Energies **2015**, *8*, 3503-3528; doi:10.3390/en8053503

OPEN ACCESS

energies

ISSN 1996-1073

www.mdpi.com/journal/energies

Article

Sustainability Assessment of the Agricultural and Energy Systems of Senegal

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Academic Editor: Susan Krumdieck

Received: 18 March 2015 / Accepted: 21 April 2015 / Published: 27 April 2015

Abstract: To improve decision-making, sustainability-based approaches to assessment of options and undertakings demand that we move beyond narrowly defined considerations to address the full suite of requirements for progress towards sustainability. This paper reports on a sustainability assessment exercise that originally focused on burning agricultural residues, primarily peanut shells, for cooking applications in Senegal. The scope of assessment had to be expanded to address the agricultural and energy systems of Senegal, when closer examination revealed a complex set of energy and agricultural system interactions that could undermine the anticipated positive effects of initiatives centred primarily on peanut residue cookstoves. The case highlights the need to be open to expanding the scope of assessment to address underlying and/or unexpected issues that cannot be addressed appropriately at the project scale. In particular, the case illustrates how the assessment of an energy system may serve as an entry point into a deeper exploration of the context in which the energy system is embedded. The analysis also illustrates a situation in which different paths that may be followed, each with its own degree of uncertainty, path dependence, feasibility, fairness, cultural sensitivity, trade-off acceptability and possibilities for public judgement of overall desirability.

Keywords: sustainability assessment; agricultural residues; peanut cultivation; international development; bioenergy; sustainability criteria

1. Introduction

How sustainable is it to burn peanut shells as a cooking fuel in Senegal? In Senegal and elsewhere, using agricultural residues as a cooking fuel appears to offer an attractive means of reversing deforestation, avoiding the hazards related to collecting fuelwood, and—with properly designed cookstoves—reducing the adverse health impacts related to cooking with traditional stoves [1–4]. Since peanut shells in Senegal often collect next to processing facilities, or are burned in the fields, the potential to use residues for a productive task is enticing. Given that Senegal has lost almost half of its forest cover since the 1960s [5,6], the need to provide the forests some respite is apparent.

This paper reports on a research project that set out to explore the potential for burning peanut shells in Senegal, with a particular focus on the country's Peanut Basin, an area that accounts for approximately 30 percent of Senegal's surface area and 75 percent of Senegal's grain and peanut production [7]. The objective was to determine how use of cookstoves burning peanut-shell residues could promote progress towards sustainability. For the assessment, we planned to develop a comprehensive sustainability-based framework of context-specified criteria and apply it to identification and evaluation of cookstove options. It seemed to be a tidy little project.

As is often the case, however, other factors emerged. Initial efforts to understand the context for using peanuts shells as cookstove fuel revealed important considerations—especially interactions among soil fertility effects of peanut farming and the causes of deforestation—that undermined the assessment objective and pointed to larger issues and options at the scale of Senegalese agricultural and energy policy. In response, we realigned the project to explore these complex interactions at the project and strategic scales and expanded the contextual scope and ambitions of the sustainability assessment framework.

The paper consequently begins with an explanation of how assessing the potential for cookstoves burning agricultural residues requires us to expand the scope of assessment to the strategic level to address the complexity and interrelationships among the agricultural and energy systems of Senegal. Following that, we apply a generic sustainability assessment framework [8] as a basis for re-formulating the research question and for specifying criteria for evaluations and decisions. The methodology, described in Section 3, involved a case study approach combing documentary analysis, key stakeholder interviews and participant observation. Third, we propose a preliminary set of context-specified sustainability criteria for guiding decision making on energy and agricultural initiatives in Senegal, and present an initial set of observations about factors (conditions and trends) that represent key energy and agricultural considerations with implications for deliberations on use of peanut residues in cookstoves. Finally, we provide an initial response to the original question by arguing that burning agricultural residues for cooking applications appears to be generally unadvisable, and illustrate the potential for more positive alternatives with two options that merit further research.

2. The Larger Context of Peanut Shell Fuelled Cookstoves

Using peanut shells instead of charcoal and wood as cookstove fuel is an attractive initial idea. The multiple win elements—turning a waste into a resource, reducing deforestation pressures, lowering risks and perhaps even cutting household costs—seem to be just what is needed to move Senegal towards sustainability. But even the most attractive options merit careful consideration in light of the complex interactions of factors in the larger context.

Senegal is the western-most country of continental Africa. Its geographical location makes it very dry, and drought has been worsening since the 1970s. It currently faces important challenges in providing adequate livelihoods for all while maintaining its non-renewable resource base and ecological systems. Senegal's population is growing at an estimated 2.5–3.0 percent per year, and has increased from 2 million in the 1960s to 14 million people as of 2014 [9]. The country ranks low on the human development index (144th place out of 169 countries), although its GINI index has improved (the GINI index measures income (in)equality, with 0 representing complete equality and 100 representing complete inequality; scores range from 25 in Scandinavian countries to 65 in southern Africa). Senegal's current GINI score stands at 40.3 [10]. Over 46 percent of the Senegalese population lives in poverty [9]. Literacy rates and education levels are low and, coupled with poverty, prevent many Senegalese from becoming active citizens [11]. Gender inequality is ever-present; girls are often pulled out of school early to perform household duties, and women cannot own land and participate less in the paid labour force [12–14]. Despite this inequality, there have still been gains. For example, over 40 percent of seats in Senegalese National Assembly in 2012 were held by women [14].

Senegal's economy suffers from a structural deficit [11,13]. Facing high rural poverty rates, many youth migrate to the cities, where they face unemployment rates of 15 percent, which has caused civil unrest [15]. Most employment opportunities are informal and maintained in a context of uncertainty characterized by personal networks of credit and exchange, a lack of basic services (e.g., running water), vulnerability to external shocks, underage labour and low wages [11,13,16]. Getting ahead is difficult for small businesses and individuals because there is a shortage of upfront capital.

Senegalese agriculture is primarily rainfed, and based on small farms growing peanuts, millet, and sorghum [12], although peanuts have been the main cash crop for decades. Despite its extensive agricultural base, Senegal suffers from serious food insecurity, which is expected to worsen in coming years due to the increased cost of imported staple foods (notably rice and dairy products), declining yields due to improper peanut farming practices, and reduced export earnings from peanuts on the world market [11,17–19].

Senegalese agriculture has been heavily affected by the changing dynamics of peanuts, which has impacted Senegalese society in various ways. Peanuts were once the economic engine of Senegal due to years of government and colonial promotion. However, the percentage of export earnings related to peanuts has dropped from 80 to 12 percent since the 1960s [11,20], in part due to competition from other oils, reduced yields and increased foreign trade barriers (e.g., regulations on aflatoxin contamination).

