Regional scale biofuel impact assessment on land use and carbon emission – a case study for Haryana, India

By
Haosong Jiao

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Associate professor Dr. William Currie, Chair

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ABSTRACT

In the past three decades the world has seen dramatic industrialization and population growth, arousing intense land-use competition. As a result, increasing pressure occurs in both food and energy supply. Bioenergy, especially biofuels that are both renewable clean supplements for non-renewable fossil fuels and also strong competitors of arable land for foodcrops, draw great attention from both sides. In India, biofuel initiatives have gained momentum with the national biofuel policy targeting 20% blending of fossil fuels by 2017 and 27% by 2050. Since India is also involved in fast development and owns the second largest population in the world, there are typical land-use conflicts between food production, biofuels and human settlement. This study, taking the middle-north state of Haryana as an example, aims at estimating the potential to achieve policy targets and its impacts on regional land-use conflicts as well as carbon emission.

This report spatially analyses land-use conflicts owing to biofuel expansion. I used an integrated modeling framework to simulate land-use change and biofuel production under two scenarios – food production with/without exportation demand. Under each scenario, three pathways of biofuel production are compared, namely bioethanol from sugarcane molasses, bioethanol from sugarcane bagasse and bioethanol from low-input high-diversity grasses. An empirical model was introduced to measure food demand and human settlement requirements due to population growth. Based on a detailed land-use classification map of Haryana, a social-environmental land-use suitability index across a number of quantitative and qualitative characteristics is constructed for each land-use type in order to define the spatial distribution behaviors. Agricultural behaviors, including carbon emission, impacts on soil organic carbon by irrigation, as well as relations to natural elements such as climate and soil conditions, are simulated by DNDC (DeNitrification-DeComposition) model. An agent-based model is used to investigate how land-use change organized within the region. Each type of land-use is defined as an intelligent agent that is able to interact with surroundings, to choose the optimal position according to land-use suitability index and to make impacts to the environment. This simulation analyzes a period of 40 years from 2010 to 2050 with spatial resolution of 1.28m x 1.28m. Then I analyze annual gaps between biofuels yield and energy target under each scenario.

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1 Introduction

In the past three decades, efforts to take care of rising greenhouse gas (GHG) emissions aggravate the challenge of developing more sustainable future (bio-)energy pathway (Das, Priess and Schweitzer 2012). Research achievements in environmental sustainability and technical breakthroughs though out the life cycle of production pushed biofuels to be an important component of renewable energy in many countries. Consequently, an increased focus has been generated on investigating direct and indirect long-term impacts of biofuel production on environmental sustainability, especially indirect impacts of land-use change that draws much attention (Fargione et al. 2008, Hyungtae Kim 2009, Pimentel 2008, Rosegrant et al. 2008). Different approaches were used to analyze carbon debts and payback time at both regional and global scales to address the complex issues of direct and indirect land-use change (iLUC) on biofuel production (Hoogwijk et al. 2005, Fargione et al. 2008, Tilman, Hill and Lehman 2006). These studies critically summarized the ongoing debate about biofuels that net carbon mission, including carbon mission from direct and indirect land use change, is the reasonable and scientific criteria in measuring long-term environmental impacts. Several authors designed integrated assessment towards different biofuel pathways. Escobar et al. (2009) conducted life cycle analysis (LCA) to discuss the farmland requirements and the impacts on food production under programs which encourage biofuel production (Escobar et al. 2009). Ewing and Msangi (2009) used IMPACT model to study the food–fuel tradeoffs (Ewing and Msangi 2009). Fallot et al. (2005) studied global scale biofuel production capacities and feedbacks between different ecosystems in tropical world (Fallot et al. 2006). Hoogwijk et al. (2005) used quantitative scenarios to investigate the potential of bioenergy under IPCC 'SRES' climate prediction (Hoogwijk et al. 2005).

Recent years, more theories and algorithms of complexity were used in measuring dynamic biofuel expansion systems. Timilsina et al. (2013) used a computable general equilibrium model that explicitly represents the biofuel industry in simulating domestic policies and international markets for biofuels in case of Argentina (Timilsina, Chisari and Romero 2013). In simulating bottom-up decision making processes, an agent-based model of farmers' best management practice (BMP) decisions was developed and linked to a hydrologic-agronomic model of a watershed to examine farmer behavior, and the attendant effects on stream nitrate load, under the influence of second-generation biofuel crop in the Salt Creek Watershed in Central Illinois as a case (Ng et al. 2011). Günther et al. (2011) employed an agent-based model to reflect impacts from market activities on decision-making under influence of biofuel production (Günther et al. 2011). These researches illustrate a trend of combining spatial-temporal dynamic models in simulating detailed regional scale biofuel impacts.

Field et al. (2007) identified complex interplay of four major factors for the future of biomass energy in the global energy system as i) conversion technology and the prospects for using new plants for increasing the yield of usable energy from each unit of available land or water, ii) the intrinsic productive capacity of the land and ocean ecosystems that can be used for biomass energy production, iii) the alternative uses for the land and water resources that are candidate sites for biomass energy production, and iv) the offsite implications of biomass energy technologies for invasive species and for levels of air and water pollution (Field, Campbell and Lobell 2008). Carbon neutral biofuels from non-food biomass grown on degraded and marginal lands are recommended with sustained advantages (Tilman et al. 2006, Fargione et al. 2008, Searchinger et al. 2008). Fargione (2008) compared crop-based biofuels and grasses grown on wasteland and came up with a conclusion that the non-crop biomass with remarkable advantages in biofuel yield and carbon saving (Fargione et al. 2008).

Experiments on low-input high-diversity (LIHD) prairies which consists of a mix of 16 species of grasses proves net negative carbon emission (Tilman et al. 2006). In addition to avoiding taking up agricultural land, the ability of surviving on land with low productivity of LIHD grass also contributes to ecosystem recovery of waste and marginal land (Zhang et al. 2009). Study from Zhou (2009) argues that the mixed low-input high-diversity grass system simulates the intrinsic ecosystem recovery processes (Zhou et al. 2009). The merits on environmental level include reducing carbon emission, avoiding pollution from large amount of fertilizers and biodiversity loss due to the plantation of conventional monoculture biofuels, and lower plant diseases and insect pests in high-diversity plant mixtures, thus decreasing pollution from large amount of pesticides (Zhou et al. 2009). Another global scale study argued that planting the second generation of biofuels feedstocks on abandoned and degraded cropland with marginal productivity may fulfill 26−55% of the current world liquid fuel consumption, without affecting the use of land with regular productivity for conventional crops and without affecting the current pasture land (Cai, Zhang and Wang 2010). Brittain (2010) studied biodiesels from jatropha and argued that its main pro-poor potential is within a strategy for the reclamation of degraded farmland along with local processing and utilization of the oil and by-products (Brittaine and Lutaladio 2010). In addition, by providing physical barriers, jatropha can control grazing and demarcate property boundaries while at the same time improving water retention and soil conditions (Brittaine and Lutaladio 2010).

In addition to counting for net carbon emission, land, under intense pressure of supporting several requirements of the growing population ranging from housing, food, feed to biofuels production plays a decisive role as a critical limiting factor (Das et al. 2012). Consequently, the interaction of energy and agricultural sectors need to be addressed in biofuel studies (Kløverpris et al. 2008). Gibbs et al. (2008) and Searchinger et al. (2008) found an increase in net carbon emission from crop-based bioenergy production and biomass grown on agricultural land (Gibbs et al. 2008, Searchinger et al. 2008). Studies of effects of biofuel targets on agricultural commodities at national level show a consistent increase in major commodity prices over the next decade (Rosegrant et al. 2008, OECD 2006, Banse and Grethe 2008, Elobeid and Hart 2007, Schmidhuber 2006). With more countries initiated biofuel development and set forth national blending targets for fuels, especially for whom food security and poverty reduction are still an issue, a broader examination of the tradeoffs concerning long-term environmental impacts and food security related to biofuel development merit consideration (Ewing and Msangi 2009).

Land suitability assessment is a key factor in the overall bioenergy potential estimation (Das et al. 2012), which can be strengthened by including more factors than geographical constraints as demonstrated in a regional study for Italy (Ragaglini et al. 2011). The explicit identification of marginal lands is essential for biofuel potential estimation (Zhang et al. 2010). This is especially relevant for India, since the national biofuel plans are highly dependent on wastelands and their availability for biofuel production. A review of the recent studies shows that spatially explicit models, literature based approaches and a combination of both are all used in studying availability and configuration of wasteland at national and global levels. Secchi et al. (2011) have underlined the importance of spatially explicit approaches in identifying sub-regions of particular interest (Secchi et al. 2011). Regional studies considerably differ with large or global scale studies with respect to energy crops used, land-use change drivers and productivity of the type of land evaluated (Das et al, 2012). Regional level productivity or impacts on soil fertility require processing and application of more detailed data sources and a more process-oriented approach (Das et al, 2012).

Developing countries especially those with large population under subsistence problem draw more attention in context of fuel-food land-use conflicts than developed/OECD countries, but unclear political targets, constrains in continues data availability and lack of detailed temporal-spatial information are all obstacles in the estimation of bioenergy potentials in these regions (Das et al. 2012, Thrän et al. 2010). In India, per capita availability of inelastic land resource is rapidly declining in relation to annual population growth. Besides, increasing GDP growth leads to rapid urbanization and industrialization and, therefore, more and more agricultural lands are being utilized for non-agricultural purposes (Trivedi 2010). As a rapidly growing economy, India faces with the challenge of simultaneous fulfillment of strongly increasing food and fuel demands (Das et al. 2012, Ugarte and He 2007). Not many researches in India have addressed the linkage of biofuels and food production at national or subnational scales (Das and Priess 2011, Das et al. 2012). Schaldach et al. (2011) employed a spatially explicit model to analyze the impacts of sugarcane-based bioethanol development on land-use change in India and revealed that if 20% bioethanol blending and food demands are to be fulfilled, cropping areas would expand into non-forest natural vegetation, degraded and wastelands (Schaldach, Priess and Alcamo 2011). Ravindranath et al. (2011) studied biofuel potentials of jatropha, palm oil, sugarcane and sweet sorghum then revealed that land competitions between food and fuel production are highly unlikely especially when biofuel production is restricted only to degraded land by policy (Ravindranath et al. 2011). In another study, a cellular automata model was built to predict future land-use pattern under expanding demand for bioethanol (from sugarcane) and biodiesel (from jatropha) in a case study of the state of Karnataka in India (Das et al. 2012). Results indicated that with policy limiting jatropha plantation on wasteland, the current biofuel blending target of 20% on 2017 overestimates the production capability. However, the study did not consider the linkage between urbanization, food and fuel demand increase under the same driver of population increase, and dismissed the bottom-up decision making process driven by pursuing highest yield, thereby flexibility in simulation. Variations in the results of the existing studies indicate the importance of underlying assumptions and emphasis aspects of biomass, pathways of biofuel production, land classification systems and expected yields.

This study aims to complement existing studies by covering additional aspects and improving details mainly in three aspects. First, a self-adaptive land-use decision-making system was used to reflect bottom-up decision-making process involving local social-environmental information. Second, we link urbanization, food demand and bioenergy consumption with population growth to identify the irresistible trend of land-use competition caused by population growth and its internal cooperation. Additionally, bioenergy productions from three resources (sugarcane molasses, sugarcane bagasse and low-input high-diversity grasses) are compared in measuring state-wide bioenergy potential. A high-resolution land-use classification system was used accounting for the fragile land ownership system in study area. We examine total biofuel and food production as well as impacts on food security through land-use change in two policy scenarios. Environmental and economic feedbacks from food and fuel production are also addressed. We applied a spatially self-adaptive land-use model to simulate the land-use dynamics, using the state of Haryana in India as a case study. This study mainly aim to i) apply a agent-based cellular automata model to address land resources competition among urbanization, food and fuel production, ii) quantify policy scenarios to assess current biofuel targets and its impact on food-fuel security, iii) quantify biofuel scenarios to assess potential land-use strategy to meet food and energy requirements, iv) evaluate mitigation of carbon emission. Our analyses cover total agricultural potential and environmental feedbacks, biofuel production potential, impacts on land-use and food commodities, impacts on carbon storage from land-use change and biofuels. We conclude with future options for the Indian biofuel strategy. The approximately 44,212 km^2 in this case study has relative high economic level and agricultural yields in India. Analysis of food security and energy sustainability in this state is indicative of the entire India food-fuel policy. The methods and concepts used in this study are well suited for similar dynamic systems.

2 Study area

The study was conducted in the densely populated state of Haryana in the northern plain of India (44,212 km^2; population about 25 million in 2011 census). This area locates between 27.37' to 30.35' E latitude and between 74.28' to 77.36' N longitude in the sub-tropical belt. The landscape of the state varies from hills in the northern region to almost level alluvial plains in the central parts and sand-dunes in the southern districts. The region mainly has three types of climate: arid, semi-arid and sub-humid. The annual average rainfall of the state is 650 mm, varying from less than 300 mm in the south-western parts to over 1,000 mm in the hilly tracts of Siwalik hills. The mean annual temperature ranges from 23°C to 26°C with minimum temperature close to freezing in December/ January and maximum daily temperature above 40°C in May/June. The soils of the area can be broadly classified into red and black soils (Patna 2002) with loamy, sandy and sandy silt loamy textures (ESDB 2013).

Haryana is a main agricultural zone of India and also a leading contributor to the country's production of foodgrains. Agriculture is the leading occupation for the residents of the state. Haryana contributed heavily to the Green Revolution that made India self-sufficient in food production in the 1960s. Its diverse agricultural systems highly depend on rainfall, with river Yamuna and Ghaggar as main sub-resources. At the same time, Haryana suffers with remarkably agricultural land degradation. In 2010, total degraded and wasteland takes up 551 ha (about 11% of total ground area) in Haryana (Trivedi 2010). Over recent decades, the economy of the state has seen high growth and has the second highest per capita income in India. Besides, its agricultural and manufacturing industry has experienced sustained growth since the 1970s. Rising economy and population directly leads to urbanization and growth of energy consumption both in cities and rural area. Escalating fuel dependence on import and mitigate land resource pressure has been evolved into state sustainable development goal.

Following the global trend of blending fossil fuel dependence especially in transportation sector and Indian renewable energy policy for taking use of marginal land, special emphasis has been laid on alternative fuels such as biofuels especially feedstocks grown on wasteland. Scientific land use strategy plays vital role in optimize land use efficiency given the fragile land owning condition. Haryana has been awarded Best State Award consecutively for the four years since 2007 for promotion of energy conservation (Government of Haryana 2013). The Department of Renewable Energy of Haryana state implemented schemes concerning utilization of biogas and biomass energy to promote the policies and programs necessary for popularizing the applications of various new and renewable energy technologies in the state, as well as promoting the energy conservation measures for efficient uses of energy resources (Department of Renewable Energy 2013). Densely-distributed panchayats have been set up in regulation of biofuel feedstock plantation (PCRA 2014). In a bid to make Haryana eco-friendly with mass production of bio-fuels from all kinds of biomass and organic waste (Financial Express 2014), research institutes such as Chaudhary Charan Singh Haryana Agriculture University has enhanced cooperation with government and companies on providing policy support, training and field implementation for biofuel plantation and commissioning (Parikh 2014). Systematically cooperation have been set up in promote biofuel production with minimum extra pressure on land resources.

3 Methodology overview

The study designed an integrated agent-based automata approach on ArcGIS Agent Analyst (resources.arcgis.com) to model spatial-temporal land-use changes and social-economic consequences in regional scale. This model applies functions of four submodules, namely, multicriteria suitability analysis of land-use, agent-based land-use allocation driven by commodity production/demands (food and fuel) and urbanization, simulation of crop growth (commodity production) by the DNDC model (Li 2012) and analysis of food-fuel yield. Main land-use types in Haryana are defined as agents that choose locations and interact with the surroundings according to a set of rules developed in regard of social-economic conditions. The spatial land-use pattern is the result of agent behaviors. Effects of biofuels on land-use change, food crop production were simulated, as well as carbon emission. Given the fragile agricultural parches in Haryana, spatial resolution of the study was 128m x 128m.

4 Agent-based model structure

Referring to a common regional scale land-use modeling framework Simulation of Terrestrial Environments (SITE) (Mimler and Priess 2008, Schweitzer, Priess and Das 2011) and a cellular model on food-fuel land-use change in case of kanataka, India (Das et al. 2012), this study employed an integrated model to simulate land-use conflicts among food, fuel and human settlement, in which land-use suitability, demand/supply change and feedbacks to the environment are reflected by agent attributes and behaviors.

Agent-based model is an increasingly popular adaptive model in simulating rarely deterministic land use decision-making (Brown et al. 2005). Agents in this model are given “intelligence” to represent their attributes and to behave interactively with the environment. It comprises multiple, interacting actors, and proves to well represent complex adaptive and multiple equilibrium economic and ecological systems in general (Pahl-Woštl 1995) and spatial land-use systems in particular (Atkinson and Oleson 1996, Balmann 2001), thus expects to aware the unpredictability of land use decision making patterns and maximum simulation accuracy with consideration of a variety of social-environmental factors (Kok et al. 2001, Pijanowski et al. 2002, Pontius Jr 2002, Verburg et al. 2002).

