Case Studies Identifying Scenarios of Influence to Priority-Setting: Rio de Janeiro Disaster Management and Commonwealth of Virginia Biojet Fuels

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ABSTRACT

Corporate decision makers in the public and private sectors must allocate scarce resources to acquire knowledge relevant to their plans and future investments. Such knowledge includes the variety of emergent sources of risks and opportunities. This thesis tests an existing method that combines scenario analysis with multi-criteria analysis for priority-setting, with an emphasis on identifying whether particular scenarios matter irrespective of their likelihoods, and whether sufficient relevant scenarios have been considered. The goal of this thesis is to generate practical results and lessons learned from the testing of this method in two case studies: (i) disaster planning in Rio de Janeiro, Brazil, and (ii) formation of a biojet fuel industry for the Commonwealth of Virginia. Scenarios of concern for the disaster case study include flooding, landslide, drought, radiological emergency, population behaviors, and terrorist attack related to the upcoming World Cup and 2016 Summer Olympics. Scenarios of concern for the fuels case study include markets, competitors, regulations, long-term availability of crude oil feedstock, and environmental change. The results in each case study include definitions of initiatives and performance criteria, generation of emergent conditions, assembly of up to five scenarios from the emergent conditions, and knowledge of which scenarios most matter to priority-setting. The results suggest to decision makers where to improve robustness of planning initiatives, what are the influences for priority-setting of combining diverse emergent and future conditions, and where additional information on scenarios would be most beneficial.

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1 INTRODUCTION

1.1 Motivation

Uncertainty in emergent future scenarios complicates decision-making. The economist Keynes (1937) describes, "[under uncertainty] there is no scientific basis on which to form any calculable probability whatever. We simply do not know. Nevertheless, the necessity for action and for decision compels us as practical men to do our best to overlook this awkward fact". An executive of Shell International has described, "No one can definitively map the future, but we can explore the possibilities in ways that are specifically intended to support decision-making" (Shell International BV 2008).

Scenario analysis is a widely used tool for supporting decision makers. A spokesperson for the United Nations Department of Economic and Social Affairs, Division for Sustainable Development (Roehrl 2012) has described, "Good governance calls for…scenario analysis."

There clearly are needs for systematic approaches to analyzing scenarios and robustness of government policies and industry strategic plans. Decision makers can benefit from the identification of the scenarios that are most or least impactful when considering alternative decisions. Furthermore, single conditions are prevalent in scenario analysis despite that combining of conditions to acknowledge the possibilities for perfect storms is at least as important to avoid surprise and regret in real-world large-scale systems.

1.2 Purpose and Scope

This thesis will use scenario analysis and multi-criteria analysis to support priority-setting, where the robustness of the priorities across technology, and other initiatives, to scenario uncertainties is essential to quantify and address. The two case studies that comprise this effort are (i) disaster response in Rio de Janeiro, Brazil, and (ii) formation of a biojet fuel infrastructure for the Commonwealth of Virginia, USA. The thesis will demonstrate the construction and prioritization of scenarios for the two case studies as follows:

(1) Disaster preparedness in Brazil focusing on radiological disasters, Olympics, World Cup, populations behaviors, flooding, and landslides

(2) Biojet fuel industry including markets, competition, regulations, technologies, agriculture sources, and logistics

The objectives are to:

- Develop criteria, initiatives, and scenarios for the multi-criteria analysis
- Refine and test an existing method of scenario analysis for new application areas
- Discover which scenarios have the most influence on prioritization of initiatives for two case studies
- Integrate the findings and lessons learned to recommendations for next steps, both in methodology development and the practical situations of the case studies.

The elements of the technical approach are:

- Set of criteria pertinent to decision makers
- Set of initiatives, either of investments or alternative actions

- Assessment matrix evaluating how well the initiatives address the criteria
- Set of uncertain future scenarios assembled from emergent conditions
- Weights measuring influence of criteria and value function for prioritizing the initiatives
- Synopsis of which scenarios are most and least influential to priority setting

This approach finds the sensitivity of a prioritization of agency or industry initiatives in order to determine the most influential scenarios, showing what are the greatest needs for knowledge in planning. The approach avoids several of the common practical shortcomings of risk assessment which include that diverse sources of expertise (political, technological, economic, etc.) are ignored, real-world alternatives are not mutually exclusive, probabilities cannot be reliably assessed or agreed with available time and resources, and/or that the event space of future conditions is not complete. The results can inform decision makers on the robustness of initiatives and the impacts of various emergent and future conditions, both alone and in combination.