Peanut growers are paid a government-set price, which has been kept artificially low. This low price serves as an indirect taxation of rural areas for urban benefits, and has encouraged an unlicensed peanut trade through Mali. (Since the fieldwork, there has been both a military coup and ongoing violence in Mali, as well as a change of government in Senegal and it is unclear how these factors have affected the licensed and unlicensed peanut trade). In recent years, increased demand from Asia has fuelled higher prices for peanuts, often in a manner that bypasses local millers (who continue to purchase peanuts at the government-set price) [21]. It is not yet clear how this new export avenue will affect the overall economics of peanuts in Senegal.

Beyond economic considerations, peanut agriculture is linked to deforestation. While burning peanut shells in cooking is seen as one means of combatting deforestation, poor peanut farming practices have led to decreasing soil fertility and productivity, and associated losses of livelihood opportunities. Failure to replenish soil fertility, for example, by returning peanut shells and other plant wastes to the land, has led to soil exhaustion. Farmers then abandon their fields and clear forests in the southeast in order to renew farming [5]. Using peanut shells in cookstoves instead of for soil enhancement may therefore exacerbate soil fertility depletion and lead to deforestation. This larger dynamic undermines the initial research premise about the desirability of burning peanut residues in cookstoves.

Senegal's energy system, made up of both modern and traditional energy pathways, is also facing challenges. Senegal relies largely on inefficient fossil-fuelled infrastructure that is unable to meet demand and suffers from increasingly frequent power outages. The system's unreliability discourages economic growth and fuels public discontent [22–25]. Due to inadequate refining capacity, over 60 percent of imported oil is externally refined at a higher cost [22,26,27].

One consequence of the weakness of Senegal's energy system is that the country remains heavily reliant upon traditional bioenergy, primarily fuelwood and charcoal for cooking, and is overexploiting its forest resource base [28]. The overuse of wood and charcoal for cooking has worsened deforestation and desertification, and these factors coupled with overgrazing and agricultural expansion have led to an almost 50 percent reduction in forest cover since 1965 [5,6].

In this demographic, agricultural and energy context, burning peanut shells in cookstoves is at best a questionable option. Even if forest protection were the only key objective, using peanut residues for cooking (thereby displacing charcoal and fuelwood demand) would conflict with using peanut and other agricultural residues for soil enhancement (thereby sustaining existing farmland and reducing deforestation pressures). Beyond that are much broader considerations—relating to energy, agriculture and Senegal as a whole—that are crucial for the decision-making processes affecting burning peanut shells in cookstoves.

In sum, this case demonstrates the crucial importance of considering the larger context before defining purposes and selecting the options to be examined. As is typical, the relevant context in this case is very broad. It encompasses two major sectors (energy and agriculture) and a wide range of interacting social, economic and biophysical factors—all of which reflect the functioning of dynamic complex systems with many key influences, vulnerabilities and opportunities. To facilitate explicit and manageable consideration of all these matters, a contextually specified framework for sustainability-based decision making provides a useful tool.

Any serious sustainability-based framework necessarily attempts to address the full suite of key interacting concerns. The common foundation is the globally generic set of requirements for progress towards sustainability that is quite easily extracted from the vast sustainability literature and decades of experience with sustainability-based initiatives. These general requirements are then elaborated in light of the major concerns and aspirations, stresses and resources, openings and vulnerabilities, *etc.*, that characterize the particular context. The next sections describe specification of a sustainability-based assessment framework as an approach to decision making about what to do with peanut residues in Senegal.

3. Sustainability Assessment

Because of the larger contextual factors discussed above, it is reasonable to replace the initial question—how best to approach burning peanut shells in cookstoves—with a broader and more strategic question—what to do with peanut shells in the context of improving the alignment of energy and agricultural policies and associated systems in Senegal to enhance rural livelihood opportunities, reverse deforestation and strengthen the national and local economies. In that assessment, peanut shell fuelled cookstoves represent only one option, probably at best an imperfect one.

For this larger agenda, the assessment framework to guide the identification and evaluation of options needs to integrate attention to the interacting set of influencing energy and agricultural system factors, and recognize the full suite of objectives for enhancement of prospects for lasting wellbeing in Senegal, especially the rural, peanut growing areas.

Sustainability assessment refers to the use of integrated frameworks to identify and evaluate the potential effects of alternative undertakings and find the best options for progress towards sustainability [29–31]. The context-specified frameworks require assessment agendas defined broadly enough to capture all significant social-ecological system interconnections, feedbacks and uncertainties and to address the full suite of requirements for sustainability [29,32]. The objective is to identify options most likely to deliver multiple, mutually reinforcing fairly distributed and lasting gains while avoiding significant adverse effects. An important step in undertaking sustainability assessment is combining established sets of generic sustainability criteria with attention to the key considerations for the particular case and context.

For the current research we began with the generic sustainability assessment framework described in Gibson *et al.* [29], which is based on a broad synthesis of the sustainability literature and has been applied in various context-specified forms in several energy systems cases at both the strategic and project levels [33–36]. The starting point was the set of eight generic criteria categories shown in Table 1. The eight categories represent the well-recognized requirements for progress towards sustainability, but depart from the common three pillars (ecological, social and economic) structure to help facilitate attention to interactive effects [29]. These criteria serve as a broad template that must be elaborated and specified for each particular case and context.

The elaboration and specification of these criteria for a specific case recognizes the key roles of context in determining possibilities, constraints, concerns, aspirations, and priorities. In this case the criteria specification for application the agricultural and energy systems of Senegal involved an interim step. This was a broad initiative to move from the eight generic criteria categories in Table 1 to a more detailed criteria set for application to energy undertakings, including bioenergy undertakings. The process and result, presented in Gaudreau ([37], Chapter 4), drew from four domains of energy-related literatures, including available works on sustainability-based assessment of bioenergy initiatives [36,38–46]. The generic criteria, elaborated for energy applications, were then specified for the Senegalese context and the question of what to do with agricultural residues, primarily peanut shells.

Table 1. Sustainability assessment decision criteria categories.

Socio-ecological system integrity
Build human-ecological relations to establish and maintain the long-term integrity of socio-biophysical systems and protect the irreplaceable life support functions upon which human as well as ecological well-being depends.
Livelihood sufficiency and opportunity
Ensure that everyone and every community has enough for a decent life and that everyone has opportunities to seek improvements in ways that do not compromise future generations' possibilities for sufficiency and opportunity.
Intragenerational equity
Ensure that sufficiency and effective choices for all are pursued in ways that reduce dangerous gaps in sufficiency and opportunity (and health, security, social recognition, political influence, *etc.*) between the rich and the poor.
Intergenerational equity
Favour present options and actions that are most likely to preserve or enhance the opportunities and capabilities of future generations to live sustainably.
Resource maintenance and efficiency
Provide a larger base for ensuring sustainable livelihoods for all while reducing threats to the long term integrity of socio-ecological systems by reducing extractive damage, avoiding waste and cutting overall material and energy use per unit of benefit.
Socio-ecological civility and democratic governance
Build the capacity, motivation and habitual inclination of individuals, communities and other collective decision-making bodies to apply sustainability requirements through more open and better informed deliberations, greater attention to fostering reciprocal awareness and collective responsibility, and more integrated use of administrative, market, customary and personal decision making practices.
Precaution and adaptation
Respect uncertainty, avoid even poorly understood risks of serious or irreversible damage to the foundations for sustainability, plan to learn, design for surprise, and manage for adaptation.
Immediate and long term integration
Apply all principles of sustainability at once, seeking mutually supportive benefits and multiple gains.