4.1 Agent definition

Depending on differences in attributes and behaviors for types of land-use and requirements for simulation accuracy, this model employed seven kinds of agents to represent the main sources for land resources pressure in Haryana. They are urban agents which represents human settlement and urbanization process, agricultural agents namely wheat, rice, foodgrains, cotton, sugarcane which are the main commodity crops in Haryana (Government of HaryanaHaryana 2013) and biofuel agents representing LIHD grasses. Considering the fragile irrigation land distribution in the densely-populated agricultural state Haryana and the resolution of base-map, the size of an agent equals a 128m x 128m unit cell in the lattice. For each type of land-use, allocation preference is measured by a set of environmental-economic factors and constraints as its land-use suitability (see land-use suitability in following content). Annual yield and feedback to the environment such as changing soil organic carbon pool through growing as agent attributes for food and fuel crops are simulated by DNDC model (see growth simulation in following content). Net profit margin as another attribute for crops is projected by time-series data (see net profit margin in following content).

4.2 Agent Environment

In agent allocating process, each position is necessary to contain social environmental information. Agent-based modeling of spatial land-use patterns requires an initial land-use map corresponding to a historical period in time. There was not such a map readily available at the reasonable resolution and the level of detailed classification for achieving the objective of simulating food-fuel land-use conflicts. This study employed a sequence of steps to construct a suitable initial map. First, a land-use classification map was developed according to suitable classification system for food-fuel land-use simulation. It contains allocation of types of land-use. Second, two soil maps were developed. One of them contains necessary soil condition information for each crops' growth simulation, and the other contains initial soil organic carbon (SOC) map in representation of initial carbon pool which will both influence growing and being influenced by agricultural activities. Detailed allocation of food crops to agricultural area was simulated by current total yields and optimal land-use suitability of each crop.

4.2.1 Land-use classification

Haryana serves as a typical example of poor developing area with large population, long-term poverty, low-level agriculture, food crisis and increasing energy requirement, it makes sense in providing reference for reducing conflicts between biofuel production and food security in areas under similar social-ecological conditions in the world. The land classification system was a combination of traditional land-use classes and regional significant classes to adequately represented major sources of pressure on land in the food-fuel issue. Considering both of these aspects and the availability of statistical data for these classes, two tiers of land-use classes containing five tier 1 classes and nine tier two classes were employed (Table 1).

Table 1 Land-use classification for Haryana

Tier I basic classes	Tier II 9 classes for food-fuel research[Π]

Agricultural land	Wheat, rice, foodgrains*, sugarcane, cotton
Human settlement	Human settlement
Wasteland	Wasteland
Water	Water
Other	Forest, protected area, other**

*Barley, millet, Jowar, Bajra

**sand, bareland, rocky land

ΠCrops were selected and grouped based on contribution to total food production, growth and yield similarity in growth simulation and occupied land in Haryana. Low-input high-diversity grass did not appear in the initial map.

Global cropland classification map (ESODIS 2013) was used as base map to distinguish cropland, forest and from other land use classes. Spatial database on land use land cover from Indian Haryana Space Applications Centre (HARSAC) (Geo-portal 2013) was used to improve its classification by distinguishing urban land use. Vector maps of water, waterline, railways, railway stations and roads distribution from ThinkGEO and Maptell (Map 2013, Maptell 2012) were used to measure accessibility to water and transportation. Wasteland information comes from Haryana wasteland map 2005 and 2010 (NRSA 2003, NSRA 2010) and the total percent of 11% of wasteland in 2010 was used for validation. Detailed spatial data resources are listed in Appendix. Wasteland expands fast in Haryana taking up 7.39% of total ground area in 2005 and 11% in 2010 in Haryana (Trivedi 2010, Department of Land Resources 2005). Assuming technological improvement on land conservation, this study used a slow land degradation rate of 0.1% of total ground area.

4.2.2 Soil maps

Soil data from Harmonized World Soil Database (HWSD) (ESDB 2013) was downscaled for the study area. This soil map contains main parameters of soil condition such as soil organic carbon, bulk density, texture (sand, silt and clay fractions) and soil pH which serves as important factors in agricultural activities and land-use decision-making (Li 2012, DNDC 2010). According to HSWD, soil condition in Haryana is originally divided into 12 types (Table 2).

Table 2 Original soil condition in Haryana

Region code	Drainage grade	Sand fraction	Silt fraction	Clay fraction	texture class	SOC kg C/kg soil	pH	Bulk density g/cc
3541	4	56.63	25.58	17.8	Sandy loam	0.0043	7.45	1.44
3671	3	41.75	34	24.25	Loam	0.0067	6.62	1.4
3686	4	40.3	37	22.7	Loam	0.0068	7.3	1.35
3716	4	42.34	32.52	25.15	Loam	0.0091	6.92	1.4
3740	3	38.25	41.3	20.45	Loam	0.0057	7.49	1.4
3798	4	42.95	31.55	25.5	Loam	0.0058	6.4	1.45
3800	4	65.75	14.7	19.55	Sandy loam	0.0049	6.21	1.46
3811	4	41.85	33.35	24.8	Loam	0.0053	7.01	1.42
3841	4	58.1	26.55	15.35	Sandy loam	0.0041	7.44	1.42

3855	4	47	32.25	20.75	Loam	0.0066	6.52	1.37
3875	4	38.45	36.95	24.6	Loam	0.0044	7.98	1.32
3879	4	33.05	38.98	27.98	Clay loam	0.0055	7.8	1.4

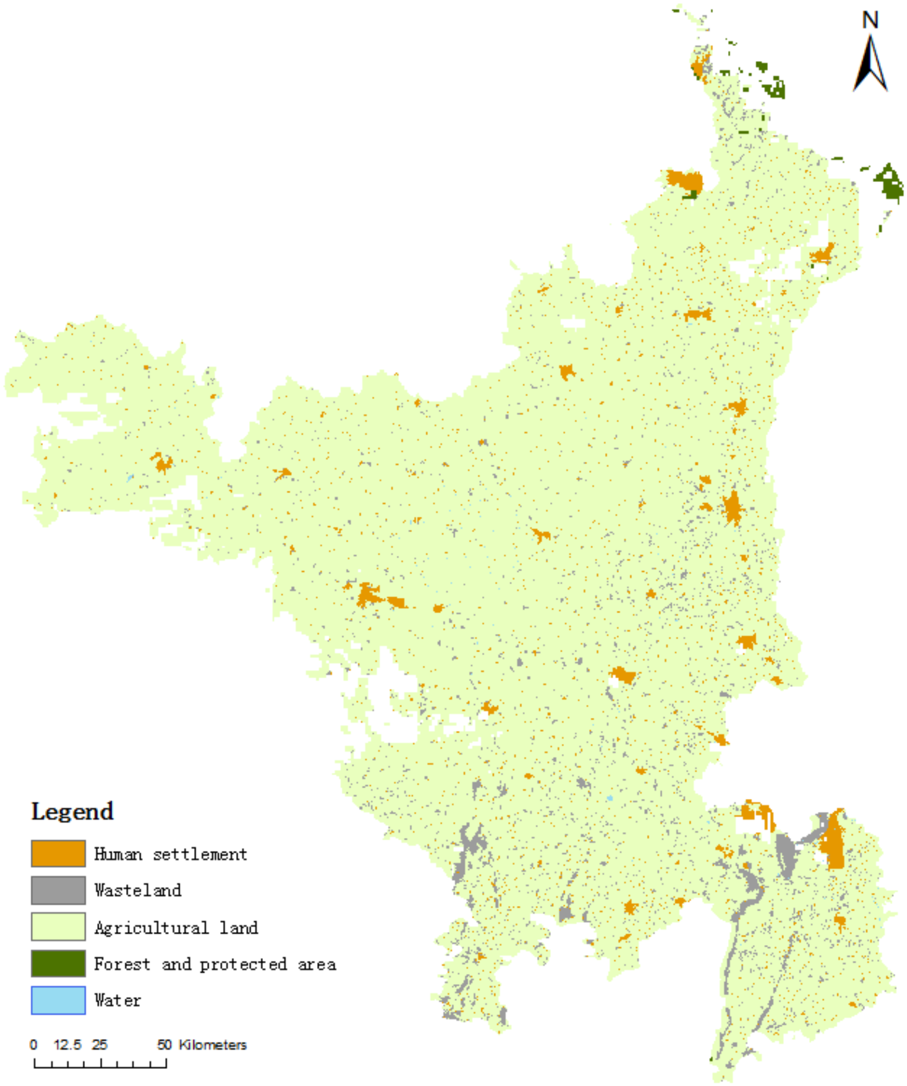


Figure 1 Initial land-use classification map

4.3 Agent Behaviors

The model was developed to project scenarios of biofuel and other crops competing for land resources with urbanization. In the real decision-making process at both political/governmental and household level, types of land-use aims to match to the most suitable locations with different types emphasizing on a variety of factors. In this study, a sequence of land-use allocation strategy is employed to achieve an optimal food and fuel production capacity. First, in annual modeling steps, existing crop agents re-evaluated its suitability at current position and move to positions with higher suitability. In reality, land transfer happens in a micro-scope because of limited accessibility to land resources, thus a range of 10 km is used to achieve a regional optimal land-use suitability. Then new agents are created and distributed to satisfy the demands for food, fuel and human settlement. Settlement area with non-substitutable contribution on fundamental living condition decides human settlement agents allocate first. The number for human settlement agents enters annually depends on a theoretical model of origin of urban expansion (Bettencourt 2013) (see projection of human settlement in following content).

Agents of food crops enter then and locate on positions with highest land-use suitability until the gap between current total food yields and demands is covered. If current food production capacity is beyond demands, surplus agents die and release the position for others. Croplands without agricultural activity were considered fallow in that year. To measure the biofuel potential with minimum conflicts with food production, fuel agents enter at last. The number of new fuel agents depends on current total bioenergy demand and total yield, as well as available lands. When choosing a position, this model allows each agent to look at a number of randomly selected cells and move into the cell that provides them with the highest land-use suitability. Allowing agents to only look at a subset of locations introduces bounded rational behavior (Brown et al. 2005), effectively resulting in randomness which reflects the observation that decisions by developers, farmers, or individuals also have random components based on preferences, personal relationships, limited search, and timing (Brown et al. 2005). Besides, the model addressed important feedbacks between annual agricultural activities and environmental changes, such as soil properties that will be taken into account in subsequent decisions. Figure 2 shows the structure of the model components. The major components are described in the following subsections.

5 Land-use suitability analysis

Regional land-use decision-making depends on a set of social-environmental factors. The kind and importance of factors vary for different land-use type. It generally contains environmental condition like climate, moisture and soil condition, economic factors like commodity prices, costs and demands, as well as spatial factors like distance to transport, essential resources and markets, etc. In this study, a multicriteria assessment algorithm (Eq1) calculates suitability of each position for each land-use type represented in the model.

$$S = \mathrm{Max}\left(W_E \sum_{i=1}^{m} \alpha_i A_{\alpha m} + W_S \sum_{j=1}^{n} \beta_j A_{\beta n}\right) \times \prod_{i=1}^{n} C_i \qquad \text{(Eqn 1)}$$

W_E and W_S represent the weight for environmental and social-economic criteria, with $W_E + W_S = 1$. $A_{\alpha m}$ and $A_{\beta n}$ represent values for each criterion with the range of [0,1]. α_i and β_j are weights for each criterion, with $\sum_{i=1}^{n} \alpha_i = 1, \sum_{j=1}^{n} \beta_j = 1$. C_i represents land-use converting constraint with value either 0 or 1.

The calculation of the sum suitability value S for each position under each type of land-use class consists of two terms. The first part environmental suitability and the second part social-economic suitability are weighted using the partial weights α_i/β_j, where m and n represent the total number of criteria included (Das et al. 2012).

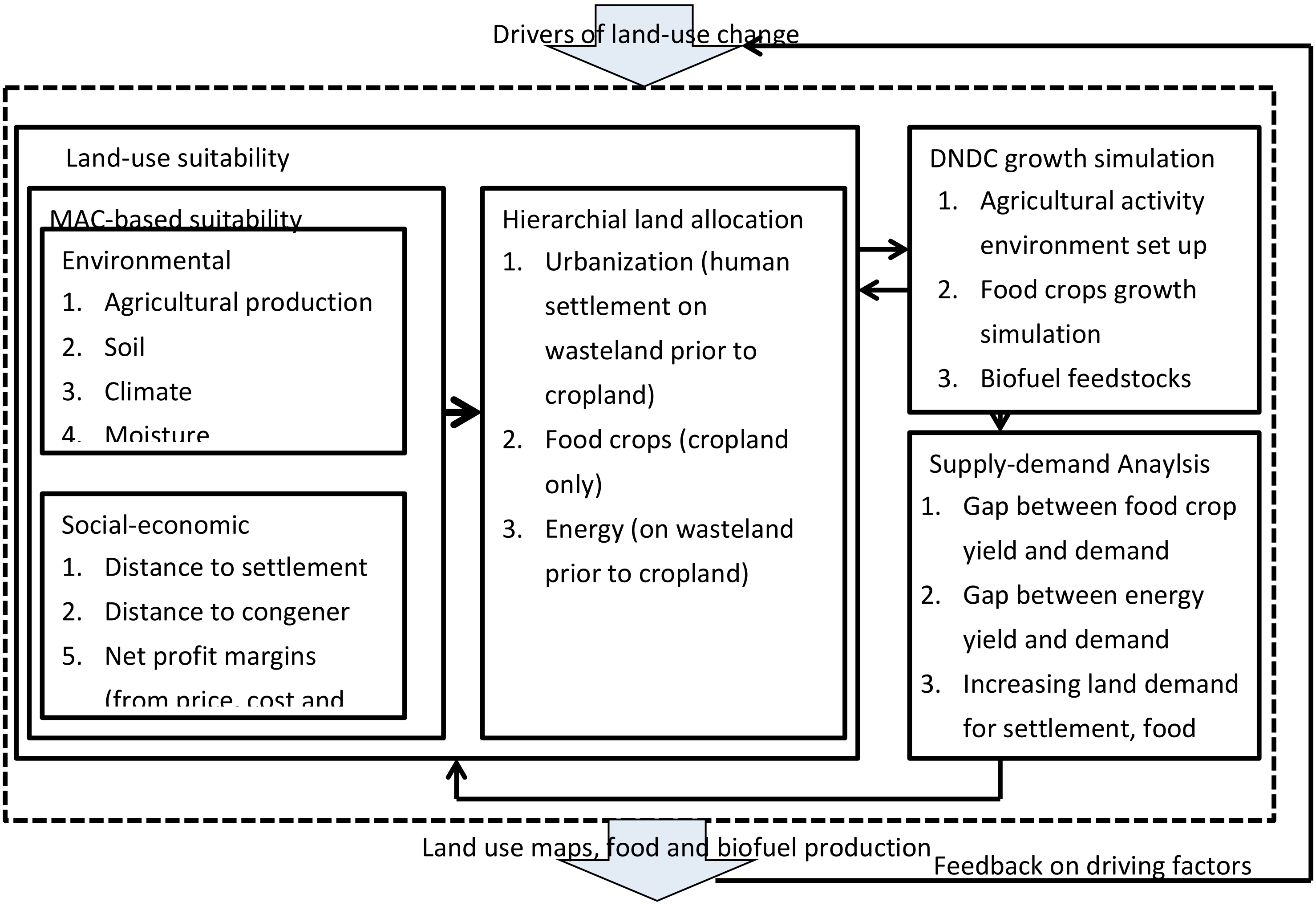


Figure 2 Structural components of the agent-based model

For human settlement, social-economic suitability is addressed by a simplified urbanization model which links urban area expansion with Euclidean distance to existing urban and demand for transport (see prediction of human settlement). The environmental suitability holds negative relation with agricultural conditions in order to maximize protection of croplands. For food and fuel areas, parameters relate to profits strongly influence crop allocation both in reality and in the simulations (Das et al. 2012). Economic suitability for each crop is addressed by simulating the benefits of cultivation and distances to markets. Projected yields with DNDC model (see growth simulation), historical data of planting cost and price prediction with time-series records (Directerate of economics and statistics 2000-2010) together decides the net profit margin for cultivation. Considering the general wide demand for crops in this study and the lack of concrete market allocation, accessibility to markets was simulated using distances to urban, roads and railways. Euclidean distances to the same class of agent is involved assuming the cluster of agriculture. Distance to water is used assuming availability to irrigation. Since other environmental factors such as initial SOC and soil texture were already represented in simulation of yield, they are not included as criteria. Table 3 shows criteria for land-use suitability.

A set of constraints limits conversion between types of land-use. Once constructed, urban area cannot switch to other land-use. Croplands can develop into urban area and also wasteland through degradation. Wasteland can be used for biofuels feedstock cultivation or human settlement. Protected areas, such as forests and water were excluded from agent allocation (see land-use classification). Since the low-input high-diversity (LIHD) grasses can survive on wastelands under relative worse growing condition (Tilman et al. 2006), which avoids competing for arable land with foodcrops, they are simulated to grow on wastelands only. Table 4 lists detailed constrains.