1.3 Organization of Thesis

The organization of this thesis is as follows. Chapter 2 describes the background and literature review for the methodology to be employed. Chapter 3 describes the methodology for studying the implications of uncertain future scenarios. Chapter 4 describes the first case study, of disaster preparedness for Rio de Janeiro. Chapter 5 describes the second case study, of biofuel production in Virginia. Chapter 6 will identify the shared features of the case studies and discuss miscellaneous technical concerns. Chapter 7 describes a review of accomplishments, the intellectual contributions, and topics for future work.

Figure 1 displays the roadmap of the chapters of the thesis.

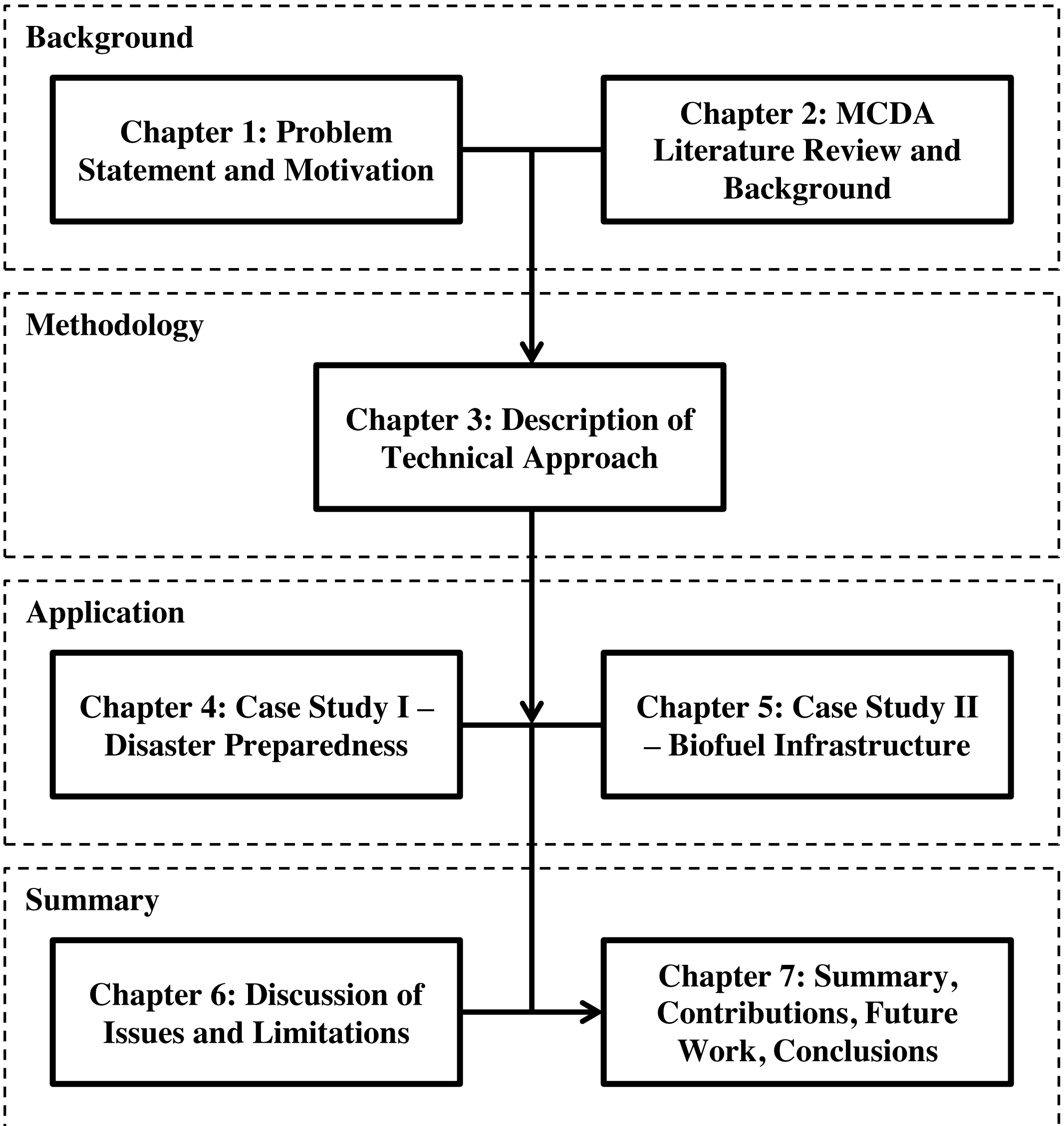

Figure 1. Roadmap of the technical approach and organization of thesis

1.4 Diagram of the Effort

The activities involved in the preparation of this thesis are as follows:

1. Literature review related to
    a. Scenario analysis and multi-criteria analysis
    b. Emergency planning in Brazil, and
    c. Uncertainties in biofuel production
2. Identify criteria
3. Identify investment initiatives
4. Assess the relative influence of criteria for the baseline and other scenarios
5. Identify future scenarios and emergent conditions
6. Prioritize initiatives for baseline and under different scenarios
7. Determine the scenarios that are most influential in ranking the initiatives
8. Publish and present findings, as thesis, journal articles, and conference presentations

The schedule of these activities is shown in Table 1.