Source: Gibson, Hassan, Holtz, Tansey and Whitelaw ([29], p. 116).

Data Collection

The research in this case study approached data collection using variety of methods, including document analysis, literature reviews, key stakeholder interviews, and participant observation. Using multiple methods facilitated triangulation of results and improve construct validity [47].

In total, eleven formal interviews were conducted with representatives from local agricultural extension officers (two), international Non-Governmental Organizations (NGOs) with a long-term presence in Senegal (three), peanut producers and their representatives (two) private enterprises (three), and biochar developers (one). Due to the broad and comprehensive nature of the analysis, the interviews were open-ended, but still guided by the full suite of requirements for progress towards sustainability. The interviewees' contributions were analyzed for relevant themes—both general and specific—relating to peanut production, and agriculture and energy production and consumption more broadly. Beyond the formal interviews, a member of the research team attended many multi-party meetings that included stakeholders from environmental and civil society, industry, and agricultural extension.

To supplement the interviews, the research team also drew from a wide variety of documents relating to the energy and agricultural systems of Senegal, as well as broader social, ecological, cultural and economic concerns. The documents were identified through various means, including searches of NGO websites and the broader academic literature, as well as from the interviewees.

The final approach to data collection was participant observation. One member of the research team was directly involved in both improved cookstove production and ecological farming practices in Senegal over a five-month period. The participant observations helped situate the broader concerns and insights into the more immediate context of burning agricultural residues in cookstoves, and allowed the research team to develop a richer understanding of the realities behind the standard accounts and common assumptions.

4. Specification of Sustainability Criteria

Over the course of five months of data collection and one year of analysis, the research team developed a set of specified sustainability criteria relevant to the particular case and context. The sustainability criteria presented in Table 2 below, are presented as a set of positive objectives to which potential undertakings should contribute, preferably in ways that generate feedbacks with mutually reinforcing results.

Table 2. Proposed sustainability criteria for energy-agriculture applications in Senegal.

Socio-ecological system integrity
Greenhouse gas (GHG) emissions and air pollution
• reduce GHG emissions; particularly upfront GHG emissions (e.g., from land clearing)
• avoid or mitigate air pollution that threatens human and ecological health (e.g., field burning)
Water supply and quality
• promote responsible water management that allows for the maintenance and/or recovery of aquatic and terrestrial ecological integrity and reduces invasive species pressure (e.g., Typha in riverine systems)
Land use change and soil resources
• reverse the spread of desertification and promote the revitalization of marginal land
• promote practices that rebuild soil fertility and maintain long-term agricultural livelihoods
• maintain long-term forest resources and avoid the conversion of forest into agricultural land
Biodiversity and ecological integrity
• improve biodiversity and ecological integrity (e.g., eliminate field burning, minimize pesticides)
• manage for species migration due to climate change
Livelihood sufficiency and opportunity
Quality of employment and business opportunities
• promote fulfilling and healthy employment and respect workers' rights (e.g., fair wages, worker safety)
• where feasible, avoid child labour and improve conditions for rural migrant workers
• provide more opportunities for youth and others seeking meaningful employment
Promotion of local economic development and capacity building
• expand desirable local employment and resilient local economic development
• promote small-business diversity and capacity

Table 2. *Cont.*

Livelihood sufficiency and opportunity
National self-reliance
• increase economic self-sufficiency (e.g., improve national balance of payments)
• strengthen energy and food security and sovereignty (e.g., through agricultural and energy diversification)
Health and safety
• improve basic health (especially indoor air quality, adequate nutrition and sanitation, clean water)
Intragenerational equity
Gender equality
• promote gender equality in broader society
Reduction of poverty
• avoid environmental poverty cycles
• promote equitable sharing of limited resources and avoid resource conflicts
Rural-urban equality
• maintain livelihood opportunities in rural as well as urban regions (especially those facing rural exodus)
• address different rural and urban needs without furthering urban-rural inequality
Land tenure
• promote appropriate and equitable land tenure rights and avoid forced migration and land pressure
Distribution of benefits and risks
• enhance fairness in the distribution of wealth and income generating opportunities (including age, gender)
• promote retraining for those harmed by a transition to sustainable energy and agricultural practices
Promotion of international equity
• promote responsible and equitable practices by the international community (e.g., removing trade barriers to products from poorer countries)
Intergenerational equity
Long-term social-ecological integrity
• reverse negative trends in long term resource availability, ecological integrity and land fertility
• promote long-term equitable distribution of wealth
• maintain and enhance long-term social capital (e.g., traditions of mutual assistance)
Perverse effects
• avoid trading off long-term needs for short-term gains (e.g., cutting down mangroves for fuelwood)
Resource maintenance and efficiency
Ecological efficiency and effectiveness of agricultural systems
• promote ecologically beneficial farming practices that build soil fertility (e.g., residue management, fallowing)
• enhance food system efficiency (e.g., avoiding food wastage) and effectiveness (e.g., improved nutrition through a varied diet)
Ecological efficiency and effectiveness of energy systems
• promote ecological means of energy production with a feasible energy return on investment
• enhance energy system efficiency and effectiveness (e.g., matching energy quality to end-use)
• promote passive uses of energy (e.g., solar bottle lights, passive ventilation)
Resources for a resilient energy and agricultural system
• prioritize reliance on locally available resources while maintaining them within their ecological limits
• promote appropriate scales and degree of centralization of energy generation and food processing