Table 3 Land-use suitability criteria

Agent	Criterion	Justification
Human settlement	Neighbor density of human settlement	Socia-economic (+ factor), minimize distance to development
	Distance to road	Socia-economic (- factor), minimize distance to urban services
	Initial soil organic carbon	Environemtal (- factor), minimize soil degradation
	Soil texture	Environmental (- factor), minimize impacts to agricultural land
Crops (include wheat, rice, cotton, sugarcane and foodgrain)	Net profit margin	Socia-economic (+ factor), equals yield multiply benefit per cell, maximum profit
	Distance to urban	Socia-economic (+ factor), minimize distance to market
	Neighbor density of same agents	Socia-economic (+ factor), Agricultural density
	Distance to railway station	Socia-economic (- factor), minimize distance to market services
	Distance to road	Socia-economic (- factor), minimize distance to market services
	Distance to water	Environmental factor (-factor), minimum distance to growth factor
LIHD grasses	Distance to urban	Socia-economic (+ factor), minimize distance to market
	Distance to railway station	Socia-economic (- factor), minimize distance to market services
	Distance to road	Socia-economic (- factor), minimize distance to market services

	Neighbor density of same agents	Socia-economic (+ factor), Agricultural density

Table 4 Land-use suitability constraints

From to	settlement	wasteland	cropland	water	other
Settlement	✓	-	-	-	-
Wasteland	✓	✓	-	-	-
Cropland	✓	✓	✓	-	-
water	-	-	-	✓	-
other	-	-	-	-	✓

6 Growth simulation

The DNDC model is used to calculate growth and yields of crops. Simulations also address important feedbacks between agricultural activities and environmental changes, such as changes of soil organic carbon storage. Crops were parameterized for Haryana and simulated for growth by DNDC model (Li 2012). Based on 40 years of simulation on various environmental conditions, main growing and carbon emission factors for types of crops were fitted using nonlinear regression equations with reasonable correlation and significance values.

6.1 Parameterization of DNDC model

DNDC (De-Nitrification-De-Composition) is a computer simulation model of carbon and nitrogen biogeochemistry in agro-ecosystems. It can be used for predicting crop growth, soil carbon dynamics, nitrogen leaching, and emissions of trace gases including nitrous oxide (N_2O), nitric oxide (NO), nitrogen (N_2), ammonia (NH_3), methane (CH_4) and carbon dioxide (CO_2) (DNDC 2010). Information of climate, soil condition and moisture of Haryana were used to parameterized growth for each crop.

6.1.1 Climate

For temperature and precipitation change from 2010 to 2050, this study used annual average temperature and precipitation of Haryana as baseline (Meoweather 2012) (Table 5). The IPCC 2010 climate change B2 storyline was employed which represents an increased concern for environmental and social sustainability for temperature (Ruosteenoja et al. 2003) and precipitation prediction. Using the average results of the six IPCC models, monthly temperature change from 2010 to 2050 is presented in Table 6.

Table 5 Annual average weather of Haryana 2013

Month	Temperature °C				Average Rainfall (mm)	
	Average		Absolute		Daily	Monthly
	max	min	max	min		
January	19.22	6.72	28.22	-0.89	0.70	21.40
February	22.61	9.22	32.00	0.00	1.10	30.40
March	28.22	13.39	37.00	5.50	0.80	24.90
April	35.61	18.28	43.22	9.78	0.50	15.40
May	39.28	23.61	47.00	10.78	1.00	31.00
June	38.00	26.00	45.72	19.11	3.40	102.20
July	34.78	26.72	45.50	20.00	5.10	157.60
August	33.39	25.78	37.61	13.61	6.60	205.20
September	33.39	23.50	42.00	17.50	3.80	113.80
October	32.22	17.22	37.78	10.78	0.50	15.60
November	28.00	11.28	35.39	0.00	0.10	3.10
December	22.11	7.72	29.78	0.00	0.30	10.20

Table 6 IPCC B2 scenarios India ocean area climate change prediction 2010-2050

Season	Temperature °C		Precipitation mm	
	2010-2039	2040-2050	2010-2039	2040-2050
DEC-FEB	0.75	0.48	0.30	0.40
MAR-MAY	0.74	0.49	3.82	1.65
JUN-AUG	0.72	0.47	-0.26	0.35
SEP-NOV	0.73	0.47	1.02	0.53

Resources: (Ruosteenoja et al. 2003)

6.1.2 Soil

Experiments with DNDC model shown that soil texture, bulk density, soil pH and SOC (soil organic carbon) are main factors for growth prediction. DCDC library parameterized fourteen soil textures (DNDC 2007) and twelve of them are used in Haryana. Soil texture is decided by fraction of clay, sand and silt (Gardener 2013). Bulk Density is the oven dry weight of a unit volume of soil inclusive of pore spaces and varies proportional to texture (AgriInfo 2011). According to general bulk density for sand, loam, silt loam and clay published by AgriInfo (AgriInfo 2011), bulk density for all twelve soil textures were calculated. For soil PH, FAO experiments and DNDC models on sample soil PH support that soil PH generally decline with clay fraction increased (FAO Land Resources 2014). Besides, soil with higher clay fraction resists better to pH change (FAO Land Resources 2014). Thus this study assumed that soil PH with clay fraction a range of 0-0.3 declines proportionally from 8 to 7 and maintains 6.5 with clay fraction over 0.3. Though significant for growth, soil organic carbon (SOC) does not have literately linear relation with other factors. So in growth simulation, the initial SOC for growth prediction was kept default by DNDC. Parameters for soil are represented in Table 7.

Table 7 Soil parameters

texture	clay fraction	porosity	saturation conductivity	field capacity	wilting point
	Fraction	Fraction	cm/min	WFPS	WFPS
Sand	0.03	0.395	1.056	0.15	0.1
Loamy sand	0.06	0.411	0.938	0.25	0.13
Sandy loam	0.09	0.435	0.208	0.32	0.15
Silt loam	0.14	0.485	0.0432	0.4	0.2
Loam	0.19	0.451	0.0417	0.49	0.22
Sandy clay loam	0.27	0.421	0.0378	0.52	0.24
Silty clay loam	0.34	0.477	0.025	0.55	0.26
Clay loam	0.41	0.476	0.0147	0.57	0.27
Sandy clay	0.43	0.426	0.013	0.6	0.28
Silty clay	0.49	0.492	0.0095	0.63	0.3
Clay	0.63	0.482	0.0077	0.75	0.45
Organic	0.66	0.701	0.012	0.55	0.26

Table 7 cons. Soil parameters

texture	specific heat	SOC at surface (0-10cm)	water tension	Bulk Density	Soil PH
	J/kg/K	kg C/kg soil	cm	g/cc	
Sand	2000	0.0096	3.5	1.6	8
Loamy sand	2000	0.0096	1.78	1.55	7.8
Sandy loam	2000	0.0096	7.18	1.5	7.6
Silt loam	2000	0.0096	56.6	1.45	7.4
Loam	2000	0.0096	14.6	1.4	7.2
Sandy clay loam	2000	0.0096	8.63	1.35	7
Silty clay loam	2000	0.0096	14.6	1.3	6.5
Clay loam	2000	0.0096	36.2	1.25	6.5
Sandy clay	2000	0.0096	6.16	1.2	6.5
Silty clay	2000	0.0096	17.4	1.15	6.5
Clay	2000	0.0096	18.6	1.1	6.5
Organic	2500	0.0096	14.6	1.05	6.5

6.1.3 Crop parameters

The main Five fundamental commodity crops (wheat, rice, foodgrain, cotton and sugarcane) of Haryana (Government of Haryana 2013) were parameterized. We used an average performance of a group of switch grasses to represent growth behavior of the Low-input high-diversity grasses, which is carbon negative biofuel feedstocks consisting of a mix of grasses such as hay and shrub (Tilman et al. 2006). The parameters used are provided in Table 8. Details on parameter definitions can be found in DNDC library of crops (DNDC Library 2010).

Table 8 Crop parameters

Crop name	Wheat	Rice	Foodgrain	Cotton	Sugarcane
Harvest times	2	2	1	1	1
max biomass C kg C/ha	7610	8238	8320	4500	17760
grain fraction	0.41	0.41	0.3	0.32	0.01
leaf fraction	0.21	0.27	0.23	0.26	0.44
stem fraction	0.21	0.27	0.23	0.26	0.44
root fraction	0.17	0.05	0.23	0.16	0.1
Grain C:N	40	45	45	10	150
Leaf C:N	95	85	75	45	130
Stem C:N	95	85	75	45	130
Root C:N	95	85	85	75	150
Water Demand kg water/kg DW	200	508	250	400	500
Optimum T Degree C	22	25	21	25	32
TDD	1300	2000	1300	2500	5000
N fixation	1	1.05	1	1	1
fertilization month/year	2	2	2	2	2

Table 8 cons. Crop parameters

Crop name	LIHD grass	Legume hay	Non-legume hay	Annual grass	Perennial grass
Harvest times	1	1	1	1	1
max biomass C kgC/ha	7553	11000	11000	4444	9333
grain fraction	0.06	0.01	0.01	0.01	0.02
leaf fraction	0.30	0.4	0.4	0.22	0.35
stem fraction	0.30	0.4	0.4	0.22	0.35
root fraction	0.33	0.19	0.19	0.54	0.28
Grain C:N	49.22	50	80	33	35
Leaf C:N	67.67	50	80	33	35
Stem C:N	67.67	50	80	33	35
Root C:N	76.56	90	90	50	50
Water Demand kgwater/kgDW	383.33	550	550	300	200
Optimum T Degree C	21	21	21	21	21
TDD	2333.33	2500	2500	2500	2000
N fixation	1.39	2.5	2	1.01	1.5
fertilization month/year	0	0	0	0	0

Table 8 cons. Crop parameters

Crop name	Shrub	Cover crop	Sedge	Ever greens	Boreal sedge
Harvest times	1	1	1	1	1
max biomass C kgC/ha	2400	4000	20000	4324	1480
grain fraction	0.01	0.01	0.1	0.37	0.01
leaf fraction	0.25	0.4	0.3	0.22	0.2
stem fraction	0.25	0.4	0.3	0.22	0.2
root fraction	0.49	0.19	0.3	0.2	0.59
Grain C:N	30	15	50	50	100
Leaf C:N	150	25	61	75	100
Stem C:N	150	25	61	75	100
Root C:N	150	30	44	85	100
Water Demand kgwater/kgDW	250	300	800	400	100
Optimum T Degree C	15	25	25	25	15
TDD	2000	1300	3000	4000	1200
N fixation	1	1.5	1	1	1
fertilization month/year	0	0	0	0	0

6.1.4 Yield parameters

In annual step, DNDC simulates crop growth through the algorithm fully considering all parameters and report yields by carbon contents. So the simulated yield should first be converted into product weight. According to FAO, "the carbon content of vegetation is surprisingly constant across a wide variety of tissue types and species (Steen Magnussen 2004). Schlesinger (1991) noted that carbon content of biomass is almost always found to be between 45 and 50% (by oven-dry mass)" (Schlesinger and Bernhardt 1991). We use 47.5% as the constant carbon content for all experimented crops. Yield was calculated by Eqn 2 and Eqn 3. Details for carbon and water contents of each crop are presented in Table 9.

$$\text{Carbon content} = 47.5\% \times (1 - \text{water content}) \quad (\text{Eqn } 2)$$

$$\text{Yield} = \text{C yield weight} \div 47.5\% \div (1 - \text{water content}) \quad (\text{Eqn } 3)$$

Table 9 Carbon and water content in crops

	C content	Water content
Wheat	41.33%	13.00%
Sugarcane	33.00%	65%
Rice	41.99%	11.60%
Cotton	44%	7.85%
Foodgrain	41.33%	13.00%

Note: water content for LIHD grass was got from http://bunniesinneed.net/hay-nutritional-value-chart/ and others from Wiki.

6.2 Simulation of yield and carbon emission

Both crop yields and irrigation impacts on soil organic carbon storage are simulated in DNDC Model. Yields are converted to product with unit kg/hect yr^{-1}, and simulation of decrease in soil organic carbon (dSOC) is measured as kg C/hect. To combine the DNDC model with agent-based spatial land-use simulation, we used nonlinear regression to figure out main growing factors for each crop then reveal the formulas for yields and carbon pool changes with 40 years simulation results. Table 10 and 11 show the nonlinear regression formulas of yields and decreases in soil organic carbon storage for each crop. Calibration for each crop with R2 and p values is in Appendix. Since LIHD grasses can survive on marginal land (Brittaine and Lutaladio 2010, Cai et al. 2010, Fargione et al. 2008, Tilman et al. 2006) but DNDC does not define attributes for this soil condition, LIHD grasses was assumed to require less input and environmental suitability with fixed yield of 681000 MJ/km^2 (Tilman et al. 2006). Fallow was considered containing no yield and carbon pool change.

Regression results show that, yield and soil organic carbon changes for most crops relates to initial soil organic carbon content and clay content. For climate information, only highest/lowest temperature and average rain in season II (Match-May), III (June - August) and IV (September-November) have significant correlation with yield and soil organic carbon changes, specifically the product of highest temperature, product of lowest temperature and the product of average rain of the three seasons. According to IPCC climate change scenarios (Ruosteenoja et al. 2003), we assumed smooth temperature and precipitation change in two periods, namely 2010-2039 and 2040-2050. Then seasonal climate information is calculated by baseline climate (2010) and time-serial information in future years (Table 12). Figure 3 shows the comparison between observed and simulated crops.

Table 10 Annual crop yield

Crop	Yield
Wheat	$0.062\times S_i - 6838.93\times C_i - 16461.87\times T_{n\,max} - 63.99\times T_{n\,min} + 172.78\times R_n + 996187.85$
Rice	$0.000298\times S_i + 30.17\times T_{n\,max} - 83.57\times T_{n\,min} - 0.069\times R_n - 428328$
Foodgrain	$-0.3228\times T_{n\,max} + 0.8655\times T_{n\,min} + 0.00069\times R_n + 6356.59$
Cotton	$-0.43\times T_{n\,max} + 1.1364\times T_{n\,min} + 0.00014\times R_n + 7251.20$
sugarcane	$-0.297\times S_i - 6921.27\times C_i - 2.0606\times T_{n\,min} - 0.028\times R_n + 52972.64$

Table 11 Annual crop dSOC

Crop	dSOC
Wheat	$0.28\times Y_i - 0.05\times S_i - 533.90\times C_i - 4.14\times T_{n\,max} + 10.61\times T_{n\,min} - 0.002\times R_n + 70746.54$

Rice	$0.47\times Y_i - 0.01\times S_i - 16.20\times T_{n\,max} + 43.50\times T_{n\,min} + 0.0061\times R_n + 249686.6$
Foodgrain	$-1.79\times Y_i - 0.015\times S_i + 1.54\times T_{n\,max} - 4.21\times T_{n\,min} - 21853.30$
Cotton	$-6.69\times Y_i - 0.016\times S_i + 1.84\times T_{n\,max} - 4.99\times T_{n\,min} - 26241.2$
sugarcane	$1.42\times Y_i - 0.04\times S_i - 3624.53$

Table 12 Parameter explanation 2010-2039

Parameter	Formula
$T_{n\,max}$	$(34.37 + 0.025n)\times(35.39 + 0.024n)\times(31.2 + 0.025n)$
$T_{n\,min}$	$(18.43 + 0.025n)\times(26.17 + 0.024n)\times(17.33 + 0.025n)$
R_n	$(23.57 + 0.114n)\times(155 - 0.01n)\times(44.17 + 0.026n)$

$T_{n\,max}$ Product of max temperature in season II, season II and Season IV

$T_{n\,min}$ Product of min temperature in season II, season II and Season IV

R_n Product of average precipitation in season II, season II and Season IV

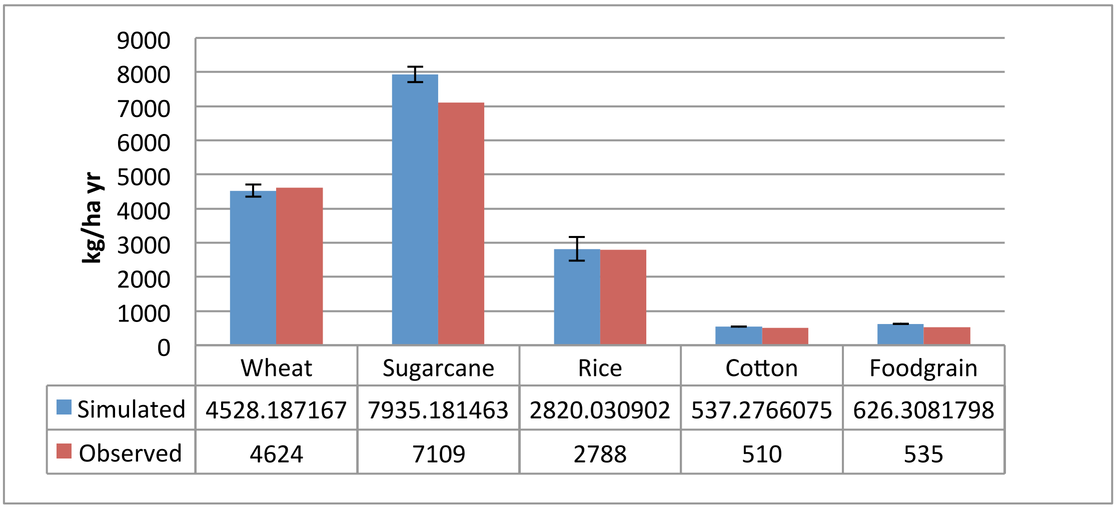
Table 12 con. Parameter explanation 2040-2050

Parameter	Formula
$T_{n\,max}$	$(35.15 + 0.044n)\times(36.14 + 0.042n)\times(31.97 + 0.007n)$
$T_{n\,min}$	$(19.21 + 0.044n)\times(26.92 + 0.042n)\times(18.1 + 0.007n)$
R_n	$(27.2 + 0.012n)\times(154.68 + 0.007n)\times(44.93 + 0.007n)$

$T_{n\,max}$ Product of max temperature in season II, season II and Season IV

$T_{n\,min}$ Product of min temperature in season II, season II and Season IV

R_n Product of average precipitation in season II, season II and Season IV



	Wheat	Sugarcane	Rice	Cotton	Foodgrain
🟦 Simulated	4528.187167	7935.181463	2820.030902	537.2766075	626.3081798
🟥 Observed	4624	7109	2788	510	535

Figure 3 Comparison between simulated and observed crop yields in Haryana

7 Demand prediction - human settlement

Human settlement is always a basic need all over the world as well as in Haryana, India. The crucial property of cities is that they are mixing populations, which is the basis of definitions of functional cities (Roy M. Anderson 1991, Bureau 2013).The allocation of land for settlements, which is represented by urbanization, has the highest priority and is allocated first in the model. In this study theoretical framework from Bettencourt that derives the general scaling properties of cities through the optimization of a set of local conditions was employed to explain how urban area and urban transportation energy consumption change gradually from the bottom-up (Bettencourt 2013).

