *Jatropha* cultivation  
14 and harvesting and the seedcake residue resulting from *Jatropha* oil extraction.

15 Because *Jatropha* production was stalled at the time of fieldwork, there was no market  
16 for *Jatropha* by-products. We estimate the useful energy provided by using *Jatropha*  
17 by-products as substitutes for *Prosopis*. Additionally, the *Prosopis* uprooted to  
18 establish *Jatropha* plantations can be considered a by-product to the *Jatropha* system.  
19 We included the annual useful energy from the uprooted *Prosopis*, assuming it is used  
20 in the same manner as the existing *Prosopis* system, amortized over a 20-year lifespan  
21 of a *Jatropha* plantation (Almeida et al., 2011).

22

23 We conducted a scenario analysis to estimate the range of useful energy provided by  
24 *Jatropha* biodiesel plus various combinations of *Jatropha* by-products (Table 1).

25 Because of the uncertainty of the *Jatropha* system productivity, following Almeida et  
26 al (2010), we also conducted a sensitivity analysis of *Jatropha* seed yield using the

1 seven global yield classification values by Trabucco et al (2010): 0.5, 1, 1.5, 2, 2.5,  
2 3.5 and 5 t/ha/yr after maturity.

3

4 [Table 1]

5

## 6 **4. Results**

7

### 8 **4.1 Prosopis**

9

10 Prosopis is used for three main functions in Sattur: as a fuelwood for cooking in  
11 households and restaurants, as a fuelwood for a variety of industries including paper  
12 mills, brick making, match making and oil mills and as a feedstock for electricity and  
13 charcoal production. Approximately 222 kilo-tonnes (ktonnes) of Prosopis are  
14 consumed annually within Sattur (Table 2). The power plant is the largest user,  
15 consuming just over 89 ktonnes per year (40.3% of total Prosopis usage), followed by  
16 households (30.4%), paper mills (15.2%), brick making (7%), charcoal (5.2%) and  
17 restaurants, match factories and oil mills (1.9% combined).

18

19 Prosopis users either self-collect or purchase Prosopis from wood traders or local  
20 villagers. Charcoal manufacturers self-collect all of their Prosopis supplies,  
21 households self-collect approximately 74% of their Prosopis supplies and restaurants  
22 and match factories self-collect about 3% of their Prosopis needs (Table 2). These  
23 users self-collect Prosopis typically within a few kilometer radius of their home or  
24 industry. Yet, the overall amount of self-collection accounts for only 28% of the  
25 Prosopis circulating in Sattur. The majority of Prosopis circulating in Sattur is  
26 purchased (Table 2).

27

1 Prosopis is also the main energy feedstock across user groups accounting for 80-  
2 100% of total feedstock demand (Table 2, column 5). Brick makers, charcoal makers  
3 and oil mills use Prosopis for 100% of their feedstock needs. The power plant uses  
4 Prosopis for 90%, on a mass basis, of its feedstock and uses wood wastes from match  
5 making and plywood manufacturing in the neighboring state of Kerala for its  
6 remaining feedstock demand. The paper mills and match factories use Prosopis for  
7 approximately 85% and 96% of their feedstock needs respectively, and use other  
8 trees, mainly Neem, Tamarind, and a native Prosopis variety, Prosopis cineraria, and  
9 other wood and agricultural wastes for the remaining needs. Restaurants use Prosopis  
10 for about 81% of their fuelwood needs and use wood wastes, native Prosopis and  
11 Indian mulberry (Morinda citrifolia)<sup>7</sup> for their remaining needs.

12

13 All of the households surveyed were rural households. Prosopis represents 95% of  
14 their cooking fuel on a mass basis.<sup>8</sup> Rural households use Indian mulberry, wood  
15 wastes, kerosene and LPG for their remaining feedstock needs. Due to time  
16 limitations, we did not conduct a cooking energy survey in the town of Sattur, the  
17 only urban region in Sattur taluk. However, based on Government of India census  
18 data, we estimate that urban households in Tamil Nadu use fuelwood for  
19 approximately 34% of their cooking energy (Government of India, 2001). Using these  
20 figures and the number of rural and urban households in Sattur, we estimate Prosopis  
21 represents 80% of household cooking energy in Sattur.

22

---

<sup>7</sup> Indian mulberry is colloquially known as Manjanathi in Tamil.

<sup>8</sup> On a calorific basis, Prosopis represents 91% of cooking energy feedstocks. Results are presented on a mass basis to be commensurate with Census of India data.