Table 2. *Cont.*

Resource maintenance and efficiency
Resource stewardship
• promote stewardship, resilience and effective use of both renewable and non-renewable resources (e.g., forests, water, mines)
• prioritize uses of non-renewable resources to facilitate transition to renewable resource systems (e.g., liquefied petroleum gas as a transition fuel)
Socio-ecological civility and democratic governance
Good governance
• foster local decision-making and more broadly participative multi-stakeholder governance
• enhance collaborative and transparent governance, accountability, and trustworthiness (e.g., resource allocation rights)
Ecological civility
• contribute to public understanding of ecological systems and to the protection of natural resources
• promote active and informed participation in environmental management
• provide appropriate means of valuing ecological services and avoid market distortion (e.g., through NGO subsidization)
Social civility
• promote respect for marginal members of society and the maintenance of desirable spiritual values and traditional knowledge
• respect basic rights (liberty, security, equity, health, education)
• promote corporate social responsibility and respect for laws and regulations
• maintain and promote current culture of mutual assistance
Promotion of a positive social-ecological regulatory environment
• provide an integrated regulatory environment that promotes equity and stewardship (e.g., fair land tenure)
Prudence, precaution and adaptation
Promoting resilience and adaptive capacity and avoiding lock-in
• ensure sufficient resilience and adaptive capacity in food and energy production as well as broader society to accommodate changing conditions (e.g., drought, increased fossil fuel prices)
• seek mutual gains in resilience and efficiency (e.g., ecological farming practices)
Developing anticipatory planning and managing for uncertainty
• promote anticipatory planning for risk management with attention to indirect effects
• reduce vulnerability in key areas of uncertainty (e.g., resource availability, world market demands, soil fertility)
Immediate and long-term integration
Seeking mutually reinforcing impacts and synergy
• seek positive integration linking energy, agriculture and other industries and stakeholders at all scales
• promote the co-evolution of energy and agricultural systems with one another and with broader society, at an appropriate pace and in a manner that favours sustainability objectives
Creating opportunity for multi-level change
• provide innovation space for promising alternative approaches to energy and agriculture (especially organic farming, renewable energy, and local processing) that fit well with sustainability objectives
• promote grassroots and top-down change
Harnessing key windows and players for change
• plan for long cycles of change (e.g., transition away from foreign aid), while using avenues for rapid change
• seek out leverage points and windows of opportunity (e.g., decline of peanuts, electricity crisis) to foster changes that can deliver maximum net gains
• empower key stakeholders for positive change at all levels

The criteria were developed with guidance from the interviews and meetings, document analysis and participant observation. Several of the respondents were available for further interviewing and were thus able to help ensure that the key issues developed through the research process were captured and remained relevant to the case. The criteria share many similarities with other sets of sustainability criteria or indicators for bioenergy systems (e.g., [48,49]). For the Senegal case, the key themes in the criteria and initial observations are grouped under the eight categories of the initial generic criteria set, which use terminology generally familiar to assessment professionals. For practical application in policy and project deliberations, it is typically preferable to reorganize the criteria and results into categories and terms that facilitate ease of understanding and informed discussion among the relevant stakeholders [8]. Such reorganization would also allow a deeper deliberation regarding trade-offs among the various possible avenues for cookstoves and peanut residues, and present an avenue for further deliberation.

The criteria in Table 2, and their subsequent application in an initial analysis, are products of an academic exercise. They do not have the benefit of engaged authorities with decision making intentions or the contributions of stakeholders for whom the deliberations may have substantial consequences. Such involvement—preferably open and iterative—is likely to enrich the specification and application of sustainability-based criteria and to affect the contents as well as structure and presentation of frameworks and conclusions drawn from them. Our objective here is to illustrate an approach, not to provide conclusive results.

The context-specified criteria provided in Table 2 provide a package to help assess the key strengths and limitations of the energy and agricultural systems of Senegal especially as they touch upon the peanut residues question. The criteria are contestable, and further discussion of whether or not they in fact represent the full set of relevant characteristics would help clarify what should be recognized as important and desirable.

The criteria themes and particular points overlap to some extent, as is to be expected in a world of intertwined components. As well, the points are unlikely to be equally important or to have the same relative importance in each particular application and we have not attempted to propose weightings. Consequently, this is not a framework of criteria that can be used in a simple matrix for adding up the positives and subtracting the negatives. Our intent here is merely to establish a reasonably comprehensive base of considerations that ought to be addressed in the design, evaluation and implementation of undertakings involving energy and agricultural systems in Senegal.

5. Consideration of Senegal's Current Energy and Agricultural Systems in Light of the Sustainability Criteria

After the case-specific sustainability criteria in Table 2 were developed, we applied them in a test exercise. The result is the set of observations on the case and context presented in Table 3 below. The observations draw from a wide variety of quantitative and qualitative indicators, and provide an initial analysis of the most significant considerations relating to Senegal's energy and agricultural systems, approached with particular attention to aspects potentially relevant to options for use of peanut residues. The observations provide a baseline against which potential contributions of new policies, programme, and projects may be judged.

Table 3. Initial observations on the energy and agricultural systems of Senegal.

Socio-ecological system integrity
GHG emissions and air pollution
• Inefficient energy infrastructure (e.g., diesel power stations, charcoal production, cookstove usage) and transportation infrastructure are a source of air pollution and GHG emissions.
• Field burning and land clearing have contributed significantly to air pollution and GHG emissions [19].
Water supply and quality
• Agriculture, which is predominantly rainfed, already suffers from drought and rainfall variability, which has been increasing in recent decades and is predicted to worsen, with adverse effects on food production [6,11].
Land use change and soil resources
• Soil fertility in much of Senegal is dropping rapidly (approximately 418 kg/ha/yr) due to inappropriate farming practices, field burning, and erosion, and will be worsened by climate change [5,50]. • In some areas soil fertility is increasing due to land abandonment [6].
• Fuelwood and charcoal production, agricultural expansion (especially for peanuts), and illegal herding and overgrazing are causing deforestation and harming other forest products [2,5,11].
• Desertification is worsened by deforestation, drought and soil erosion. The government is promoting a Great Green Wall of vegetation to reverse encroachment of the Sahara [11].
Biodiversity and ecological integrity
• Drought is expanding the presence of Sahelian plants from the north, and promoting shrubland and savannah [23,50].
• Large areas of monoculture, improper pesticide use, and deforestation are threatening biodiversity and ecological integrity [51].
• Field burning harms wildlife and changes soil cover [6,23].
Livelihood sufficiency and opportunity
Quality of agricultural and energy business opportunities
• Agriculture provides the livelihood foundations for a majority of population but accounts for 1/5th of GDP, and generally provides seasonal employment, leading to urban migration. Farm incomes have not increased despite agricultural expansion, due to external shocks including droughts, energy crises, and structural adjustment [6,13,51].
• Low prices paid to producers reduce capacity and incentive to invest in better techniques and resource stewardship. Farmers lack credit to purchase inputs, resulting in lower yields and incomes [18,52,53].
Promotion of local economic development and capacity building
• Poor infrastructure (especially unreliable electricity) hampers economic development and provisioning of essential needs (e.g., education), and discourages investment in productive activities that justify infrastructural investment [23,54,55].
• Small businesses are hampered by low technical knowledge (e.g., for food processing), lack of capital, poor access to markets, and improper commodity chains. Low diversity of small enterprises in agri-business leads to oversupply and waste [6,52]. New ideas may require cultural change and proactive market creation to flourish.
• Agricultural processing (e.g., peanut oil) has been historically dominated by large para-statal industries. Small-scale processors are proving capable of achieving quality standards with sufficient support.
National self-reliance
• Government suffers from a balance of payment crisis due to reduced agricultural export earnings, increased cost of importing staple foods, and increased fossil fuels prices for transportation and electricity [12,28].
• Senegal is food insecure and imports staple foods (rice, milk), with the food deficit increasing, staple food prices increasing, and agricultural export revenues dropping [11,17].
• Peanuts are no longer considered a reliable crop but still employ up to 1 million people, and use 40 percent of cultivated land. Government is promoting diversification of food production, although success has been limited by inadequate supply chains [12,17].