7.1 Urban area expanding model

To model human settlement expansion, the greatest difficulties to any scientific approach have resulted from their many interdependent facets, as social, economic, infrastructural and spatial complex systems, which exist in similar but changing forms over a huge range of scales (Bettencourt 2013). Several analyses of data from many urban systems worldwide have begun to establish a series of general statistical regularities of cities as systematic nonlinear variations of urban quantities (Batty 2008, Bettencourt, Lobo and Strumsky 2007a, Bettencourt et al. 2007b, Changizi and Destefano 2010, Glaeser and Gottlieb 2009). Bettencourt’s study of these empirical scaling results suggests that, despite their apparent complexity, cities may actually be quite simple as their average properties may be set by just a few key parameters (Batty 2008, Bettencourt et al. 2007a, Bettencourt et al. 2007b). Consequently, Bettencourt’s theoretical framework which derives the general scaling properties of cities through the optimization of a set of local conditions was employed to explain how urban area change gradually from the bottom-up (Bettencourt 2013). This framework predicts urban area expansion as a function of population increase that apply to all urban systems (Bettencourt 2013). The model addressed two most important properties of cities: i) the concentration of people in space and time; and ii) more intense use of urban material infrastructure to mix population. These properties are the results of the same essential dynamics consider the simplest model of a city with land area A and population N (Batterncourt, 2013). Matching density to cost, the generalized area scaling relation was addressed as Eqn 4,

$$A(N) = aN^{\alpha}\,, \alpha\ = \frac{2}{2+\mathrm{H}} \qquad Eqn\ 4$$

$\alpha = \frac{\mathrm{D}}{\mathrm{D+H}}$ in D dimensions, H ~ 1 is special because it allows each individual to fully explore the city within the smallest distance travelled.

Census records and urban area data of Haryana (GEOHIVE 1996-2014) were used to allocate rural and urban population at the district level for 24 randomly selected human settlement area (urban, town and village) to decide a in Haryana as presented in Eqn 5. Figure 4 shows projected human settlement area change and calibration for regression is shown in Table 13.

$$Urban\ area\ A = 0.0085 \times N_t^{\frac{2}{3}} \qquad Eqn\ 5$$

N_t represents the population in year t.

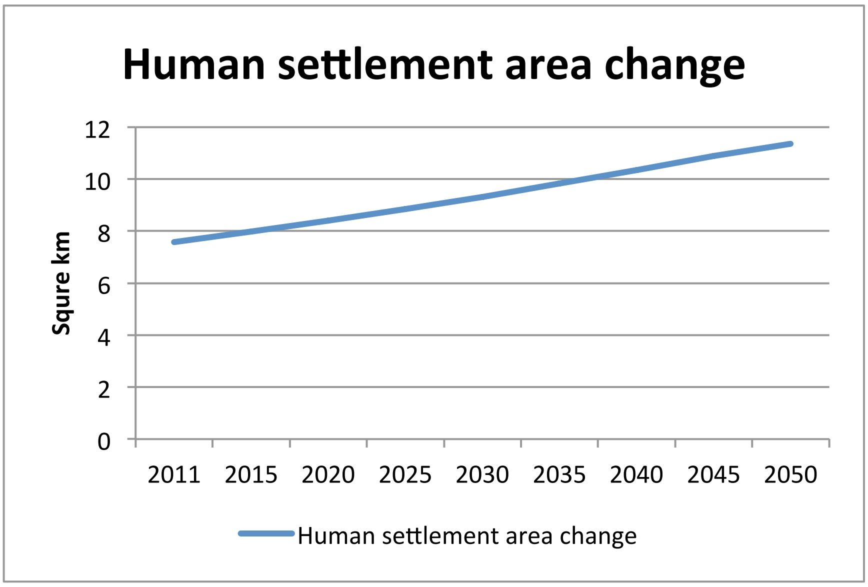


Figure 4 projected human settlement area change

Table 13 Statistical data for urban area projection

Coefficient	0.0085
R2	0.6983
F	53.2234

7.2 Population change prediction

Population change of Haryana was projected using the Economic Survey of Haryana 2012-2013 (Government of Haryana 2013), Census of India 2011 (Registrar General, India 2011) and annual population data from Wiki (Wiki 2011). These statistical reports show that population increase rate in Haryana remained around 1.57% from 2001 to 2011 which is lower than the national goal of 2.3 by 2020 (UN 2005, Library of Congress 2014). Thus, we expected population grow at a constant rate of 1.57%. Starting from 2010 with a population of 24,961,193, population change in Haryana was projected as follows (Figure 5).

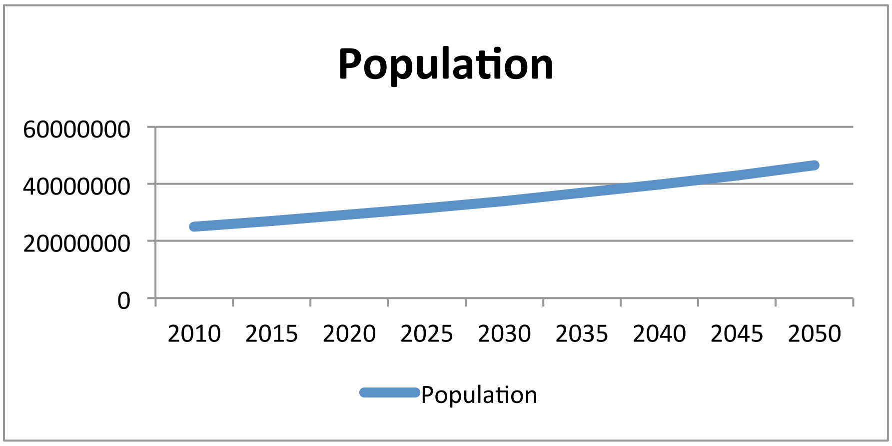


Figure 5 Population change in Haryana

8 Demand prediction- fuel

The main focus of fuel crops is to achieve fuel-demand with maximizing overall land-use suitability and minimizing land occupation. Specifically, demand for bioethanol keeps in view meeting the national sustainable development goal by blending fossil fuel with biofuels in transportation (Government of Haryana 2011b). As Battencourt's model described, urbanization is the result of transportation demand for satisfying human community (Bettencourt 2013), which means population mixing translates into the cost of realizing interactions proportional to the transverse dimension of the city. Thus, the power spent in transport processes to keep the city mixed is measured by population, transverse dimension and a force per unit time. Formalizing these principles, the geometry of path was measured through a Hausdorff dimension, H, so that distance travelled $\propto \mathrm{A}^{\frac{2}{2+\mathrm{H}}}$. and total energy consumption to satisfy travel demand to mix population is addressed as Eqn 6.

$$W(N) = W_0 N^{\omega}\ ,\ \omega = 1 + \ \delta \qquad Eqn\ 6$$

$\delta = \frac{H}{D^2}\alpha,\ \alpha = \frac{\mathrm{D}}{\mathrm{D+H}}$ in D dimensions, H ~ 1 is special because it allows each individual to fully explore the city within the smallest distance travelled.

In Bettencourt power dissipation model, energy consumption was measured as per capita travel length times force per unit use. Transportation energy consumption at a national level was measured by several researches (Afionis and Stringer 2012, Balat and Balat 2009, Bond 2004, Bozbas 2008, Demirbas 2008, Demirbas and Balat 2006, Hamelinck and Faaij 2006, Huang et al. 2012, Ito 2004) but data for Haryana transportation was not available. Thus we assume average per capita transportation energy consumption in India. National transportation dissipation data from 1990 to 2011 (IEA 2010, CSO 2013, IEA 2011) was used to formulize transportation energy consumption in relation with population. Regression result of total energy dissipation W is addressed in Eqn 7. Projected trend of total transportation energy dissipation in Haryana was presented in Figure 6 and calibration of regression is shown in Table 14.

$$Energy\ dissipation\ W = 53.48 \times N_t^{\frac{7}{6}} \quad Eqn\ 7$$

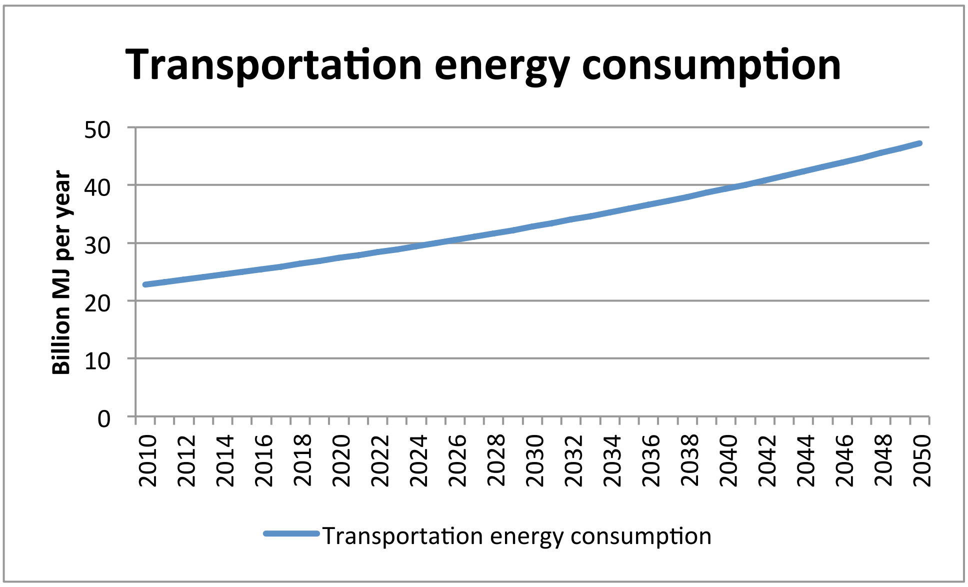


Figure 6 Projected energy consumption in Haryana

Table 14 Statistical data for energy consumption projection

Coefficient	53.48
R2	0.98
F	339.90

In some researches, scenarios for India have been developed in consideration of biofuel demands (Gambhir 2012, Government of Haryana 2011b, IEA 2010). Government of India also developed own scenarios for biofuel demand in blending of petroleum products (Ministry of Petroleum & Natural Gas 2006). The scenarios considered energy demand elasticity and impacts, Compressed Natural Gas (CNG) expansion, pertaining to GDP, and conservation and efficiency improvement measures amongst others (Das et al. 2012). In this study the scenarios of 2017 fossil fuel blending goal of India and 2050 global blending goal have been adapted to fit regional biofuel expectation in Haryana. Total transportation energy demand was measured as equivalent thermal value.

In details, the state-wise total transportation energy consumption was projected for the simulation period 2010-2050. India biofuel policy set a target for 20% blending of transportation energy use until 2017 (Ministry of New and Renewable Energy 2009) and the global biofuel scenario predicted a 27% blending until 2050 (IEA 2010). 5% blending of petrol is currently practiced in 20 states of India (Das et al. 2012). Future blending rates were calculated to reach the 20% blending target by 2017 and 27% blending target by 2050 assuming a linear growth rate. In this study, three sources of bioethanol production are considered, namely sugarcane molasses-based bioethanol production, sugarcane bagasse-based bioethanol production and bioethanol from a combination of bagasse and low-input high-diversity (LIHD) grasses. The above two goals of transportation energy dissipation with biofuel were used as ratio of bioethanol demand to total transportation energy demand in Haryana. Figure 7 and Table 15 show the projected annual demand of bioethanol in Haryana.

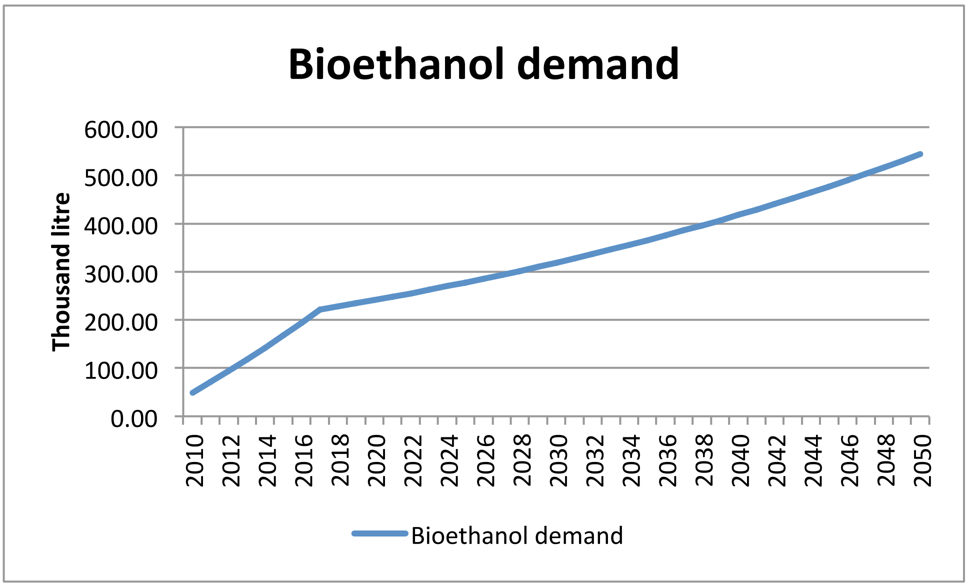


Figure 7 Projected bioethanol demand in Haryana

Table 15 Projected bioethanol demand in Haryana

Year	Target	Energy demand (billion MJ)	Bioethanol demand (thousand litre)
2010	5.00%	1.14	48.70
2011	7.14%	1.66	70.91
2012	9.28%	2.20	93.85
2013	11.42%	2.75	117.61
2014	13.56%	3.33	142.21
2015	15.70%	3.92	167.68
2016	17.84%	4.54	194.03
2017	20.00%	5.18	221.51
2018	20.21%	5.33	227.94
2019	20.42%	5.49	234.53
2020	20.63%	5.65	241.29
2021	20.84%	5.81	248.22
2022	21.05%	5.97	255.32
2023	21.26%	6.14	262.59
2024	21.47%	6.32	270.05
2025	21.68%	6.50	277.69

2026	21.89%	6.68	285.53
2027	22.10%	6.87	293.55
2028	22.31%	7.06	301.78
2029	22.52%	7.26	310.20
2030	22.73%	7.46	318.84
2031	22.94%	7.67	327.69
2032	23.15%	7.88	336.75
2033	23.36%	8.10	346.04
2034	23.57%	8.32	355.55
2035	23.78%	8.55	365.30
2036	23.99%	8.78	375.28
2037	24.20%	9.02	385.51
2038	24.41%	9.27	395.99
2039	24.62%	9.52	406.72
2040	24.83%	9.77	417.71
2041	25.04%	10.04	428.97
2042	25.25%	10.31	440.50
2043	25.46%	10.58	452.31
2044	25.67%	10.87	464.41
2045	25.88%	11.16	476.80
2046	26.09%	11.45	489.48
2047	26.30%	11.76	502.47
2048	26.51%	12.07	515.77
2049	26.72%	12.39	529.39
2050	27.00%	12.75	544.75

9 Demand prediction-food

Food demands for wheat, rice, foodgrains, cotton and sugarcane are quantified. Various researches and reports have projected food demands at the national level of India (Bhalla 2001, Rosegrant, Agcaoili-Sombilla and Perez 1995). For instance, Kumar’s scenario analysis projected a 7% increase in food demand in 2007 while in 2008 Mittal projected it to be 8% (Kumar 1998, Mittal 2008). Chand (2004) projected higher pulse, cereals and foodgrains demand than Hanchate and Dyson (Chand, Jha and Mittal 2004, Hanchate and Dyson 2004). But no suitable data can be located concretely in Haryana. Given Haryana an agricultural area and assuming per capita food demand remains the same in India, in this study, a food consumption prediction methodology considering human behavior approach captured through demand elasticity's (Mittal 2012, Mittal 2008) was employed in projection of per capita food demand. In general, future demand for each commodity was based on projected per capita consumption and population.