1 At these Prosopis usage rates, we estimate that Prosopis currently provides  
2 approximately 4,191 TJ/yr of total primary energy and delivers roughly 825.1 TJ/yr of  
3 useful energy to the Sattur region (Table 3). Nearly 80% of total primary energy is  
4 lost in conversion and combustion due to low technological efficiency rates  
5 (Appendix C). Prosopis is invasive and has spread throughout the Taluk with little  
6 active intervention. As a result, it requires no active management. It is harvested on a  
7 three-year cycle and regenerates through coppicing with no additional inputs. Thus,  
8 the only energy input of the Prosopis energy system is the diesel fuel used to transport  
9 Prosopis via lorry and to aid in the combustion of Prosopis at the power plant.

10

11 Approximately 20% (164.2 PJ/yr) of the useful energy provided by Prosopis are  
12 exported from the Sattur region in the form of charcoal and electricity (Figure 3). Just  
13 over 72% of the charcoal manufactured in the region is exported to other parts of  
14 India, including urban centers like Chennai, Hyderabad and Mumbai as well as the t-  
15 shirt manufacturing region of Tirupur in northern Tamil Nadu. In addition, because  
16 the 10 MW power plant accounts for only a small portion of Tamil Nadu's 20.7 GW  
17 of installed capacity (Government of India, 2013), we assume that electricity  
18 produced by the power plant and sold to the Tamil Nadu grid (90% of generation) is  
19 exported outside Sattur Taluk.

20

21 [Table 2]

22

23

## 24 **4.2 Jatropha**

25

26 At maturity, we estimate that the Jatropha biodiesel system, consisting of 16,573 ha,  
27 the same area of the current Prosopis economy, will produce approximately 294.5

1 TJ/yr of total primary energy and deliver 80 TJ/yr of useful energy (Figure 3). Just  
2 over 242 TJ/yr of energy inputs are required annually (Figure 3).<sup>9</sup> If by-products of  
3 Jatropha production and the uprooted Prosopis are used for energy provision, the total  
4 useful energy would increase to over 335 TJ/yr. This represents a 4-fold increase over  
5 the useful energy provided by Jatropha biodiesel alone (Figure 3). Thus, similar to  
6 biofuel LCAs, by-product usage is also a key determinant of EFA results.

7

8 According to the Government of India's Biofuel Purchasing Policy, all biodiesel will  
9 have to be shipped to the closest oil marketing centre (OMC) for testing and blending  
10 (Government of India, 2005). The closest OMC to Sattur is located in Karur, Tamil  
11 Nadu, 230 km away. Thus, all Jatropha biodiesel produced in Sattur would be  
12 exported from the region. Economics will determine what, if any, percentage returns  
13 to Sattur. Assuming that 90% of electricity generated from Jatropha system by-  
14 products is also exported to the grid, that the uprooted Prosopis is consumed in the  
15 same manner as the existing Prosopis system and that 90% of electricity generated  
16 will be exported to the grid, a maximum of approximately 61.3 TJ/yr of useful energy  
17 provided by Jatropha by-products and uprooted Prosopis would be consumed within  
18 Sattur (Figure 3).

19

20 Based on these results, the Prosopis system provides approximately 2.5 to 10.3 times  
21 more useful energy depending on how, if at all, by-products from the Jatropha system  
22 are used for energy provision (Figure 4).

23

---

<sup>9</sup> Inputs include annual inputs for cultivation, harvest, oil extraction and transesterification stages of Jatropha production. We also amortized the nursery and land preparation inputs over an assumed 20-year Jatropha plantation lifespan, the typical lifespan assumed in the literature (Almeida, et al, 2010).

1 [Figure 3]

2 [Figure 4]

3

4

### 5 **4.3 Energy Return on Investment**

6

7 Based on practices observed in Sattur, the Prosopis system has an EROI of 367 (Table  
8 3). If no by-products of the Jatropha system are used for energy provision, Jatropha  
9 biodiesel would have an EROI of 1.2. This indicates that Jatropha biodiesel would  
10 provide about the same amount of primary energy that is required for its production.  
11 If all by-products are used for energy provision, the Jatropha system EROI can  
12 increase to 10.7. While these results indicate that Jatropha production yields positive  
13 energy returns, the returns from Jatropha are significantly lower than the returns from  
14 Prosopis.