Table 3. *Cont.*

Livelihood sufficiency and opportunity
Health and safety
• Food insecurity causes a high prevalence of malnutrition notably in women and children [56].
• Indoor air pollution from traditional cookstoves impacts health, reduces productivity, and reinforces environmental poverty. WHO estimates 5400 annual cooking-related deaths in Senegal [2].
• Deforestation is increasing burdens of, and risks to, rural women (e.g., collecting fuelwood) [26].
Intragenerational equity
Gender equality
• In return for food and access to farm plots, rural women and children perform household tasks (e.g., cooking, caring for children, fetching water, collecting fuelwood) [3,53]. Women cannot own land, and are thus discouraged from investing in stewardship.
• Previous government promotion of peanuts prioritized men, who expanded peanut production at the expense of their dependents. Women were unable to access farm equipment, causing late seeding and weeding, and lowering yields. Market liberalization indirectly addressed the inequality, but has heightened social tensions [53].
Reduction of poverty
• Due to lack of upfront capital, the poor must generally purchase items in single usage units (e.g., charcoal), and obtain illegal electrical connections, generally at higher per unit costs [57].
• Urban poor spend a significant portion of their income on charcoal, while in rural areas LPG and charcoal are unavailable, and fuelwood is generally gathered for cooking [26,57].
• Poverty and gender have strong influence on levels of education. Girls are often removed from school to perform household duties [11].
• Structural adjustment programs have dismantled supply chains and deepened poverty and unemployment. Despite this, the government is still planning to privatize SENELEC in accordance with structural adjustment [12,25,54].
Reduction of urban-rural disparity
• Urban areas generally have better access to health, education, electricity and other necessary services and opportunities [12].
• Large urban migration (especially men and youth) is causing rural labour shortage and urban unemployment.
• Low government regulated price for peanuts is considered an indirect taxation of rural areas to support cities. Similarly, the sale of grains to cities exacerbates rural grain shortages during hungry season and drives up prices in rural areas [52,53].
Land tenure
• Migrants often settle in peri-urban areas that lack basic services and harm peri-urban agriculture [6,57,58].
• Pressures on marginal and fragile land are rising due to drought, population growth, withdrawal of state support, and poverty), all without adequate understanding of the adverse effects or enough effort to identify livelihood alternatives [18,50].
Distribution of benefits and risks
• The recently cancelled government subsidy of LPG often benefited the rich and Gambians (who crossed the border), at the expense of poor Senegalese who were the intended beneficiaries.
• Government targeting richer households for solar PV (especially where transmission and distribution infrastructure are lacking) [28].
• Government control of charcoal quota system allows urban companies to profit from charcoal production at the expense of rural gains. International agencies are seeking to change this [59].
• Agricultural and bioenergy initiatives (e.g., projects to rebuild soil carbon) may worsen land tenure problems, and reduce livelihood opportunities of people using the land [17,50].

Table 3. *Cont.*

Intragenerational equity
Promotion of international equity
• International pressure maintains Senegal in an export mode of agriculture that is sensitive to world dynamics and threatens the long-term resource base [11].
• Consolidation of foreign direct investment in agri-food leads to unequal bargaining power and exploitation by multi-national companies (e.g., export of tomatoes) [60].
• International food quality standards and agricultural subsidies present a trade barrier to Senegal (e.g., U.S. domestic peanut subsidies and threshold levels for Aflatoxin contamination) [60,61].
Intergenerational equity
Long term socio-ecological integrity
• Overuse of natural resources is reducing the productive base and worsening poverty. Population growth and climate change are expected to accelerate resource degradation and exacerbate social problems (e.g., youth unemployment) [11].
• Climate change is expected to have negative health impacts (e.g., increased waterborne diseases) that will affect vulnerable populations most [11,18].
Perverse effects
• Population growth coupled with resource degradation (deforestation, desertification, soil erosion) is leading to negatively reinforcing long-term trends (e.g., loss of livelihood, reduced yields) [2,11].
• Urbanization places pressure on peri-urban farmland and promotes “hit and run” farming (farmers crop intensively but apply few amendments to regenerate the soils) that prioritizes short term gains [62].
• Structural balance of payments problem may create economic lock-in (e.g., continued focus on export crops) and spiral of debt.
Resource maintenance and efficiency
Ecological efficiency and effectiveness of agricultural systems
• Soil fertility is declining due to mono-cropping, inadequate fallow and inputs, and drought and rainfall variability. Compost and increased fallow have not compensated for lack of fertilizers [18]. Most fallow periods result from unavailable seeds and land abandonment [6,63].
• Peanuts, the primary cash crop, cause soil depletion (with yields dropping over 50 percent over several decades) because they are harvested by pulling entire crop up [18,19].
• Residues are often used as livestock feed or as a construction material, or are burned in the fields, rather than directly used for soil fertility improvements [62,63].
• Inability to store food products causes a glut in the market during harvest, reduces income, and produces waste (e.g., milk is spoiled during the rainy season) [52].
Ecological efficiency and effectiveness of energy systems
• Charcoal is currently produced by inefficient means by workers with generally low vested interest in resource stewardship, although improved methods exist [2].
• Electricity is largely fossil based with inefficient and poorly maintained generation facilities (estimated 21 percent losses). Power outages have increased due to under-capacity and high fuel costs [12,22,28].
• About 40 percent of electricity is used for low quality applications (e.g., cooling) [2].
• Increasing energy supply may promote increased usage (meeting suppressed demand), not necessarily for productive purposes, potentially increasing household expenditures while not increasing income.