Demand for all commodities of this study used the demand projection methodology for per capita constructed by Surabhi Mittal (Mittal 2012, Mittal 2008). The projected sugarcane demand on aspect of food supply only considered sugar production excluding demands for biofuels. As described in the model, human consumption approach along with behavior approach captured through demand elasticity's (Mittal 2012, Mittal 2008). Thus per capita demand was modeled as Eqn 8, and total demand for food commodity in Haryana was a function of population, per capita income and time as presented in Eqn 9.

$$per\ capita\ demand = d_0(1 + y \times e)^t \qquad (Eqn\ 8)$$

$$Domestic\ demand = d_0 \times N_t(1 + y \times e)^t \qquad (Eqn\ 9)$$

Domestic demand = Household direct demand + Indirect demand, d_0 is per capita demand in base year; y is growth in per capita income; e is the expenditure elasticity of demand; N_t is the projected population in year t (Mittal 2012, Mittal 2008).

The expenditure elasticity projected from the 61th national sample survey results (Mittal 2012, Mittal 2008) for all India for wheat, rice and sugar was used as elasticity for demand projection in Haryana. A general production rate of 7.69 kg sugarcane to 1 kg sugar (Thangavelu 2004) was used for converting demand from sugar to sugarcane. The mean value of elasticity for other principal commodities was used as foodgrains elasticity. Similar to rice, wheat and sugar, cotton is not irreplaceable necessary commodity, the mean value of elasticity of rice, wheat and sugar was assumed elasticity of cotton. Per capita demand for rice, wheat, foodgrains and sugar 2009-2010 from Mittal (Mittal 2012, Mittal 2008) (Table 16) were used as baseline data. Since India’s current per capita consumption of all fibres is 6.86 kg and cotton accounts for 60 percent of fibre (Textilemagazine 2013), the baseline cotton consumption in Haryana was assumed 4.12 kg yr^{-1}.

Per capita income data for a period of seven years (Government of Haryana , 2006-2013) was used for prediction of income growth. Since continues time-series data for Haryana was not available. The data gap for the year 2006-2007 was filled by mean value. A consistent annual increase rate of 7.2% was used as per capita income growth rate for all crops during the projection period. Table 17 shows projected total food demand in Haryana. Figures 8(a) to Figure 8(e) show the demands for each commodity (Annual demand data see Appendix).

Table 16 Projected agricultural commodity per capita demand (kg yr^{-1})

year	foodgrain	cotton	sugarcane	wheat	rice
2010	17.04	4.12	72.75	52.97	69.79
2011	17.06	4.13	73.08	53.29	69.92
2012	17.09	4.15	73.42	53.60	70.05
2013	17.11	4.16	73.76	53.93	70.18

2014	17.14	4.18	74.10	54.25	70.31
2015	17.16	4.19	74.44	54.57	70.45
2016	17.19	4.21	74.78	54.90	70.58
2017	17.21	4.22	75.13	55.23	70.71
2018	17.24	4.24	75.47	55.56	70.84
2019	17.26	4.26	75.82	55.89	70.97
2020	17.29	4.27	76.17	56.22	71.11
2021	17.31	4.29	76.52	56.56	71.24
2022	17.34	4.30	76.87	56.90	71.37
2023	17.36	4.32	77.23	57.24	71.51
2024	17.39	4.33	77.58	57.58	71.64
2025	17.41	4.35	77.94	57.92	71.78
2026	17.44	4.36	78.30	58.27	71.91
2027	17.46	4.38	78.66	58.62	72.04
2028	17.49	4.40	79.02	58.97	72.18
2029	17.51	4.41	79.39	59.32	72.31
2030	17.54	4.43	79.75	59.67	72.45
2031	17.56	4.44	80.12	60.03	72.59
2032	17.59	4.46	80.49	60.39	72.72
2033	17.61	4.47	80.86	60.75	72.86
2034	17.64	4.49	81.23	61.11	72.99
2035	17.66	4.51	81.61	61.48	73.13
2036	17.69	4.52	81.98	61.85	73.27
2037	17.72	4.54	82.36	62.22	73.40
2038	17.74	4.56	82.74	62.59	73.54
2039	17.77	4.57	83.12	62.96	73.68
2040	17.79	4.59	83.51	63.34	73.82
2041	17.82	4.61	83.89	63.72	73.96
2042	17.84	4.62	84.28	64.10	74.09
2043	17.87	4.64	84.67	64.48	74.23
2044	17.89	4.66	85.06	64.86	74.37
2045	17.92	4.67	85.45	65.25	74.51
2046	17.95	4.69	85.84	65.64	74.65
2047	17.97	4.71	86.24	66.03	74.79
2048	18.00	4.72	86.63	66.43	74.93
2049	18.02	4.74	87.03	66.83	75.07
2050	18.05	4.76	87.43	67.23	75.21

Table 17 Projected food demand in Haryana in thousand tonne

year	foodgrain	cotton	sugarcane	wheat		rice	
				domestic	domestic & export	domestic	Domestic & export
2010	0.43	0.10	1.82	1.32	2.38	1.74	4.27

2015	0.46	0.11	2.01	1.47	2.65	1.90	4.66
2020	0.50	0.12	2.22	1.64	2.95	2.07	5.08
2025	0.55	0.14	2.46	1.83	3.28	2.26	5.55
2030	0.60	0.15	2.72	2.03	3.66	2.47	6.05
2035	0.65	0.17	3.01	2.27	4.07	2.69	6.60
2040	0.71	0.18	3.33	2.52	4.54	2.94	7.21
2045	0.77	0.20	3.68	2.81	5.05	3.21	7.86
2050	0.84	0.22	4.07	3.13	5.63	3.50	8.58

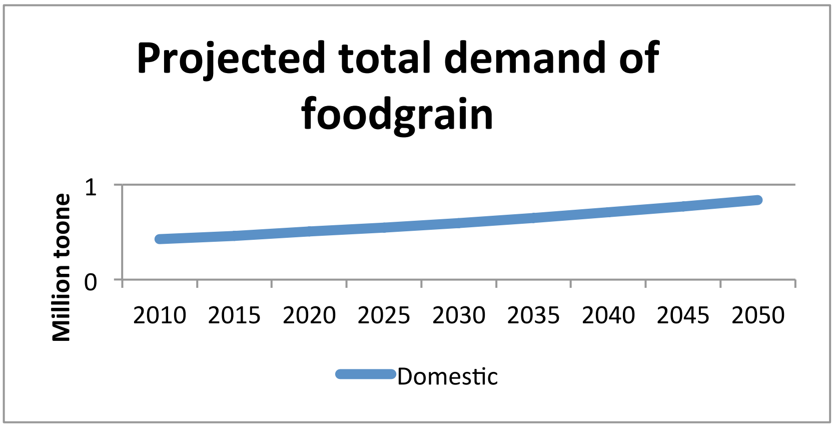


Figure 8(a) Foodgrains demand in Haryana from 2010 to 2050

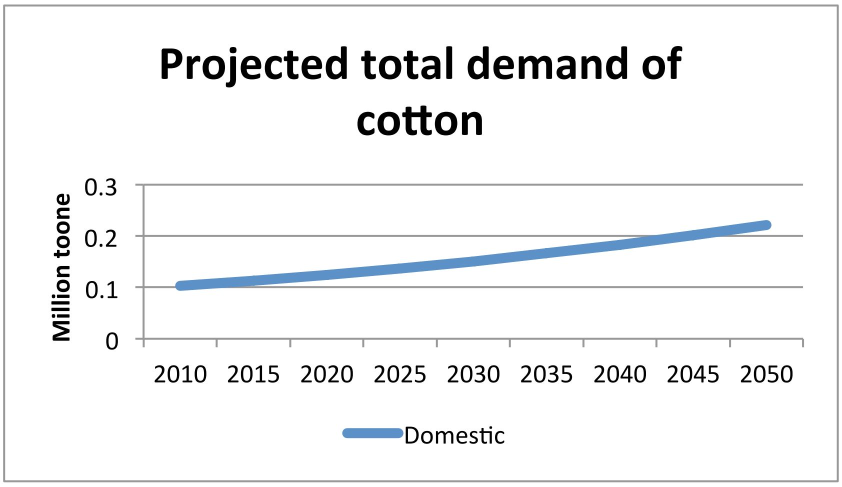


Figure 8(b) Cotton demand in Haryana from 2010 to 2050

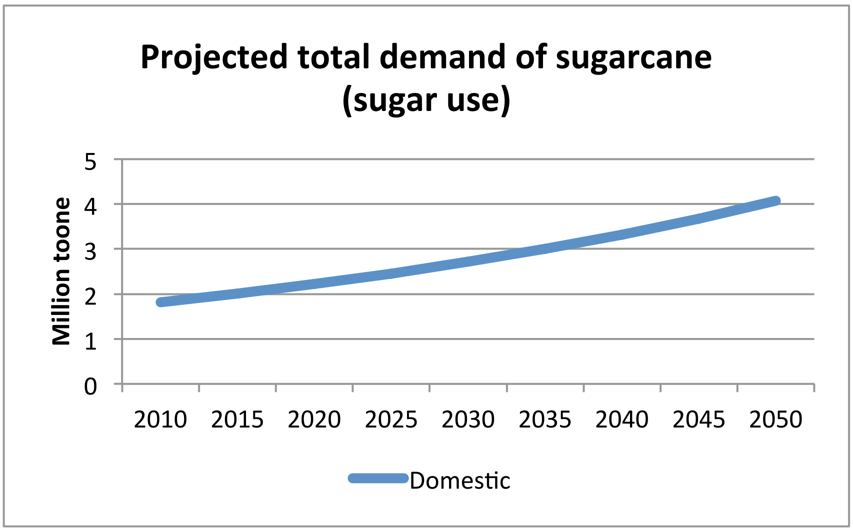


Figure 8(c) Sugarcane demand in Haryana from 2010 to 2050

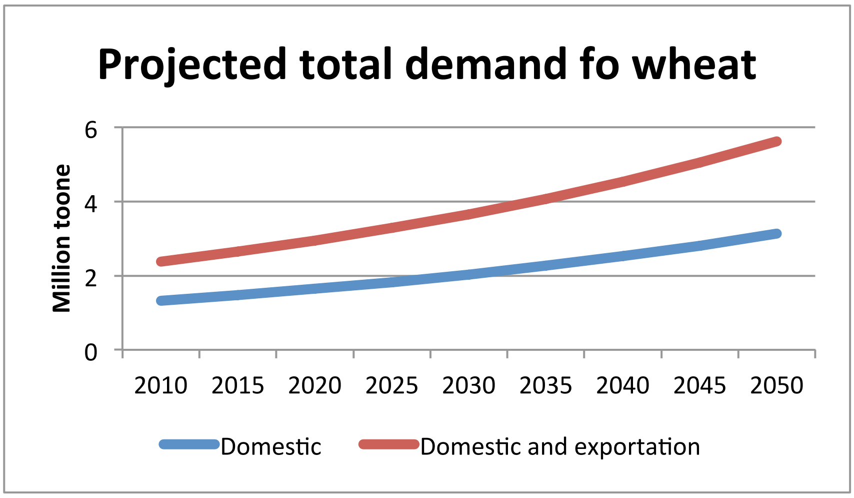


Figure 8(d) Wheat demand in Haryana from 2010 to 2050

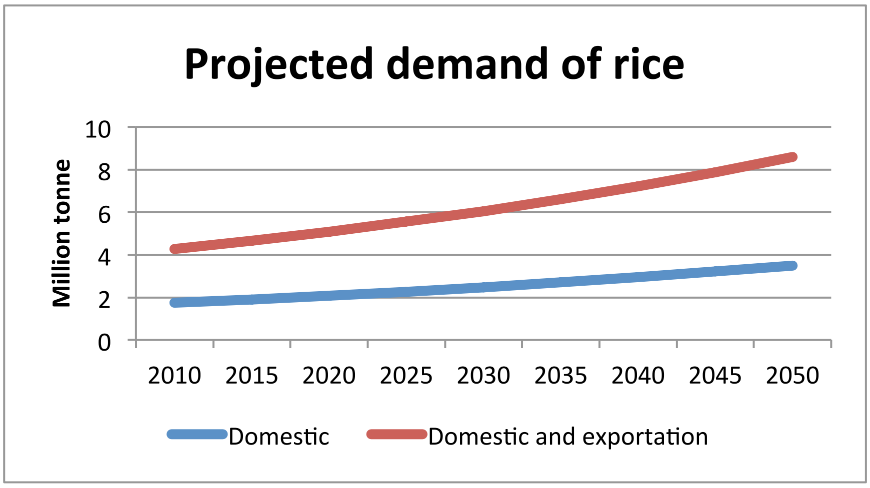


Figure 8(e) Rice demand in Haryana from 2010 to 2050

10 Net profit margins

Net profit margin was calculated using farm harvest price and cost of cultivation. Farm Harvest Prices (FHP) or Farm gate prices are defined as the average wholesale price at which the commodity is disposed of by the producer at the village site during the specified harvesting period (Directerate of economics and statistics 2000-2010). Using continuous time serious data of main product value in Haryana for each type of crop from 2000 to 2010 (Directerate of economics and statistics 2000-2010), we calculate annual rates of increase in FHP using the mean value for the ten years data. The items of cost of cultivation (COS) cover both paid out costs (out of the pocket expenses) and imputed costs including labour cost (human and animal), machine use, fertilizer (N,P,K), insecticides, seed value, land revenue, irrigation cost, impute and depreciation. We computed annual increase in cost of cultivation over ten-year period (2000-2010) to maintain consistency for each type of crop.

Based on the FHP and COS for each year from 2010 to 2011, net profit margin was calculated for each year. We computed annual difference between price and cost as the net profit margin for all crops. Initial values and increasing rates for farm harvest price and cost of cultivation for each type of crop are shown in Table 18 and Figure 9.

Table 18 Net profit margins in INR for each crop

crop	price 2010	cost 2010	Profit 2010	price rate	cost rate
grain	12.26	11.48	0.78	0.06	0.09
cotton	30.36	26.93	3.43	0.05	0.04
rice	17.03	11.92	5.12	0.10	0.07
sugarcane	2.74	1.40	1.34	0.12	0.07
wheat	13.32	9.92	3.40	0.07	0.06

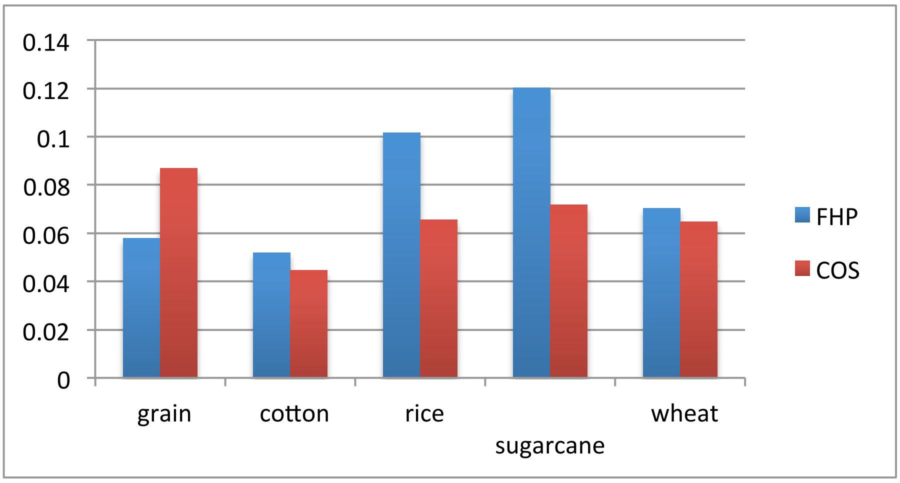


Figure 9 Annual increase for price and cost for each type of crop

11 Scenarios

Two sets of scenarios were quantified for the time period 2010-2050 using 2010 as the base year (simulation of crop allocation started on 2010). In 2010, agricultural production is higher than local food demand in Haryana but energy demand is much more than local supply (Government of Haryana 2011a). With our goal of exploring influence of food-fuel competition, we explored future pathways of land-use change in the form of two food demand conditions. In the 'Domestic Demand (DD)' scenario, inelastic instate food demand is prior to satisfy encompassing state-wise food security with no fixed export requirements for main principle food crops of Haryana. In the 'External Demand (ED)', we assume the responsibility for internal and external food demand with a fixed export requirement for main principle food crops. Scenario storylines cover parameters of population and economic growth, food and bioethanol demands, costs of production and producer prices of agricultural commodities. In both scenarios, it is assumed that the political targets of 20% mix of bioethanol in 2017 and 27% in 2050 are met onwards. Under each scenario, three sub-scenario for bioethanol production was considered, i) first generation of bioethanol production from sugarcane; ii) second generation of bioethanol production from sugarcane bagasse; iii) introducing low-input high-diversity grasses into wasteland for bioethanol production in addition to sugarcane bagasse. The scenarios were based on projection of food, fuel and population as described in demand chapters in above contents. Population projections are inclusive of intra-state (rural–urban) and inter-state migration.