15

16 [Table 3]

17

18

### 19 **4.4 Sensitivity Analysis**

20

21 While increasing seed yield improves the useful energy of the Jatropha system, the  
22 increases do not exceed the useful energy of the Prosopis system even under the most  
23 aggressive yield assumptions (5 t/ha/yr) (Figure 5). The useful energy of the Jatropha  
24 system under the most aggressive yield assumptions and full by-product use are 500.2  
25 TJ/yr, which is approximately 40% of the useful energy delivered by the Prosopis  
26 system (825.1 TJ/yr). Holding all yield-independent variables constant, a seed yield of  
27 17.7 t/ha/yr would be required to provide the same quantity of useful energy as the  
28 Prosopis system (authors' calculations), which is far beyond any conceivable yield.  
29 Indeed, the most optimistic projections for Jatropha are a doubling of yields  
30 anticipated by SG Biofuels, one of the main companies developing hybrid Jatropha  
31 seeds (SG Biofuels, 2010).



1

2 [Figure 5]

3

4 **5. Discussion**

5

6 The above analysis demonstrates that the Jatropha system provides less useful energy  
7 than the Prosopis system in terms of both quantity and service function. Further, the  
8 sensitivity analysis reveals that Jatropha seed yield improvements cannot significantly  
9 reduce this gap.

10

11 Yet differences in the quantity of useful energy do not reveal the full magnitude of  
12 differences between Jatropha and Prosopis useful energy. The systems also differ in  
13 terms of the type of useful energy offered. At present, Prosopis is used as a fuelwood  
14 by households and industries and as a feedstock for charcoal and electricity  
15 manufacturing. Jatropha biodiesel is a liquid transportation fuel and thus, cannot  
16 substitute for the current useful energy provided by Prosopis. By-products from the  
17 Jatropha system could be substitutes for some of the useful energy of Prosopis,  
18 particularly for industries and the power plant.<sup>10</sup> Due to the toxicity of Jatropha, the  
19 Jatropha seedcake should not be used for cooking. As result, Jatropha by-products  
20 should not be used to replace household and restaurant Prosopis usage (Matsumura,  
21 2012). These results indicate that replacing Prosopis with Jatropha could create an  
22 energy deficit that could reduce, rather than improve, energy security.

23

24 Baka (2014) has previously analyzed how the majority of industries using Prosopis  
25 would likely shut down or seek out other biomass substitutes in the case of a Prosopis

---

<sup>10</sup> Based on our analysis, the air dry basis calorific value of Jatropha seedcake (20.9 MJ/kg) is higher than Prosopis wood (18.9 MJ/kg) but lower than Prosopis charcoal (31.1 MJ/kg).

1 shortage or price spike. She also reveals how the Prosopis economy currently  
2 provides about 7 times more jobs per hectare than Jatropha to a mix of men and  
3 women and at higher wages. In addition to these changes, replacing Prosopis with  
4 Jatropha could also engender further changes in economic and property relations. At  
5 present, the Prosopis system has more elements of an informal economy than would a  
6 Jatropha system. Household users freely cut Prosopis while cutting crews who work  
7 for industries or sell to wood merchants cut Prosopis from common property lands or  
8 pay landowners a small sum to cut Prosopis. In some instances, landowners do not  
9 charge cutting crews because removing Prosopis frees up their lands for other farming  
10 activities.

11

12 In contrast, based on observed practices, Jatropha plantations would be enclosed and  
13 would often involve the sale or leasing of land to private companies. Based on our  
14 biofuel company interview, companies would enclose land in part to protect Jatropha  
15 trees from grazing animals and to reduce the chance of children consuming poisonous  
16 Jatropha seeds. Yet, overall, these processes represent a change in access (Ribot and  
17 Peluso, 2003) because they alter the current land use practices and derived benefits of  
18 Prosopis users. Further, because of the government's expressed interest to produce  
19 biofuels via public-private partnerships (Government of India, 2003), the Jatropha  
20 system would be a more formal, market-based economy than Prosopis. As result,  
21 market forces would determine what, if any, portion of Jatropha by-products would be  
22 used for energy provision within Sattur.

23

24 Further, these results are not necessarily specific to Sattur. As has been documented  
25 by other researchers, Prosopis is widely found throughout India (Gidwani, 2008;

1 Gold, 2003; Robbins, 2001b) and Africa (Mwangi and Swallow, 2008). Based on the  
2 government's Wasteland Atlas of India (Government of India, 2010), scrublands, the  
3 categorical classification of Prosopis, is the largest category of wastelands in the  
4 country, currently representing 18.5 Mha or 5.8% of the total geographic area of  
5 India. Additional research is required to determine how Prosopis functions as an  
6 energy feedstock, if at all, in these regions.