Table 3. *Cont.*

Resource maintenance and efficiency
Resources for a resilient energy and agricultural system
• High solar potential (3,000 hours annual sunshine) provides opportunities for PV and thermal electricity, thermal drying, and water distillation with a comparatively low system cost [26,51].
• Government is promoting Jatropha, a rainfed oil crop that may grow for 50 years with minimal upkeep although yield is based on soil fertility. If properly implemented, Jatropha oil can be used for community purposes (e.g., pumping water), and the residues for energy or compost.
• Diversity of secondary sources includes wind, anaerobic digestion, and energy tree plantations, all at varying degrees of technological sophistication [2].
• Residues are processed at multiple scales and have multiple uses (e.g., electricity, biochar, direct combustion), opening possibilities for coordinated multi-scale approaches to residue management.
• LPG could serve as a bridge between current over-exploitation of soils and forests and a future renewable energy supply for cooking.
Stewardship of forest resources
• Deforestation due to fuelwood and charcoal production, and land clearing has led to 40 percent drop in forest cover since 1960. Land pressure prevents the 4–12 years necessary for proper forest regrowth and will be worsened by population growth and poverty. Ecologically and economically important trees are not protected [2].
• Tree seedlings are often not protected and many do not reach maturity. Some villages are banning goats in lieu of chickens to better protect trees.
• Agroforestry is being slowly introduced with positive results (e.g., Moringa) [6].
Stewardship of aquatic resources
• Degradation of mangroves has adverse effects on fishing and tourism [11].
• Water quality is threatened (e.g., in sulphurous regions water is becoming acidified, causing soil destruction).
• Fish is an important part of Senegalese economy and food security, but marine resources are being depleted. Government is limiting international fishing and promoting aquaculture. Climate change is expected to lower catches and cause seawater intrusion [11].
Social ecological civility and democratic governance
Good governance
• Government has abdicated many social service responsibilities to NGOs and municipalities. Lack of coordination between NGOs reduces their effectiveness, encourages duplication, and hampers sharing of knowledge and experiences [6,11,12].
• Mix of traditional and rational-legal methods for determining property rights and other land use rules may create conflict, but also provide diversity of available perspectives and mechanisms [58].
• Low level of citizen involvement in decision making is partly due to lack of education and poverty [11].
Ecological civility
• Better stewardship of natural capital is needed, but short term needs often outweigh long-term stewardship (e.g., cutting down mangroves provides fuel but removes an ecological service).
• Dependence on traditional and "free" biomass may lead to undervaluing of renewable resources [51].
• International aid generally does not promote full cost accounting (e.g., indirect subsidization of cookstoves can distort markets and hamper local self-reliance).
Social civility
• Peanuts are deeply embedded in the culture and are important for cooking, soap-making, and livestock feed. Cultural habits can run counter to desired best practices (e.g., adopting improved cookstoves) [2].
• Community solidarity is an important asset [64], which may facilitate or slow desired change.

Table 3. *Cont.*

Social ecological civility and democratic governance
Promotion of a positive social-ecological regulatory environment
• Senegal's regulatory system is plagued by overlapping and potentially conflicting policies concerning forests (protect forests), agriculture (promote peanut production, expand land under cultivation), livestock and rangelands management, land tenure, and water resources [6,11].
• Environmental enforcement is inadequate (e.g., too few park rangers) [2,23].
• Land management decisions are often driven by religious, political, or financial motives, often for urban benefit [11]. Government has historically ignored relationships between property rights and poverty [58].
Prudence, precaution and adaptation
Promoting general resilience and adaptive capacity and avoiding lock-in
• In many places locally available drivers for adaptive change are addressing many problems in an integrated manner (e.g., eco-villages, market gardening) [65].
• History of adaptation and income diversification in Senegal is positive, notably in agricultural areas that have suffered from drought [18].
• Lack of education and poverty impede adaptive capacity (e.g., for climate change) [18].
Promoting agricultural resilience and adaptive capacity and avoiding lock-in
• Agricultural dependence on erratic and declining rainfall coupled with inability to purchase inputs increases yearly variability, and complicates long term planning that must account for both poor years and seasonality [18,62].
• Reliance on exports of cash crops (e.g., peanut oil) and imports of staple foods increases vulnerability to world market prices. If properly undertaken, increased domestic production of staple crops and development of internal markets may reduce food wastage, improve food security and promote local economic development [6,11].
Promoting energy resilience and adaptive capacity and avoiding lock-in
• Dependence on fossil fuel imports for electricity generation increases economic vulnerability due to fluctuating world market prices [23].
• Both urban and rural populations have adapted to the fluctuating availability of electricity, although discontent is increasing and entrepreneurialism is discouraged [24].
• Adaptive energy technologies (e.g., solar PV) exist at a number of scales and exhibit high technical potential, are minimally vulnerable to geopolitics and could save on transmission and distribution infrastructure and losses, but care must be taken to ensure cultural sensitivity.
Developing anticipatory planning and managing for uncertainty
• Challenges of keeping up with the pace of environmental change (e.g., deforestation rate) and the expected acceleration of change due to population growth are overwhelming capacities to consider long-term implications.
• Social-ecological effects of structural adjustment and other policy decisions are still undetermined.
• Data on some significant concerns are inadequate: only estimates available on the impact of government subsidy of LPG; total agricultural production is uncertain due to non-regulated supply chains; total charcoal consumption is unknown but is estimated to be growing [2,22]
Immediate and long-term integration
Seeking mutually reinforcing impacts and synergy and promoting virtuous circles
• Increases in food and energy security could improve health and access to education, which may reduce population growth and improve long-term food and energy security.
• Promotion of small-scale energy and agricultural systems could improve food and energy security while targeting youth and promoting steps towards greater gender equality.

Table 3. *Cont.*

Immediate and long-term integration
Seeking mutually reinforcing impacts and synergy and promoting virtuous circles
• Farming productivity could be greatly improved by eliminating bad practices including those with logistical, institutional and cultural roots [52]. Efficiency and resilience of farming and energy practices can be increased simultaneously.
• More appropriate means of valuing alternative energy and agricultural practices (e.g., solar PV, organic farming) could reduce dependence on long-term financial support from the international community.
• Strengthening the capacities of community and regional level bodies to direct interventions (e.g., training, equipment, market access), could reduce unnecessary duplication, facilitate citizen engagement, and assist a transition away from foreign aid.
• Modern energy services (notably electricity) can bring livelihood opportunities, but they require productive uses to be justified, and this depends on effective design and use of market instruments as well as government policies and programmes, and emphasis on delivering benefits to the disadvantaged rather than only to the already successful.
Creating opportunity for multi-level change
• The potential for positive gains is spread across the full spectrum of technology levels: many types of bioenergy can be both low-tech and hi-tech (e.g., biogas, combustion of residues).
• Empowering small agricultural and energy entrepreneurs could mobilize new capacities, though mechanisms will be needed to ensure sufficient diversity in new products.
Harnessing key windows and players for change
• The declining strategic value of peanuts opens a window to exploring alternative cash crops that may promote food and energy security.
• The current crisis facing the electricity system (declining infrastructure and expensive imported fossil fuels), opens possibilities for more decentralized and endogenous electricity supply systems.
• Coordination with other West African countries (e.g., West African electricity power pool) could improve efficiencies, and encourage cooperation, and build on Dakar's reputation as a hub.

The criteria presented above and the observations presented below were developed jointly and iteratively, with the initial sustainability criteria informing the data collection, which in turn informed further iterations of criteria specification. Throughout the iterative development of the criteria and observations, care was taken to ensure all the generic sustainability assessment criteria were addressed in the case-specific context.

6. Discussion

The sustainability criteria in Table 2 and observations in Table 3 reveal the range and significance of the many factors and interdependent dynamics at play within and between the energy and agricultural sectors in Senegal. While the criteria and observations are necessarily tentative, they provide useful indications of what desirable characteristics and trends ought to be supported, protected and enhanced, and what undesirable characteristics and trends ought to be corrected or reversed at several scales, from local to national.

The following section discusses some important threads arising from the initial observations from Table 3. We begin by describing three important themes that serve as broad constraints on what types of decisions can be made in Senegal. Following that, we identify three promising areas for consideration of improvements the Senegalese energy and agricultural systems, and in doing so, return to the original question of burning peanut residues in cookstoves.