11.1 Storyline scenario DD

This scenario assumes a domestic decision-making process that annual food crop production is only necessary for supporting local food demand. Economic growth would not necessarily rely on agriculture so local food consumption would dominate food production without clear target for food exportation. In this scenario, local food demand would be achieved prior to biofuel feedstocks and crops for exportation in order to satisfy basic food security. Then fuel crops and external food crops which will be used for exportation are allowed to compete for land resources to achieve overall maximum benefit (yield * benefit per cell), maximum overall land-use suitability and minimum land occupation.

Haryana remain a constant population growth rate at 1.57% which has already satisfy the national target of 1.9% for more than ten years, with relative smooth economic growth namely average 7.2% per capita income growth from 2005 to 2012 (Government of Haryana , 2006-2013). Hence, it is assumed that in this scenario, population and per capita income would continue to grow at the same rate. DD assumes minimum food demand, only in support of local human food consumption. Food commodities will see an increase in demands as a result of population growth and higher consume capacity. Increased urbanization, industrialization and merging markets would lead to demands and prices for some commodities grow faster than others. For example, demand increase rate for sugar is about 0.46% p.a. and that for rice is about 0.18% p.a. because of higher demand elasticity for products with rigid demand (see demand projection-food). Similarly, prices of sugarcane and rice grow faster than other principle crops (12% and 10%) (see net profit margin). In energy sector, transportation energy consumption will increase exponentially to population increase as a result of travel and social network demand correlate to urbanization. The average transportation energy demand increase rate would be 1.8% p.a., rising to around 47 billion MJ converting all kinds of fuel consumption into equivalent thermal value (see demand projection-fuel). Bioethanol demand was calculated accordingly to achieve the 20% blending target of the Indian biofuel policy by 2017 and 27% blending target of global biofuel policy by 2050. Technological improvements leads to three sub-scenarios of bioethanol production, namely first generation of bioethanol production from cane molasses, second generation of bioethanol from molasses and bagasse, and involving low-input high-diversity grasses on wasteland in combination with sugarcane bagasse for bioethanol production. Common bioethanol yield rate for all three types of biomass was used as the technological level for Haryana and was assumed constant (85 litre/tonne of sugarcane, 42.3litre/tonne of bagasse, 68100MJ/ha of LIHD grasses) (SHELL 2014, Suman Swami 2012, Tilman et al. 2006). Pure energy production excluding energy consumption during refinery and converting processes was used as final bioethanol yield. Mitigation of carbon emission was calculated in replacement of gasoline. Low-input high-diversity grasses only take up wasteland according to India biofuel policy (see land-use suitability), and forest does not participate in land-use type conversion.

11.2 Storyline scenario ED

In this scenario, it is assumed that food crop production in Haryana is both responsible for local and external food security, which means that a macro scale increase of food demand is reflected by the food exportation of Haryana which cannot yield to local bioethanol production. This scenario assumes political support for emphasis on food production to maintain food production satisfying exportation demand. Wheat and rice are main export commodities of Haryana, with local demand only takes 44.18% of total rice production and 60% of total wheat production (Government of Haryana 2011a). The population growth rate of 1.57% and the 7.2% per capita income growth from 2005 to 2012 (Government of Haryana , 2006-2013) are used. Since Haryana remains a lower population growth rate than Indian average for years and holds higher food production than local demand. Food crop production including both local and export demand would be prior to biofuel production in allocation. Local fuel demand remains the same as in the DD scenario, as well as the three approaches for bioethanol production. Land-use competitions for all scenarios are limited to available irrigation land and wasteland. Demand for Forest products, livelihood products and aquatic products are not involved in the scenario analysis. A summary of the key assumptions used is listed in Appendix.

12 Results

Simulations for the two sets of scenarios DD and ED were run from 2010 till 2050. Table 19 and 20 show the simulation results of land-use change for DD and ED scenarios. Figure 10a–q show the spatial distribution of different land-use classes in twenty-year steps. Table 21 shows the bioethanol yield in each scenario and its contributions to carbon demission.

Obviously shown in Fig. 10, owing to increased demand of food and fuel, croplands are increasingly being taken up under both scenarios. Under both scenarios, distribution of types of crops show clearly spatial cluster. Parcels near human settlement and water resources face most violent competition among all types of crops. Sugarcane mainly locates in south-western Haryana where is relative rich in clay density and water resource while wheat prefers riverside areas in north-east with lower clay density. With sharp demand increase, rice plantation expands remarkably from urban buffer area towards all available fallow croplands. Till 2050,rice covers most of the croplands in all simulated scenarios, following by wheat plantation. As Table 19, 20 shows, human settlement area expands fast driven by population increase but the percentage of wastelands converted into urban declines in both scenarios. With relative slight land-use conflicts, wasteland consists to 4.33% of urban area in 2010 and decreases to 1.14% in 2030 in both scenarios because of limited amount of wasteland and unsuitable positions of them. Till 2050, wasteland consists to 1.07% in ED scenario against that of 0.74% in DD scenario, mainly because of higher pressure of land resources competition. For foodgrains, cotton and sugarcane, which are only responsible for local demands in both scenarios face similar increase rate in simulations. Their areas increase by 39.31%, 46.57%, 56.30% in DD scenario and 39.64%, 46.35%, 54.19% in ED scenario for the first 20 years. Then the expanding speed slows down to 38.29%, 42.82%, 47.65% in DD scenario and 38.29%, 42.82%, 46.79% in ED scenario. In DD scenario, total area under wheat plantation increases by 63.45% till 2030 and slows down to 38.38% till 2050. While in ED scenario, wheat plantation expansion faces similar increase of 64.03% for the first 20 years but sharply slows down to 1.75% after then because of limited land resources. Rice yields various remarkably under different environmental conditions in Haryana, in addition, with high and still rising price and demand, rice plantation expands extremely fast, with 155.8% in both scenarios for the first 20 years. Even under heavy pressure of land resources after 2030, rice plantation still expands by 340.67% in DD scenario and 175.71% in ED scenario. Plantation of sugarcane for bioethanol expands for more than 5 times in both scenarios. With higher yield of bioethanol from combined bagasse and LIHD grasses is higher than bagasse-based bioethanol production than molasses-based production, the areas under plantation is always smaller in both DD and ED scenarios.

Table 19 Land-use change in DD scenario in hectare

DD scenario		2010	2030	2050
Urban	Total area	756.94	15820.39	37355.52
	Converted from wasteland	4.33%	1.14%	0.74%
foodcrops	wheat	161388.95	263782.40	365022.41
	rice	249215.39	637583.36	2809639.73
	foodgrains	303498.85	422812.06	584695.81
	cotton	192361.27	281944.06	402677.76
	sugarcane	315000.42	492331.01	726948.25
Sugarcane for biofuel	Molasses-based	79609.86	480890.06	0.00
	Bagasse-based	60257.08	361852.11	0.00
	Combining LIHD grasses	51893.04	352598.43	0.00

Table 20 Land-use change in ED scenario in hectare

ED scenario		2010	2030	2050
Urban area	Total area	756.94	15820.39	37355.52
	Converted from wasteland	4.33%	1.14%	1.07%
foodcrops	wheat	225945.1904	370629.0176	377120.3584
	rice	398747.2384	1020082.586	2812477.44
	foodgrains	302795.98	422812.06	584695.81
	cotton	192651.26	281944.06	402677.76
	sugarcane	314241.84	484514.20	711235.99
Sugarcane for biofuel	Molasses-based	79491.89	489388.44	0.00
	Bagasse-based	60176.79	371228.67	0.00
	Combining LIHD grasses	51835.70	362158.49	0.00

As simulated, existing croplands are not enough to fully support the food-fuel demands under all scenarios till 2050. But different scenarios varies in amount and start year of supply shortage. Food crisis occurs in late 2040s in all scenarios. In DD scenarios, pathways for biofuel production influence little of foodcrops plantation because of priority. The simulation results indicate that local food demands are possible to be satisfied till 2043. After that, a shortage first occurs in foodgrains supply (7.3%) in 2044 then in sugarcane supply (61.28%) in 2045, following by shortages of wheat (72.43%), rice (7.15%) and cotton in 2046.Simulation results of ED scenario indicates more intense land-use conflicts because of competitions between exporting foods and biofuels. A shortages of wheat (29%) and rice

(7%) occur in 2042, following by foodgrains facing a demand-supply gap of 7%.Then, shortage also comes to sugarcane (63%) in 2046 and cotton (100%) in 2047 because of limited area and profit competition among crops.

Biofuel targets of the state are 20% blending for 2017 and 27% for 2050. Our simulations indicate that bioethanol 2017 target is possible to achieve but 2050 target cannot be fulfilled completely under either scenario. The simulation results show that bioenergy demands can possibly be satisfied till 2042 under DD scenarios and 2039 under ED scenarios. Prediction for bioethanol production indicates that bagasse-based pathway and introduction of LIHD grasses help to slightly slow down the trend of bioethanol crisis but land-use competition influence more on total bioethanol production. Under DD scenario, with bioethanol produced from sugarcane molasses, a demand-supply gap of 42% first appears in the year of 2043, and there is no cropland available for bioethanol production after 2044 because of priority in foodcrops production and a lack of croplands. Bagasse-based bioethanol production faces demand-supply gaps from 2043 with a percentage of 24.5% to 100% after then. Introduction of LIHD grasses makes a bit sense in reducing energy shortage, making the demand-supply gap 23.24% in 2043, but cannot resist the crash of bioenergy production since 2044 because of pressure from food production. During the 40 years, LIHD grasses covers an average of 3.74% total bioethanol demand and less than 1% after 2044. Since food exportation aggravates competition for arable lands, the energy crisis under ED scenarios occurs three years earlier than that under DD scenarios. With bioethanol purely coming from molasses-based pathway under ED scenario, a demand-supply gap is predicted to appear on 2040 (42% shortage of demand). With food demand-supply gaps expanding sharply from 2042, there becomes no cropland available for sugarcane-based bioethanol. The situation improves a little with bagasse-based bioethanol production. With bioethanol demand satisfied till 2039, 23% of demand is not satisfied after then. Same as molasses-based bioethanol production, limit of land resources also happen on 2042. When LIHD grasses introduced to wastelands for external bioethanol production, demand-supply gap first appears on 2040 with a shortage of 21.58% and then bioethanol production falls to less than 1% of demand in 2042 with failure in land resource competition.

Table 14 shows a comparison between DD and ED scenarios of bioethanol total yield and total carbon demission by using bioethanol. Without food exportation, DD scenario has a capacity of about 20% more bioethanol production capacity than the EE scenario by each of the three pathways. Lifecycle analysis shows that total GHG (Green House Gas) emission of gasoline is 92 gCO_2/MJ (Searchinger et al. 2008), which equals about 25.09 gC/MJ. Bioethanol from sugarcane and switch grasses without land-use change bring reduces in lifecycle GHG emission by 20% and 70% (Searchinger et al. 2008). As shown in Table 21, production of bioethanol in Haryana helps to reduce million tonnes of carbon emission. Under DD scenario, bagasse-based bioethanol brings about 1.14% more carbon demission than molasses-based bioethanol while introducing LIHD grasses brings about

10.45% more carbon demission. Similar phenomena appear under ED scenario, with bagasse-based bioethanol brings about 1.54% more carbon emission displacement than molasses-based bioethanol and LIHD pathway brings about 13.08% more carbon emission displacement.

Table 21 Bioethanol yields and carbon emission displacement

Scenario	Bioethanol pathway	total yield (MJ)	Displacement (thousand tonne)
DD	Molasses-based	1.50E+14	753104.56
	Bagasse-based	1.52E+14	761711.00
	Combining LIHD grasses	1.53E+14	831790.0817
ED	Molasses-based	1.24E+14	623466.91
	Bagasse-based	1.26E+14	633055.33
	Combining LIHD grasses	1.28E+14	705027.96
Comparison of DD and ED scenarios	Molasses-based	120.79%	120.79%
	Bagasse-based	120.32%	120.32%
	Combining LIHD grasses	119.81%	117.98%

* Carbon emission displacement is calculated in replacement of gasoline.