Table 1. Diagram of the effort

Tasks	2011		2012			2013		
	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer
Literature review (a)								
Literature review (b)								
Literature review (c)								
Identify criteria								
Identify initiatives								
Present initial work & findings*								
Assess relative influence								
Identify future scenarios								
Prioritize initiatives								
Determine influential scenarios								
Publish findings*								

*Early work was presented at the INFORMS Annual Meeting (Lambert & Connelly, 2012) and a journal article has been submitted for review (Connelly et al. 2013a), and a second journal article is in preparation (Connelly et al. 2013b).

2 BACKGROUND

2.1 Overview

This chapter describes literature that defines the needs and challenges and supports the approach involving scenario analysis and multi-criteria analysis. After commenting on the shortcomings of each separately, this chapter concludes that an integration of methods is preferable. The chapter presents papers that have used an integrated approach on a wide range of topics.

2.2 Literature Review

Decision makers in the public and private sector must allocate scarce resources to acquire knowledge relevant to their strategic plans, including the emergent sources of risk and opportunity. Investment decisions in the face of uncertainties can benefit from the use of scenario analysis. Goodwin and Wright (2001) describe the use of scenario analysis to address uncertain conditions. Montibeller and Franco (2010) emphasize the role of multi-criteria decision analysis in aiding with strategic decisions, which are subject to uncertainty and have lasting consequences involving significant resource implications. Belton and Stewart (2002) describe a theoretical framework for integrating scenario analysis with multi-criteria analysis.

The integration of scenario analysis and multi-criteria methods has been demonstrated for a variety of applications. Parlak et al. (2012) develop methods identifying the most significant scenarios for the prioritization of radiological disaster preparedness investment initiatives. Scenario analysis and multi-criteria analysis methods have also been used for evaluating transportation infrastructure assets (Lambert, Wu, et al. 2012; Schroeder & Lambert 2011), facility energy investments (Karvetski & Lambert, 2012), infrastructure investments in Afghanistan (Lambert, Karvetski, et al. 2012), coastal infrastructure in Alaska (Karvetski, Lambert, Keisler, Sexauer, & Linkov, 2011), electricity capacity expansion (Martinez et al. 2011), energy security in military installations (Karvetski, Lambert, & Linkov, 2011), business processes for a risk organization (Teng et al. 2012), infrastructure vulnerable to climate change (Haowen You et al. 2013) and others. Thekdi and Lambert (2013) investigate quantifying scenarios and stakeholder perspectives relevant to transportation networks. This thesis will contribute to these works by expanding on the areas of application and considering scenario-based preferences in multi-criteria analysis.

2.3 Chapter Summary

This chapter has provided support for the use of a methodology that combines scenario analysis with multi-criteria analysis. The examples at the end of Section 2.2 show that scenario analysis and multi-criteria analysis can be applied to many fields of study as well as to decisions of varying scale and impact. This work proposes to further test the use of these methods for assessing influential scenarios for two disparate problems. The next chapters will describe the methodology and the two case studies.

3 TECHNICAL APPROACH

3.1 Overview

This chapter describes the technical approach that will be applied for each case study. Section 3.2 describes the general methodology that will be described in more detail for the two case studies in later chapters. Figure 2 depicts an overview of the elements of the technical approach. Section 3.3 provides a summary of the chapter.