6.1. Three Broad Themes

6.1.1. Interactive and Mutually Reinforcing Adverse Effects

The first theme that emerged was that many of the most important issues and opportunities involve the interactions of multiple factors. Resource degradation, insufficient rural livelihood options, and population growth all reinforce one another, both in general, and in the Senegalese case study [11]. The end result is people are often forced to favour options that are not in their own economic interest beyond day-to-day survival.

One example of such an interactive effect relates to purchasing fuel for cooking. Many Senegalese in Kaolack and other areas cannot afford to purchase liquefied petroleum gas (LPG; also referred to as propane or cooking gas) because of the upfront cost. Instead they are forced to purchase charcoal on a daily basis, which over the long term costs more than LPG [57]. Likewise, in some areas people cut down mangroves because they are the only available source of fuel for cooking, even though mangroves are crucial as fish nurseries, barriers to erosion and protection against tidal surges and stormwaters.

These examples point to the value of attending to interactive effects as opposed only individual criteria. Likewise, interventions should be designed to offer positive reinforcing effects (e.g., perhaps quite modest microfinance interventions would make LPG purchases possible and reduce both household and ecological costs). Gradually, such interventions might provide the foundations for more forward thinking and broader strategies.

6.1.2. Peanut Dependency

The second theme that emerged is peanut dependency. As mentioned previously, peanuts have traditionally played important cultural as well as economic roles in Senegal. However, peanut growing (and processing) is not likely to be viable in the long term as the core foundation for livelihoods and the national economy in Senegal. There are several reasons for this.

Ecologically, growing peanuts is hard on the soil and is a significant cause of dropping soil fertility. Farmers tend to grow only peanuts until soil fertility drops to a point that they are forced to rotate with millet. In certain areas, yields have declined more than 50 percent over several decades [18,19]. This has led to deforestation, as previously mentioned.

Economically, peanut-related export earnings have declined over the past several decades [11,20]. The government has been promoting agricultural diversification in order to improve food security [12,17], but no viable alternatives have fully taken root. While increased demand from Asia may partially reverse the fortunes of the peanut, this is not necessarily desirable, given the ecological impacts of intensive peanut cultivation.

Despite all the challenges they present, peanuts are hard to eliminate. Peanuts are a key established agricultural specialization and economic foundation for many people and are likely to continue to be important well into the foreseeable future, though less central to the national economy or to foundations for community and family livelihoods. Peanuts are also deeply rooted in Senegalese culture and cuisine.

Ultimately, Senegal likely must continue to pursue economic and agricultural diversification. Ways must be found to make peanut growing and processing more viable and beneficial for the long run while also fostering alternative livelihood and economy foundations.

6.1.3. The Soil Fertility—Deforestation Nexus

The third theme that emerged is the dynamic link between deforestation and soil fertility. The initial attraction of cookstoves that burn peanut residues was that they would quite directly reduce forest pressure by replacing wood and charcoal combustion. But deforestation also results indirectly from soil exhaustion.

Soil fertility in much of Senegal is dropping rapidly (approximately 418 kg per hectare per year of organic matter is lost.) due to inappropriate farming practices, field burning, and erosion, and will be worsened by climate change [5,50]. As noted previously, low yields from poor fertility have encouraged farmers to abandon their fields and clear forests in order to renew farming [5]. There has already been a 40 percent drop in forest cover since 1960 and the land pressures that prevent forest regrowth are increasing due to population growth and poverty [2].

Initiatives to maintain or recover soil fertility are needed to protect the remaining forests and using peanut shells and other agricultural residues for soil enhancement is one possibility. Burning agricultural residues as a fuel source is probably less desirable than using them as a soil amendment. That said, present practices—treating the residues as wastes and burning them in the fields—are clearly worse. The three themes described above—interactive and mutually reinforcing adverse effects, peanut lock-in, and the soil fertility/deforestation nexus—serve to guide identification of implications for the future in the next section.

6.2. Implications for the Future

The themes that emerged from consideration of peanut residues in Senegal's larger sustainability context point to evident needs and opportunities. Deciding how particular responses might best be defined, elaborated and placed among other priorities is, like the specification of sustainability criteria, a matter for the Senegalese. The following discussion aims only to explore how application of sustainability assessment criteria could affect evaluation of some possibilities.

6.2.1. Limitations of Peanut Residue Fuelled Cookstoves

While burning peanut residues instead of wood or charcoal in household cooking would reduce some immediate pressures on forest resources, on the whole this option appears generally unadvisable because it would eliminate a key means of preserving soil fertility and indirectly encourage further deforestation. Using peanut residues as a fuel source might not only eliminate their potential use as a soil amendment but also entrench habitual removal of residues from the fields.

Despite these concerns, it may be advantageous to allow for the burning of agricultural residues in certain situations. For example, as a result of government centralization of agricultural processing, peanut shells currently collect outside processing plants in the cities, where there is no obvious use for them. In these circumstances, burning the shells in cookstoves (or even burning them for electricity generation) would promise beneficial use, though returning the shells to the fields as soil amendments might well be even better. For all particular applications, careful consideration of implications and broader alternatives—guided by the sustainability criteria set—is needed. For example, some peanut producer cooperatives in Senegal have lobbied for decentralized peanut processing, and it is important to consider whether centralized production of cooking fuel or electricity from peanut shells would hinder local agricultural value-added chains.

The issue of burning peanut residues also opens the door to a deeper discussion of the future of peanuts in Senegal. As noted above, while peanuts may well retain economic as well as cultural importance, dependence on significant levels of peanut cultivation may not be desirable or viable as a long-term agricultural path for Senegal. It may therefore be prudent to avoid energy systems that depend uniquely upon peanut shells as a source of bioenergy.

6.2.2. Liquefied Petroleum Gas as a Near Term Energy Bridge

In 1988 the Senegalese government began subsidizing LPG as a substitute for charcoal and fuelwood consumption, especially in urban areas [22,26,57,66]. The government has been phasing out the LPG subsidy for various reasons including its cost, equity effects (the rich tended to benefit most), and risks of promoting reliance on fossil fuels [66]. The LPG subsidy nonetheless remains a serious option for reducing forest pressure by providing an alternative fuel source. Furthermore, LPG stoves are clean-burning and culturally appropriate for cooking.

While an improved version of the LPG subsidy is not a potentially permanent solution, it could serve as a useful intermediate step or bridge in the transition to more sustainable energy systems (e.g., involving biochar, see below). The LPG subsidy option might best be considered as a temporary contribution to a long term strategy. The international community, which is heavily involved in development initiatives in Senegal, might be willing to fund temporary use of LPG as an energy transition bridge if it were a component of a concerted and far-sighted approach to development efforts in Senegal.

As is often the case, no present option is likely to be problem-free, and there are rarely easy ways of defining the boundary between what is and is not acceptable. Particular decisions may therefore benefit from assessments using more locally specified sustainability-based criteria for identifying and comparing options. The continuing uncertainties also suggest reasons to favour options that are easy to adjust or replace.