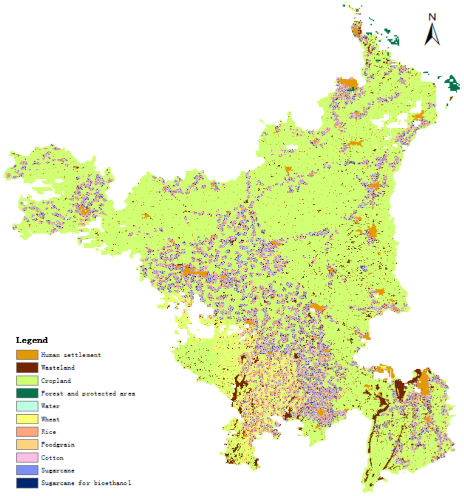


Figure 10a DD scenario molasses-based 2010

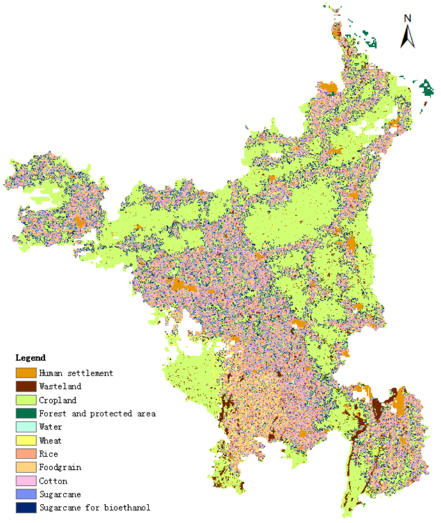


Figure 10b DD scenario molasses-based 2030

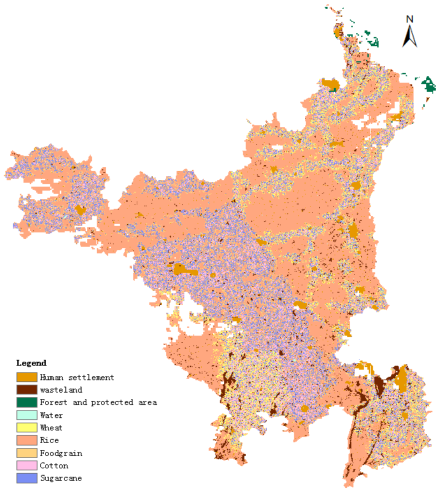


Figure 10c DD scenario molasses-based 2050

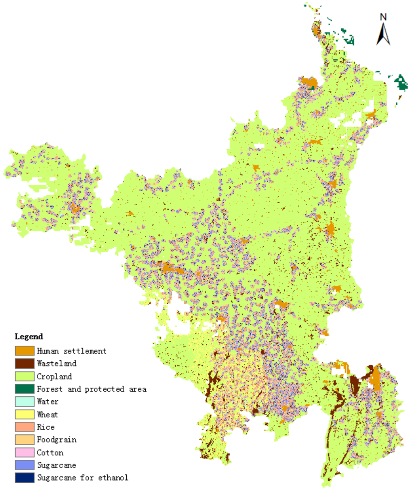


Figure 10d DD scenario bagasse-based 2010

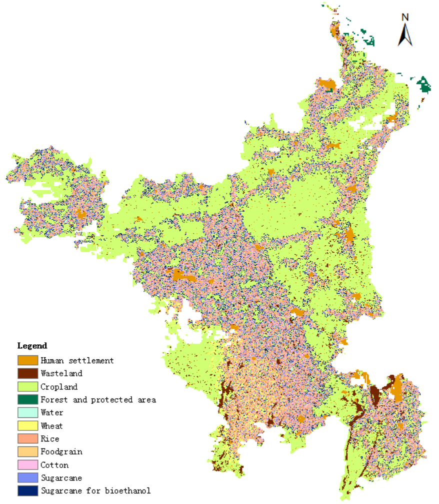


Figure 10e DD scenario bagasse-based 2030

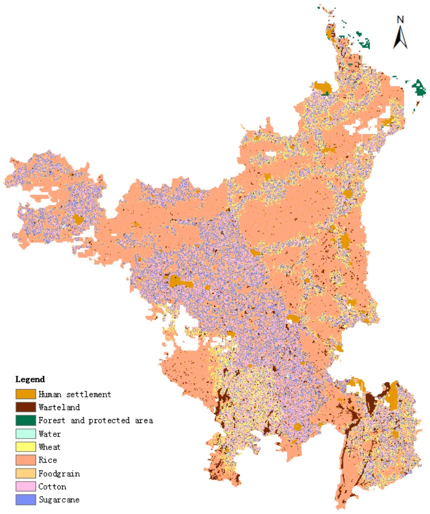


Figure 10f DD scenario bagasse-based 2050

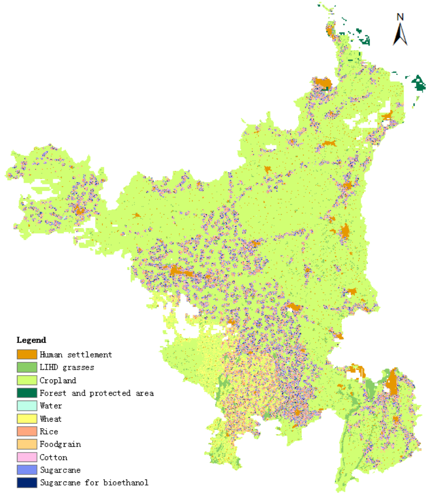


Figure 10g DD scenario LIHD 2010

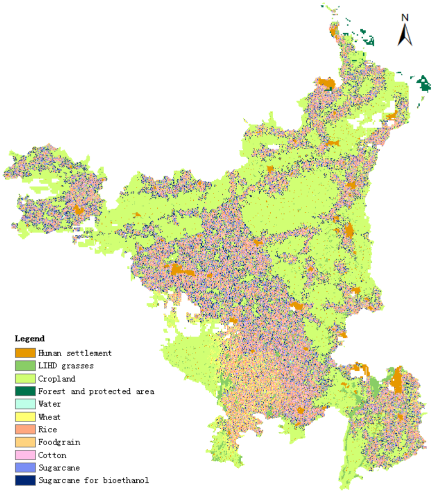


Figure 10h DD scenario LIHD 2030

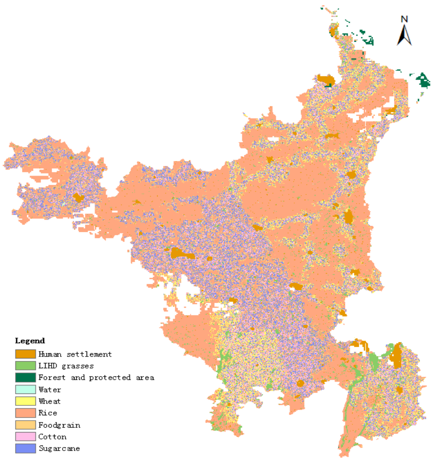


Figure 10i DD scenario LIHD 2050

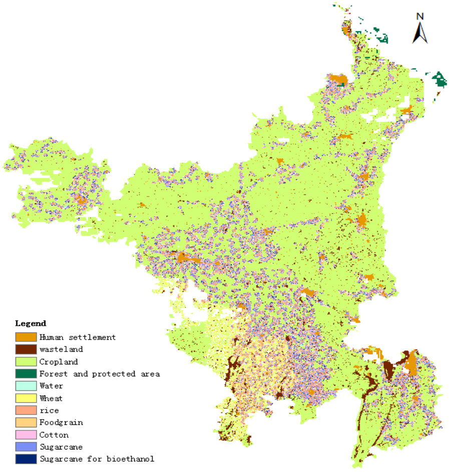


Figure 10j ED scenario molasses-based 2010

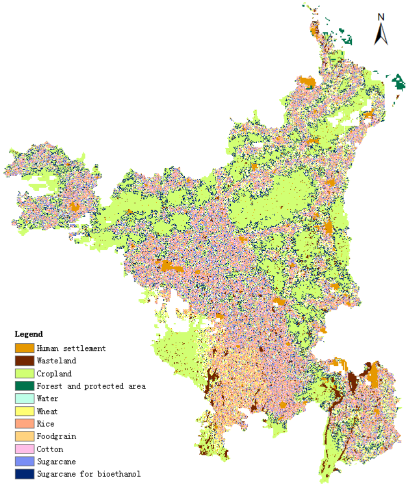


Figure 10k ED scenario molasses-based 2030

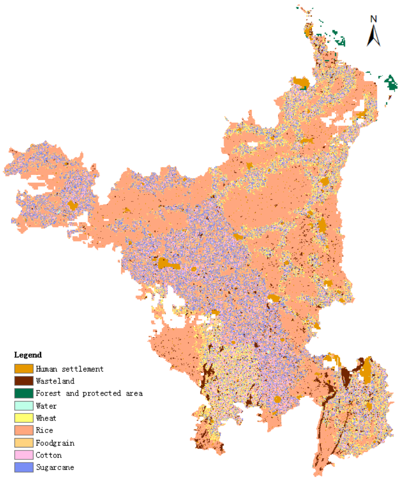


Figure 10i ED scenario molasses-based 2050

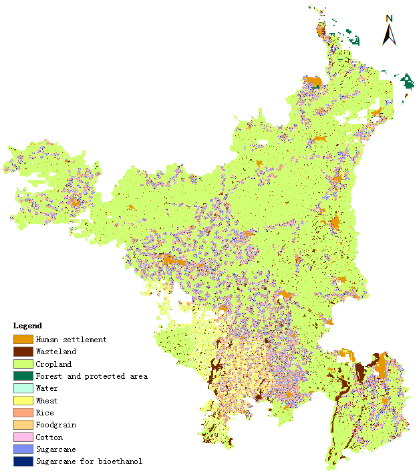


Figure 10m ED scenario bagasse-based 2010

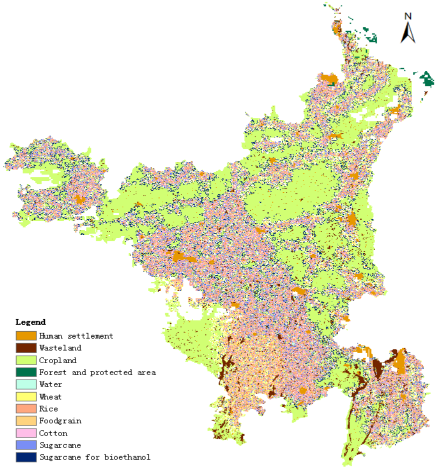


Figure 10n ED scenario bagasse-based 2030

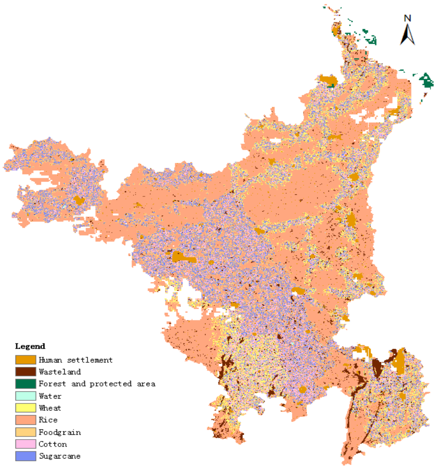


Figure 10o ED scenario bagasse-based 2050

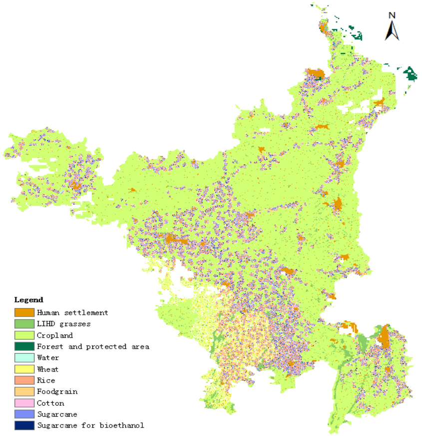


Figure 10p ED scenario LIHD 2010

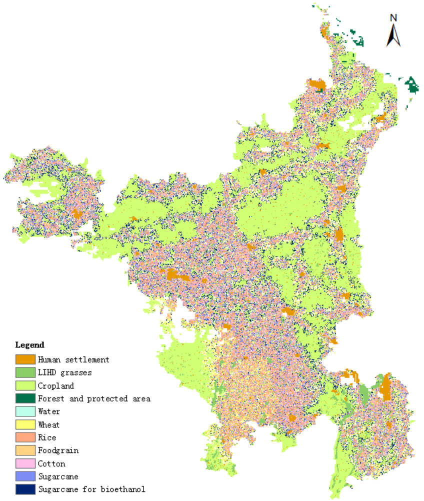


Figure 10p ED scenario LIHD 2030

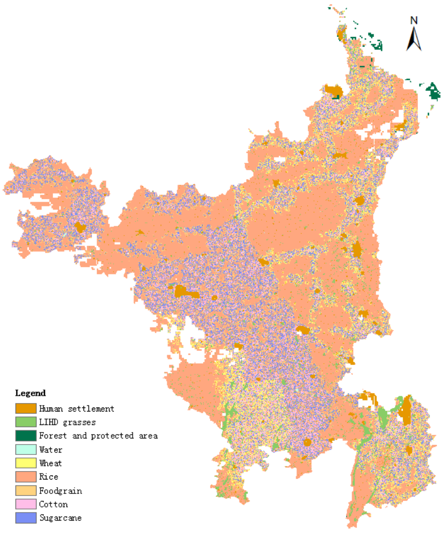


Figure 10q ED scenario LIHD 2050

13 Discussion

In this practicum, we studied the three main drivers of future land resources competition, namely urbanization, food demand and fuel demand from biomass. The experiment in the agriculture-based state with a large population reveals that the three drivers are deeply internal linked. Population growth leads to inevitable urbanization and food demand increase, human-beings socialization and communication demand aggregates energy consumption especially for transportation. Expecting local biofuel production to achieve the fuel-blending target will certainly extrude space for food production, but under optimized land-use plan and flexibility of political protection on food security, the target of 20% blending of gasoline in 2017 is able to achieve while the target of 27% blending in 2050 is far beyond local bioethanol production capacity. Similar case studies also discussed the "over-ambitious" political biofuel targets of India. In one case in Karnataka, India, scenarios addressed an overestimated target of potential productivity in a state with less agricultural dependence and more political support for biofuels than Haryana (Das and Priess 2011, Das et al. 2012, Das, Priess and Schweitzer 2010). These scenarios show that without political support for external food protection, biofuel production has higher priority in local land-use process, which reveals the fact that food security cannot get automatically protected by economic-leading agricultural activity. However, with basic food demand politically assigned prior to biofuel production in our cases, our study is a strong indication that with rich land resources, local biofuel production is able to fulfill short-term transportation energy blending demands, especially improvements in technology and biomasses are introduced with degraded land fully explored. The fulfillment of 2017 goal and the failure of 2050 goal indicate significant influences of land resources and land-use competition among food, fuel and settlement.

In both scenarios, our results imply that land resources become the main limitation for food-fuel production after 2040. The rich arable land in Haryana succeeds to support food-fuel production for almost 30 years. With soil production capacity declines after decades of irrigation and increasing demands for food and settlement driven by population growth, land-use conflicts becomes extremely violent to meet food production even without exportation, leaving a large gap between biofuel blending target and the real production capability. The results show that in the scenario without crop exportation, a demand-supply gap of 23.24% starts on 2043 with bioethanol produced from sugarcane bagasse and LIHD grasses, against that of 24.5% with bagasse-based and that of 43% with molasses-based bioethanol production. However, with heavier land-use competition occurs on 2044, few cropland is available for energy-purpose sugarcane plantation and LIHD grasses becomes the only available biomass resource for bioethanol.

The simulation results in the scenario with crop exportation demands indicate worse land-use conflicts than the one without crop exportation. The first bioethanol demand-supply gap appears on 2040, three years earlier than that in the other scenario. Improved bioethanol production pathways shrink the demand-supply gap (21.58% with bagasse and LIHD grasses, 23% with bagasse-based bioethanol, 42% with molasses-based bioethanol in 2040) to some extend but do not fundamentally change the decreasing trend of bioethanol production because of increasingly intense land resources. Since 2042, no more arable land is available for sugarcane for bioethanol production. With this study assuming wasteland fully explored for LIHD grasses plantation with optimized annul yield, the local bioethanol production still cannot fully support energy demands. Sugarcane being a food–fuel crop serves multiple demands in addition to sugar and sweetener, such as chemical industries and medical industries.

In our simulations, only per capita sugar demand and bioethanol are considered, the shortfall of bioethanol in reality will be even larger. There are limiting factors in both the demand and supply chains that contributes to the shortfall. In our scenarios, we compared the molasses based ethanol production route and the bagasse-based production. Net yields from bagasse-based production are more profitable with about 1.5% higher yield than molasses-based production. However, since current distilleries in Haryana mainly focus on molasses-based production that is compatible with sugar production, external or surplus investigation is necessary but hard to project in order to expand the bagasse-based production. Without clear bagasse refinery investigation targets from government of Haryana, the supposed bagasse-based bioethanol production in the scenarios could fail to satisfy the required demands.

Encouraging the construction of advanced bioethanol converting and refinery facilities in combination with decentralized processing of ethanol would increase ethanol production to fulfill blending targets. Besides, availability to vital growth factors of sugarcane also greatly influence ethanol yields. Growth simulation in DNDC model and spatial distribution in our scenarios show that sugarcane is relative sensitive to water resources and soil texture. As Bharadwaj *et al*. (2007) suggested, drip irrigation plays a significant role in sugarcane production and yield increment, optimizing marginal benefit of sugarcane expansion as a result (Bharadwaj, Tongia and Arunachalam 2007). In addition, technical improvements in vehicular efficiency for both bioethanol and mixed-fuel engines can also contribute to energy reduction of current and future fuel use, demands for biofuels, as well as GHG emission. Such ways of energy conservation contributes to make biofuel blending targets more achievable. But considering our results of extreme limits of land resources, we throw doubt on its effects that whether biofuel production capacity is possible to support even smaller demand. Given this situation, the cultivation of other dual use, food–fuel crops, such as the low-input high-diversity grasses have significant influence on fulfill the long-term energy-blending goals.

With respect to land-use change, the initial land-use condition indicates that agricultural land enables a production larger than local demands for principle agricultural commodities, but extreme land-use competition occurs after 2040 driven by remarkably increase on food, fuel and settlement aspects. The initial urban area is slightly smaller than the expected size, which is empirically predicted by the population-urban area model (Bettencourt 2013) under India conditions (see human-settlement demand projection).

Consequently, in all scenarios, urban areas increase reasonably slow through out the simulation period. Though the algorithm of urban agent allocation decide that urban positions in different scenarios vary with each other, sharing the same relation between population increase and urbanization, the final urban area in 2050 in all simulations is 373.56 km2, up to 0.8% of the area of Haryana. Besides, our scenarios employed a relative flexible explanation of the Indian biofuel policy. As required, no agricultural land would be diverted to energy crop production (Das et al. 2012).

In our scenarios, this policy is followed in a way that agricultural land cannot be used for energy crop (sugarcane) until food demands (with or without exportation in different scenarios) are satisfied first. The results indicate that a maximum of 18.28% agricultural land under DD scenario conditions or a maximum of 16.14% agricultural land under ED scenario conditions can be diverted into energy crops, both happen in molasses-based bioethanol production. With time going by, however, aggregating pressure on land resources and the priority for human settlement and foodcrops leads to a failure of sugarcane in competing for more land. Besides, sugarcane for bioethanol is pushed to area with lower land-use suitability since optimized overall land-use suitability is first achieved in satisfying settlement and food demands. As a result, in both scenarios, bioethanol yield grows slower than biomass area expansion. Even when LIHD grasses are introduced as bioethanol materials on degraded area, as simulated, the bioethanol yield is still insufficient to cover the demand-supply gap later than 2040. With this study highly concentrated the land-use conflicts on human settlement, foodcrops and fuelcrops, the aggressive land-use conflicts and shortfall of land for energy crops even ignoring competition from other land-use types, such as industrialization, livestocks production and necessity for restoring soil fertility levels show a clear shortage in biofuel production to satisfy the long-term national targets.

In addition, an important assumption of this study is that distance to transportation and human settlement is in representative of markets for food and fuel. This assumption was made since an established marketing mechanism for food and a system for bioethanol extraction do not available yet. Our study shows that distance to roads, railways and urban areas, which represent connections to consumption, is directly linked to expansion and allocation of food and fuel (Fig.10a-q). In this study, profit as a main factor only works for the expansion of crops. Bioethanol expansion depends on a combination of policy and market demand in order to satisfy the energy blending targets with maximum local yield. The absence of fixed cost and price for bioethanol from all types of materials assumed a political environment that high benefit cannot contributes to land-use change to biofuels until food demand satisfied, on the other side, supports will be available to avoid negative benefits for biofuel feedstocks plantation. The preliminary economic analysis of our study reveals that sugarcane price is possible to rise sharply with increasing demand of bioethanol. Thus institutional interaction is necessary to ensure basic food supply rather than expecting the free competition between food and fuel to arrive at a balance simultaneously. On the contrary, with the plantation and refinery cost unclear in Haryana, net returns from biofuel production to farmers could be suboptimal.