7  
8 However, the Prosopis system also faces limitations – beyond its invasiveness -- that  
9 detract from its viability as an energy source. To be a self-sustaining system, annual  
10 usage rates should not exceed annual regeneration rates. Assuming 16,573 ha of  
11 Prosopis in Sattur with an average biomass of 16.5 tonnes/ha (Bailis and McCarthy,  
12 2011) and a three-year regeneration cycle, a self-sustaining harvest rate for Sattur is  
13 91.2 ktonnes/year. The current Prosopis usage rate in Sattur (221.6 ktonnes/yr) is 2.4-  
14 times the self-sustaining harvest rate.<sup>11</sup> Thus, at current usage rates, there is a high  
15 likelihood of a Prosopis shortage in coming years, which can further increase land use  
16 pressures and weaken energy security. However, absent the biomass power plant,  
17 annual usage rates (132.3 ktonnes/yr) would be 1.5 times the self-sustaining harvest  
18 rate, a marked (but not self-sustaining) improvement over current usage rates.  
19 Coupled with the Jatropha EFA analysis, these findings point to the unsustainable  
20 land use and energy security pressures resulting from the introduction of 'modern'  
21 energy technologies.

22

23 Secondly, while this study simultaneously considers the biophysical, social and  
24 political tradeoffs of replacing Prosopis with Jatropha, it does not consider the

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<sup>11</sup> Based on interviews with wood traders in Sattur, most of the wood circulating in Sattur is collected from within the talluk or within close proximity to the talluk borders. Hence, this finding is not explained away by wood trading in Sattur.

1 environmental and public health impacts of woodfuel usage. Household air pollution  
2 associated with using solid fuels is currently the fourth leading risk factor of the  
3 global disease burden (Lim, 2012). Moreover, emissions from woodfuel consumption  
4 contribute approximately 2% of greenhouse gas emissions (Bailis et al., in review).  
5 Harvesting woodfuel has also been linked to forest degradation and deforestation,  
6 although the magnitude of this relationship is unclear (Geist and Lambin, 2002;  
7 Hosonuma et al., 2012). These factors are beyond the scope of this analysis, but  
8 should be addressed in future research analyzing tradeoffs between tradition and  
9 modern bioenergy systems.

10

11 Despite these limitations, the main finding of this paper still holds: the current  
12 framing of wastelands in India's biofuel policy masks an existing biomass energy  
13 economy that provides significantly more useful energy in terms of quantity and  
14 diversity than would the country's proposed *Jatropha* biodiesel system.

15

16

## 17 **6. Conclusion**

18

19 Through a comparative energy flow analysis, this study challenges conceptions of  
20 India's wastelands as 'empty' and 'unused'. In rural Tamil Nadu, a diverse biomass  
21 energy economy based on *Prosopis* exists on these lands that services a mix of rural  
22 and urban consumers spread across residential, commercial, and industrial sectors.  
23 The *Prosopis* economy provides 2.5-10.3 times more useful energy than the *Jatropha*  
24 biodiesel economy that the Government of India envisions for these lands. Using by-  
25 products from *Jatropha* production for energy provision can substitute for some, but  
26 not all, of the useful energy provided by *Prosopis*. Thus, contrary to assertions in

1 India's National Policy on Biofuels, growing biofuels on wastelands can weaken,  
2 rather than improve, the country's energy security.

3

4 The energy security impacts of replacing Prosopis with Jatropha will depend on user  
5 responses. As Baka (2014) reveals, most users would either shut down their  
6 businesses or seek out other fossil fuel or biomass substitutes. If users accelerate their  
7 transition to LPG, a strategy favored by the government, India's fossil fuel imports  
8 could increase. Seeking out other biomass substitutes would likely increase land use  
9 pressures, which can potentially lead to land degradation. Thus, replacing Prosopis  
10 with Jatropha will likely impact energy security in perverse ways that are not  
11 currently being considered by policy makers.

12

13 Finally, replacing Prosopis with Jatropha could engender changes in economic and  
14 property relations that could further weaken energy security. These findings are not  
15 specific to rural Tamil Nadu as Prosopis is widely used as a fuelwood throughout  
16 Asia and Africa. Calls to 'develop' degraded lands through biofuel promotion  
17 similarly exist in these regions.

18

19 Theoretically, this study advances both the social metabolism and new geographies of  
20 energy literature through a combined analysis of the biophysical and political-  
21 economic impacts of biofuel promotion. Empirically, this study underscores the  
22 importance of analyzing wasteland-centered biofuel policies at local levels in order to  
23 better understand the changes in human-environmental relationships resulting from  
24 this policy push.