6.2.3. Biochar and Biocharcoal for the Longer Term

Escaping dependence on fossil energy sources is likely to be a prudent goal for Senegal's energy and agricultural systems. One emerging non-fossil option is the production and use of biochar as a soil amendment and biocharcoal as a replacement for charcoal. Biochar, produced by the pyrolysis of biomass, is gaining popularity as a means to regenerate soils by increasing soil carbon storage and nutrient holding capacity, often more effectively than the original biomass could do as a soil amendment [67].

Biochar can be produced from many different feedstocks and at multiple scales. Peanut shells could play a role in biochar production but be phased out and replaced over time. Large commercial operations can be used for biochar production, but so can cookstoves that operate as biomass gasifiers (e.g., [68]), although the science behind this is still developing [69].

Biocharcoal may also be important in Senegal, especially for cooking and brewing Senegalese tea. The German development agency and other groups in Senegal are researching a form of biocharcoal that is effectively biochar containing a binder (e.g., clay or sugar) to facilitate handling and combustion [1,70,71]. Like biochar, biocharcoal may be produced using various feedstocks (e.g., Typha, an invasive riparian weed), although it is likely only feasible with commercial-scale production, as opposed to being a by-product from gasifier cookstoves.

Both biochar and biocharcoal allow for locally appropriate economic development, do not lock Senegal into one specific type of biomass or agricultural residue, and offer broader benefits. The German development program Gesellschaft für Internationale Zusammenarbeit (GIZ) is promoting biochar production as a means of youth employment for both men and women, indicating that mutually reinforcing gains are being sought. There are, of course, open questions regarding the long-term potential of both biocharcoal and biochar. The extent to which biocharcoal could feasibly replace charcoal depends on the scale of production (artisanal *vs.* commercial scale) and the availability of biomass, both of which require further analysis [2]. Further work may also be needed to ensure that biocharcoal is at least as clean burning as regular charcoal. Biochar faces questions about the energy return on investment, which is currently unknown and likely context dependent (e.g., affected by manual or machine production), and about how to deal with the country's current lack of the high quality gasifier stoves needed to produce biochar, since promoting low quality biochar now may hamper future adoption of better stoves later. Presently, neither biochar nor biocharcoal appears to be ready for large-scale adoption in Senegal, although they seem to have great potential in the longer term.

Biochar/biocharcoal and the LPG subsidy are unlikely to be the only promising options meriting further attention and comparative assessment. They do, however, illustrate the kinds of options that may emerge from context-specified, sustainability-based consideration of broader short- and long-term energy/agriculture possibilities when a more narrowly conceived solution (in this case peanut shell fuelled cookstoves) proves unsatisfactory or inadequate by itself.

7. Conclusions

The research demonstrates the significance of contextual factors in sustainability-based assessments, the importance of flexibility in defining the focus of such assessments and the complexity inherent in integrated consideration even of apparently simple matters of waste use and cookstove design. The research began as an assessment of using peanut shells and other agricultural residues for cooking applications in Senegal. The nature of the case required that the scope of assessment be increased from the project scale up to the strategic scale, to address key issues and reveal more promising options in light of agricultural and energy system relationships and their economic, ecological and cultural contexts in Senegal.

Guided by the sustainability assessment process and situating the discussion within both the centrality of peanuts in Senegal, and the key dynamics of energy and agricultural systems affecting soil fertility and deforestation, we have found that the development and use of cookstoves that burn agriculture residues, notably peanuts, for fuel may be generally undesirable. However, we recognize that under certain circumstances, such as where peanut shells are collecting in urban areas or outside agricultural areas, it may be advantageous to develop energy technologies (e.g., for cooking or electricity generation) based on agricultural residues, so long as they promote general progress towards sustainability, meeting the sustainability-based criteria elaborated in Table 2 and addressing the key considerations in Table 3.

These conclusions about what to do with peanut residues are indicative only. While our project has illustrated the value of context-specified sustainability criteria in critical consideration of purposes and response options, the criteria set has significant limitations. It was not developed or tested in an open public process with the relevant stakeholders and it has not been authoritatively endorsed. Consequently, some important contextual factors and relationships may have been overlooked and the criteria set lacks the community understanding and credibility that are best achievable through public processes.

For some purposes, the criteria set may also suffer from being unaccompanied by quantitative indicators. While quantitative approaches introduce their own problems (especially the illusion of objectivity and precision in cases where the weighting of priorities is debatable and/or the available data sets support imperfectly representative indicators), some excellent work on indicator development has been done in global scale bioenergy assessment initiatives (e.g., [48]). Moreover, use of quantified indicators may be effectively mandatory in applications leading to specific approvals or certifications [49]. Further advances in sustainability-based criteria development for energy and agriculture applications in Senegal would benefit from more public and stakeholder discussion, inclusion in authoritative governance processes, and efforts to identify suitable indicators, including quantifiable ones, for particular applications. Furthermore, attempts should be made to harmonise with other sustainability assessment approaches.

Like many other jurisdictions, Senegal and its various governance institutions do not have established traditions of specifying criteria for determining which strategic or project level options are best equipped to promote progress towards sustainability. While government and non-governmental organizations at all scales have outlined important strategic issues regarding the energy and agricultural systems of Senegal [11,22,28], the issues have not been integrated into a comprehensive understanding of what is needed for progress towards a more desirable future for Senegal. This situation is common; few jurisdictions anywhere have clearly established, sustainability-based criteria to guide decision making and careful specification of such criteria for particular cases and contexts is rare. But without such criteria, it is difficult to determine whether, and under what circumstances, initiatives such as burning peanut shells in cookstoves represent a positive step forward.

Pending development of a more openly developed and broadly endorsed set of sustainability criteria specified for deliberations on matters at the nexus of energy and agriculture in Senegal, the sustainability criteria proposed in Table 2 provide a useful starting point for determining what criteria to focus on (and indicators to select) in the Senegalese context. They are likely to be especially appropriate in cases where basic initial issues are involved—where there may be reason for careful examination of the purposes to be served and/or options to be considered. The criteria need public discussion and further elaboration. For particular applications, they will also need review and adjustment for particular contexts. While sustainability assessment is merely a means of ensuring integrated attention to the many intersecting factors that affect lasting wellbeing, the factors are dynamic and their interactions are context-dependent. In Senegal as elsewhere, the generic requirements for progress towards sustainability apply only as part of the story. As this modest inquiry into peanut residues, energy and agriculture has shown, the complexities of the context must always be respected.

Acknowledgments

We gratefully acknowledge funding from the Canadian National Science and Engineering Research Council (NSERC), the Fonds de recherche du Québec–Nature et technologies (FQRNT), as well as the Canadian International Development Agency (CIDA).

Author Contributions

Kyrke Gaudreau conceived of the research, undertook the primary research in Senegal and the analysis of the data. Robert B. Gibson contributed significantly to the research conception and data analysis.

Conflicts of Interest

The authors declare no conflict of interest.

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