In this study, we assumed optimized agent allocating process. Both single and double cropping process under IPCC climate scenarios were considered and agent allocation follows highest environmental-economic land-use suitability. Under this process, a highest yield of bioethanol is expected with minimum impact on food security. It’s politically appealed in India to fulfill biofuel demands by using degraded land under rainfed and unfertilized conditions (Ministry of New and Renewable Energy 2009). With assumed constant high energy yield from LIHD grasses (Tilman et al. 2006) and 100% availability of wasteland, its bioethanol production can contributes to an average of 3.74% of total demand. These results, using high LIHD grasses yield expectation from experiment results (Tilman, 2006) and largely avoiding nutrient and water limitations into account, reveal limited contribution to the long-term bioethanol supply capacity. However, some studies based on simulation and field measurements conclude that the overall biofuel supply capacity of degraded lands is lower than previously expectation and has been overestimated by a number of large scale assessments, not specifically aimed at wasteland productivity (Lapola, Priess and Bondeau 2009, Li et al. 2010, Trabucco et al. 2010, Cai et al. 2010, Das et al. 2010, Gubitz, Mittelbach and Trabi 1999, Hyungtae Kim 2009). Local biofuels production from LIHD grasses in Haryana is far from enough to be the main power to achieve the energy-blending goal.

Scenarios DD and ED differ significantly in responsibility assumed in the food security. It is evident from our results that under both scenarios, the available cropland will be increasingly limited. Simulation results indicate that existing arable land is sufficient to support both domestic and external food demand for 30 years. The supply crisis for foodcrops exportation appears from 2039, three years earlier than that for domestic food supply. Consequently, the bioethanol supply crisis in ED scenario comes earlier than that in DD scenario. This result indicates the importance of analysing the responsibility towards food security and bioenergy targets simultaneously when assessing potential bioenergy production capacity and land-use changes. In addition to land resources, other factors influencing food and fuel productions in reality were that of crop and biofuels feedstock yields, including biomass yields, bioethanol extraction efficiency and energy yields after *trans*-esterification. As these factors are not simulated in this study, the results indicate that with bioenergy depleted through extraction and transportation, the supply-demand gap can be even larger. A technical improvement on reducing life-cycle energy waste is also necessary. Besides, an improvement on other aspects of bioenergy technologies, such as taking use of agricultural residues in addition to sugarcane bagasse and LIHD grasses, would also significantly raise the bioethanol yields. Growth simulation indicates that soil condition decrease after years of irrigation leads to a decline in crop yields. As a result, an improvement in irrigating techniques, seed quality and land management would make great contribution to raising yields and maintaining sustainability on agricultural lands. In addition, this study concentrate on biofuel potential through the gasoline-ethanol pathway while some studies also introduced jatropha for biodiesel in India. Since high-speed diesel demand in India is also large and technology of diesel-ethanol mix engines has patented in India (Das et al. 2012), assessing potential of bioenergy other than bioethanol in respect to local demand for diesel in Haryana are also consequential.

However, this optimized global solution is difficult to achieve in reality considering that across much of India, the conversion of cropland may be detrimental, especially to poor farmers with small land parcels, who mainly use their produce for subsistence and not as commercial crops (Das et al. 2012). Therefore, resistance from small/marginal farmers for diverting cropland to urban or biofuel area will possibly occur depending on local coordinating and compensation policies, as reported by Shinoj *et al*. (2010) and Ariza-Montobbio & Lele (2010) in their study of the conversion of fallow land for jatropha production in other states in India (Ariza-Montobbio and Lele 2010, Shinoj et al. 2010). Besides, since financial support from the government is not clear when farmers produce biofuel feedstocks, it is very important that farmers are well protected against crop failure and market failure through adequate enforcement of agreements (Das et al. 2012). A combination of minimum price, fixed political and economical support and crop insurance in case of crop failures is essential in preventing financial and yield risks especially for poor/marginal farmers. Providing agricultural loans or funding targeting on exploration of marginal land can also help in reducing the financial risk, and monetary transfers to farmers for the environmental services they provide could encourage biofuel production (Das et al. 2012, Ariza-Montobbio and Lele 2010, Pohit et al. 2010, Srinivasan 2009).

On the other side, to increase economic benefits of LIHD grasses cultivation, it would be necessary to quantify and account for other possible services or by-products, such as the methods to improve LIHD grasses yield and local biodiversity at the same time, the use of LIHD grasses as distributed energy sources for rural households, the use of residues fro bioethanol production, etc. Some other study also discussed this issue. Some researches suggested the carbon credits from the Clean Development Mechanism (CDM) being used in energy plantation programmes after clarifying whether the producer or the consumer would be the net beneficiary of the credits (Das et al. 2012, Behera et al. 2010). Approved by UNFCCC, the carbon credits plan has already successfully used on small-scale plantation projects in India (Chakraborty 2010), and could be suitable for fuelstocks plantation. This scheme will significantly help to cover planting expenses and also ensure adequate protection for the sustainability of agricultural systems by farming households. As this study indicates, a reasonable target of food responsibility and fuel production is also important in leading the construction of financial and political preventing plans in order to achieve the macro-scale food-fuel sustainability and the micro-scale profit through agricultural activities at the same time.

Conclusion

To summarize, land resource pressure from urbanization, increasing food-fuel demand driven by population growth contracts the availability of arable land for long-term biofuel sustainability. Improvements of land-use efficiency of both urban planning and agriculture distribution are necessary to reduce the uncertainty of food security and biofuel availability in the long run. No doubt that occupying wasteland for biofuels helps in reducing land resource pressure on food production and to some extent increases energy supply, the local capacity is not a dependable resolution for energy sustainability. Dependence on sugarcane and LIHD grasses can be expanded into a wider range of biomasses like all agricultural residues. Detailed yield evaluation about wasteland yield condition is also helpful in improve bioethanol production. Besides, bioenergy importation or alternative biofuel resources should be considered, such as biodiesel from jatropha or bioethanol from algae. A national blueprint is helpful in drawing concrete reasonable food-fuel targets to achieve sustainability at an acceptable speed for India. Sacrificing food exportation for local biofuel production helps with district-wise sustainability but may crisis food security to a larger extent in a national or global view. It is necessary to include the food-fuel production projections of different areas in the policy framework of India in order to take advantages of spatial differences to optimize food-fuel production. Technological improvement on agricultural practice, such as increase in agricultural extension, water conservation and reducing losses of food/fuel in harvesting, extraction and transportation also contributes to the long-term sustainability and to increase the total capacity of food-fuel production. Design and application of engines with high fuel efficiency and with increased biofuel content are also necessary. Thus, the overall goal of food-fuel security in India is more achievable under a multi faceted approach than on biofuels feedstocks cultivation alone.

14 Appendix

14.1 Main assumptions

Table 14.1 land-use assumptions

	Land-use assumptions	**Reference**
1	Wasteland area expands depending on irrigation (2010-2050)	(NRSA 2003, NRSA 2010)
2	Forest land remains constant during the entire period of simulation (2010-2050)	(ESODIS 2013)
3	Water and other land use remains constant during the entire period of simulation (2010-2050)	(ESODIS 2013)

Table 14.2 Energy assumptions

	Energy assumptions	**Reference**
1	5 % Bioethanol is assumed to have been achieved in 2010	(Ministry of Petroleum & Natural Gas 2006)
2	Bioethanol from LIHD grasses remains pure energy yield of 68100MJ/ha	(Ministry of Petroleum & Natural Gas 2006)
3	Bioethanol production from sugarcane molasses remains a consist yield of 85 litre bioethanol from per tonne of sugarcane excluding energy consumption during production	(Tilman et al. 2006)
4	Bioethanol production from cane bagasse remains a consist yield of 42.3 litre bioethanol from per tonne of bagasse excluding energy consumption during production	(SHELL 2014)
5	Transportation energy consumption is a function of population	(Suman Swami 2012)

6	LIHD grasses are carbon neutral and survive on rainfed unfertilized wasteland. It’s assumed to have no impact on soil organic carbon pool.	(Bettencourt 2013)

Table 14.3 Urbanization assumptions

	Settlement assumptions	Reference
1	Urbanization follows the same pattern with no difference between urban and rural.	(Fargione et al. 2008, Tilman et al. 2006)
2	Settlement area depends exponentially to population size	(Geo-portal 2013)
3	Human settlement trends to locate near existing settlement	(Modern Location Theory, P.Krugman, M.E.Porter, 1990)

Table 14.4 Crop assumptions

	Crop assumptions	Reference
1	Initial cropland takes 76.79% of Haryana area	(Bettencourt 2013)
2	Wasteland cannot grow food crops; however crop cells can be cultivated with Jatropha in the scenario period	(Government of Haryana 2012)
3	Fallow has no carbon pool change	(Ministry of New and Renewable Energy 2009)
4	Human settlement area is the main market for crops and influence crop agent allocation.	(Modern Location Theory, P.Krugman, M.E.Porter, 1990)

14.2 Yield simulation calibration

Table 14.5 Wheat yield calibration

Wheat Total yield	*Coefficients*	*P-value*
Intercept	996187.8509	7.13E-12

S_i	0. 062417845	1.16E-55
C_i	-6838.93137	9.3E-10
$T_{n\ max}$	-16461.8747	8.64E-39
$T_{n\ min}$	-63.99365526	4.66E-12
R_n	172.7753598	2.31E-12
R Square	0.629078372	

Table 14.6 Rice yield calibration

Rice Total yield		
	Coefficients	*P-value*
Intercept	-428328	0.000694
$T_{n\ max}$	30.17413	0.000178
$T_{n\ min}$	-83.5709	9.55E-05
R_n	-0.06911	4.61E-66
S_i	0.000298	0.963942
R Square	0.916113	

Table 14.7 Foodgrain yield calibration

Grain total yield		
	Coefficients	*P-value*
Intercept	6356.591	3.6E-05
$T_{n\ max}$	-0.322842	0.000934
$T_{n\ min}$	0.865537	0.000845
R_n	0.000692	2.1E-49
R Square	0.542268	

Table 14.8 Cotton yield calibration

Cotton total yield		
	Coefficients	*P-value*
Intercept	7251.2045	6.61E-31
$T_{n\ max}$	-0.4318	1.67E-27
$T_{n\ min}$	1.136363	1.29E-27
R_n	0.000136	1.56E-14
R Square	0.41381	

Table 14.9 Sugarcane yield calibration

Sugarcane total yield		
	Coefficients	*P-value*
Intercept	52972.6364	7.6E-296

S_i	-0.296969	2.5E-154
C_i	-6921.27	1E-151
$T_{n\,min}$	-2.060606	3.8E-177
R_n	-0.0281515	8.72E-23
R Square	0.930896	

Table 14.10 Wheat SOC decrease calibration

Wheat dSOC		
	Coefficients	*P-value*
Intercept	70746.54	5.21E-05
Y_i	0.280669	7.55E-91
S_i	-0.0457	4.63E-44
C_i	-533.087	6.76E-20
$T_{n\,max}$	-4.14638	0.000202
$T_{n\,min}$	10.60725	0.000356
R_n	-0.00244	1.26E-07
R Square	0.765665	

Table 14.11 Rice SOC decrease calibration

Rice dSOC		
	Coefficients	*P-value*
Intercept	249686.6	1.19E-27
Y_i	0.465212	1.52E-84
S_i	-0.0123	2.33E-25
$T_{n\,max}$	-16.2016	2.07E-28
$T_{n\,min}$	43.50234	8.38E-29
R_n	0.006116	7.66E-14
R Square	0.766181	

Table 14.12 Foodgrain SOC decrease calibration

Grain dSOC		
	Coefficients	*P-value*
Intercept	-21853.3	1.77E-05
Y_i	-1.79463	1.02E-08
S_i	-0.01549	5.4E-214
$T_{n\,max}$	1.53836	2.14E-06
$T_{n\,min}$	-4.20916	1.1E-06
R Square	0.891681	

Table 14.13 Cotton SOC decrease calibration

Cotton dSOC		
	Coefficients	*P-value*
Intercept	-26241.2	1.75E-05
Y_i	-6.6932	2.76E-11
S_i	-0.01555	2.9E-201
$T_{n\,max}$	1.838659	1.62E-06
$T_{n\,min}$	-4.99251	9.99E-07
R Square	0.884708	

Table 14.14 Sugarcane SOC decrease calibration

Sugarcane dSOC		
	Coefficients	*P-value*
Intercept	-3624.53	8.53E-27
Y_i	1.424337	3.7E-119
S_i	-0.0359	1.53E-15
R Square	0.754703	

14.3 Spatial data used

Table 14.15 Spatial data used in the study

Data	Source	Reference
Soil	Harmonized World Soil Database	(DNDC 2007, Li 2012)
Settlement	Haryana settlement map	(ESDB 2013)
Wastelands	NRSA	(Geo-portal 2013)
Irrigated areas	Global Cropland	(NRSA 2003, NRSA 2010)
Rainfed areas	Global Cropland	(ESODIS 2013)
Protected Area	Global Cropland	(ESODIS 2013)
Water resources	ThinkGEO, Maptell	(ESODIS 2013)
Roads and railways	ThinkGEO, Maptell	(Maptell 2012, OpenStreetMap 2013)

14.4 Demand projection

Table 14.16 Demand for non-export commodities (thousand tonne yr-1)

year	foodgrain	cotton	sugarcane
2010	425.34	102.84	1815.86
2011	432.64	104.83	1852.87
2012	440.06	106.86	1890.63

2013	447.62	108.93	1929.16
2014	455.30	111.04	1968.48
2015	463.11	113.19	2008.60
2016	471.06	115.38	2049.53
2017	479.15	117.61	2091.30
2018	487.37	119.89	2133.93
2019	495.73	122.21	2177.42
2020	504.24	124.57	2221.79
2021	512.90	126.98	2267.07
2022	521.70	129.44	2313.28
2023	530.65	131.95	2360.42
2024	539.76	134.50	2408.53
2025	549.02	137.11	2457.62
2026	558.45	139.76	2507.70
2027	568.03	142.46	2558.81
2028	577.78	145.22	2610.96
2029	587.70	148.03	2664.17
2030	597.78	150.90	2718.47
2031	608.04	153.82	2773.87
2032	618.48	156.80	2830.41
2033	629.09	159.83	2888.09
2034	639.89	162.93	2946.95
2035	650.87	166.08	3007.01
2036	662.04	169.29	3068.29
2037	673.40	172.57	3130.83
2038	684.96	175.91	3194.63
2039	696.72	179.32	3259.74
2040	708.67	182.79	3326.18
2041	720.84	186.33	3393.97
2042	733.21	189.93	3463.14
2043	745.79	193.61	3533.72
2044	758.59	197.36	3605.73
2045	771.61	201.18	3679.22
2046	784.85	205.07	3754.20
2047	798.32	209.04	3830.72
2048	812.03	213.09	3908.79
2049	825.96	217.21	3988.45
2050	840.14	221.41	4069.74

Table 14.7 Total demand with/without exportation (thousand ton yr-1)

	wheat		rice	
year	domestic	domestic & export	domestic	Domestic & export

2010	1322.19	2377.19	1742.04	4269.71
2011	1350.98	2428.94	1772.70	4344.86
2012	1380.39	2481.82	1803.91	4421.34
2013	1410.44	2535.85	1835.66	4499.16
2014	1441.14	2591.05	1867.97	4578.35
2015	1472.52	2647.46	1900.85	4658.94
2016	1504.57	2705.10	1934.30	4740.94
2017	1537.33	2763.99	1968.35	4824.39
2018	1570.80	2824.16	2003.00	4909.30
2019	1604.99	2885.64	2038.25	4995.71
2020	1639.93	2948.46	2074.13	5083.65
2021	1675.63	3012.65	2110.63	5173.12
2022	1712.11	3078.23	2147.78	5264.18
2023	1749.38	3145.24	2185.59	5356.84
2024	1787.47	3213.71	2224.06	5451.12
2025	1826.38	3283.68	2263.20	5547.07
2026	1866.14	3355.16	2303.04	5644.71
2027	1906.77	3428.20	2343.58	5744.06
2028	1948.28	3502.83	2384.83	5845.16
2029	1990.69	3579.09	2426.80	5948.05
2030	2034.03	3657.01	2469.52	6052.74
2031	2078.31	3736.62	2512.99	6159.28
2032	2123.55	3817.96	2557.22	6267.69
2033	2169.78	3901.08	2602.23	6378.01
2034	2217.02	3986.01	2648.03	6490.27
2035	2265.28	4072.78	2694.64	6604.51
2036	2314.60	4161.44	2742.07	6720.76
2037	2364.98	4252.04	2790.33	6839.05
2038	2416.47	4344.60	2839.45	6959.43
2039	2469.08	4439.19	2889.43	7081.93
2040	2522.83	4535.83	2940.28	7206.58
2041	2577.75	4634.57	2992.04	7333.42
2042	2633.87	4735.46	3044.70	7462.50
2043	2691.20	4838.55	3098.29	7593.85
2044	2749.79	4943.89	3152.83	7727.51
2045	2809.65	5051.52	3208.32	7863.53
2046	2870.82	5161.49	3264.79	8001.94
2047	2933.32	5273.85	3322.26	8142.78
2048	2997.17	5388.66	3380.73	8286.11
2049	3062.42	5505.97	3440.24	8431.96
2050	3129.09	5625.84	3500.79	8580.37

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