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**Appendix A****Table A.1: Jatropha Modeling Assumptions**

<b>Parameter</b>	<b>Value</b>	<b>Unit</b>	<b>Source</b>
Seed yield	1.72	kg/tree/yr	Almeida, et al, 2010 (reference case)
gestation period	3.00	years	Almeida, et al, 2010
Jatropha husk biomass	38%	% capsule weight	(Vyas and Singh, 2007)
Jatropha seed biomass	63%	% capsule weight	(Vyas and Singh, 2007)
Jatropha husk calorific value	15.50	MJ/kg	Reinhardt, 2008
Jatropha seed oil content	35.0%	%	Whitaker, Heath, 2008
Oil extraction efficiency	16.3%	%	Almeida, et al, 2010
Seed crusher capacity	500.00	kg/hr	ACS survey, Almeida, et al (2010)
Seed crusher electricity usage	76.00	kW	ACS survey, Almeida, et al (2010)
Seedcake calorific value	20.92	MJ/kg	calorific analysis
Transesterification efficiency	0.97	%	Whitaker, Heath, 2008
Jatropha biodiesel calorific value	39.65	MJ/kg	Achten, et al, 2008
diesel fuel efficiency 3.5-7.5 tonne truck	*	g/vkm	EcoInvent
diesel fuel efficiency 7.5-16 tonne truck	*	g/vkm	EcoInvent
diesel fuel efficiency 16-32 tonne truck	*	g/vkm	EcoInvent
Diesel fuel calorific value	44.83	MJ/kg	NIST Chemistry weBBook

\*Withheld due to EcoInvent publication restrictions.

**Appendix B****Table B.1: Prosopis Modeling Assumptions**

<b>Parameter</b>	<b>Value</b>	<b>Unit</b>	<b>Source</b>
Prosopis wood calorific value	18.91	MJ/kg	Authors' calorific analysis
Prosopis charcoal calorific value	31.14	MJ/kg	Authors' calorific analysis
Prosopis wood moisture content	2.2%	Air dry basis	Authors' calorific analysis



**Appendix C****Table C.1: Conversion and Combustion Efficiencies**

<b>Parameter</b>	<b>Value</b>	<b>Unit</b>	<b>Source</b>
Biodiesel conversion efficiency	97%	%	Almeida, et al, 2010
Charcoal conversion	49%	%	Charcoal surveys
Biodiesel combustion efficiency	28%	%	Agarwal, et al, 2007
Biomass power plant efficiency	15%	%	Power plant survey
Cookstove efficiency	12%	%	average of: (Pohekar and Ramachandran, 2004), (Rajvanshi, 2004), (Ravindranath et al., 2009)
Industrial boiler efficiency	62%	%	Average of Prosopis industrial user surveys

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## Figure Captions

Figure 1: Sattur Taluk

Figure 2: Sattur Field site villages: (1) Kumaralingapuram, (2) Sandaivur, (3) Golvarpatti, (4) Nallamanayakkanpatti, (5) Pappakudi, (6) Ammapatti, (7) Attipatti, (8) Padantal, (9) Allampatti, (10) Kattalampatti, (11) Melmadai/ Irrukungudi, (12) Chattrapatti, (13) N. Mettupatti, (14) Muthulingapuram, (15) O. Mettupatti, (16) Surankudi (17) Nenmeni (18) Ottaiyal, (19) Mudittalainagalapuram, (20) Chinnodaippatti, (21) Sevalpatti, (22) Kangarakottai/ Keelachalaiahpuram, (23) Chinna Tambiyapuram, (24) Tulukkankurichchi, (25) Sinduvampatti, (26) Sanankulam/ Sivasankapatti, (27) Sankarapandiyapuram, (28) Ayyampatti, (29) Kukanaparai, (30) Subramaniapuram, (31) Muliseval, (32) Servaikkaranpatti, (33) Ovvanayakkanpatti, (34) Uppathur, (35) Uthupatti, (36) Sippipparai, (37) Nallamuttanpatti, (38) Peranyyanpatti, (39) Kanjampatti, (dark block) Sattur town.

Figure 3: Jatropha-Prosopis energy flow comparison

Figure 4: Jatropha-Prosopis useful energy comparison

Figure 5: Useful energy sensitivity analysis



**Table Captions**

Table 1: Jatropha Scenarios

Table 2: Prosopis annual usage summary

Table 3: Energy return on investment analysis