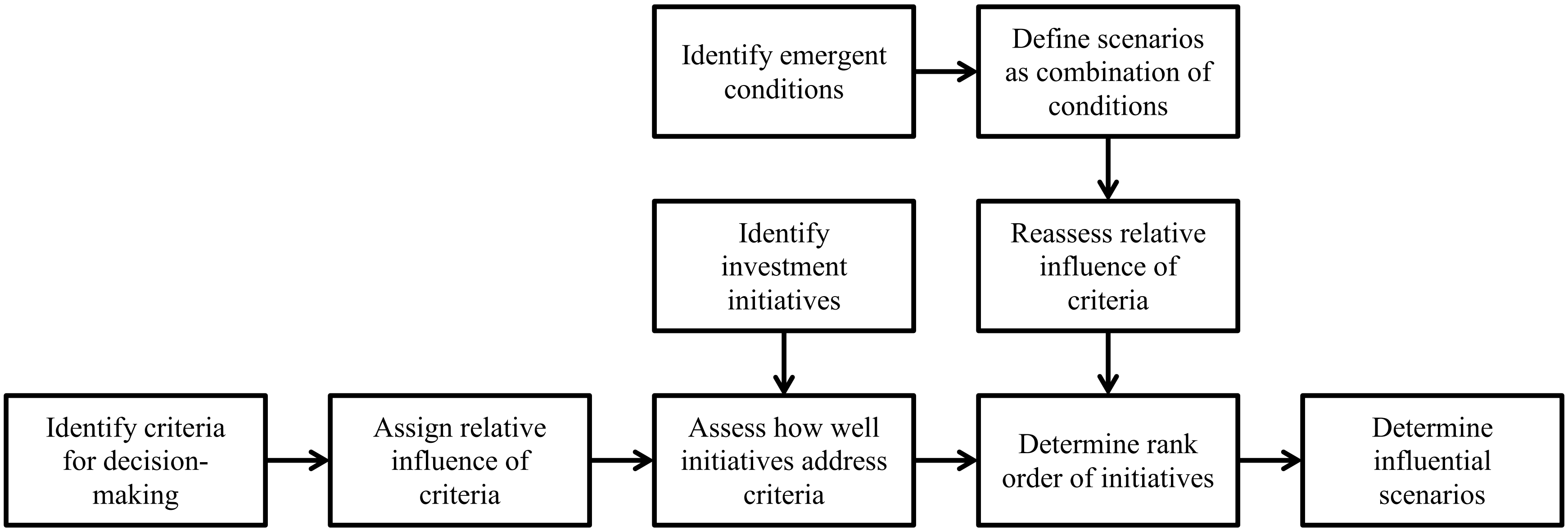

Figure 2. Methodology for constructing scenarios from diverse emergent conditions and identifying which combinations of conditions are the influential scenarios

3.2 Methodology

This section describes a model to identify scenarios that most matter to priority setting. Incidentally the model will identify initiatives related to (i) robust investment initiatives for the protection of the supply chain network in disaster response and recovery and (ii) robust courses of action for the development of a biofuel industry. The particularization and use of this notation for each case study will be made explicit in the later chapters.

Adapting notation from Parlak et al. (2012), Schroeder and Lambert (2011), Karvetski et al. (2009), and Lambert et al. (2012), the set $S_c=\{c_1,\ldots,c_m\}$ represents a set of *m* criteria used for decision-making. The set $S_x=\{x_1,\ldots,x_n\}$ represents a set of *n* initiatives being considered. An *m* x *n* matrix *A*, containing score x_{ij} is used to evaluate how each initiative x_i addresses each criterion c_j. The set $S_{ec}=\{ec_1,\ldots,ec_p\}$ represents *p* emergent conditions that are used for scenario building. The set $S_s=\{s_1,\ldots,s_q\}$ represents a variety of scenarios to address future uncertainties.

The influence of each criterion is enabled to vary in accordance with each scenario s_k, with $s_k \in S_s$. The term w_i^0 represents the weight of each criterion in a baseline *as-planned* scenario. An increase or decrease of influence for each criterion is reflected by the factor multiplier $\alpha>1$, as shown in Table 2.

Table 2. Non-normalized weight for i^th^ criterion based on change of influence for scenario s_k, where w_i is the weight of the i^th^ criterion in the baseline scenario.

Influence of criterion c_i under scenario s_k compared to baseline scenario	**Non-normalized weight w_i'**
Increased influence	$w_i' = \alpha * w_i$
Decreased influence	$w_i' = \frac{1}{\alpha} * w_i$
No change in influence	$w_i' = w_i$

The normalized weights w_i^k are then used for the multicriteria value function. Thus, the value function $v(x_i)$ is defined for each scenario s_k where $v(x_i)^k \in [0,100]$, as follows:

$$v(x_i)^k = 100 \text{ x } \Sigma_{j=1,m} w_j^k x_{ji}$$

The value function is then used to rank initiatives in response to different scenarios. The rankings enable decision makers to identify critical scenarios, assess how priorities change as a result of various scenarios, and identify investment initiatives that are most robust to scenarios of emergent conditions.

3.3 Chapter Summary

This chapter has described the methodology for studying the influences of uncertain future scenarios to priority-setting. The methods will be demonstrated in Chapter 4 and Chapter 5, particularizing the notation for the individual case studies.

4 APPLICATION TO DISASTER PLANNING IN RIO DE JANEIRO

4.1 Overview

This chapter will demonstrate the methodology for disaster planning in Rio de Janeiro, Brazil. Section 4.2 provides the background for this case study. Section 4.3 adapts the notation described in Chapter 3 to apply the methods. Section 4.4 describes the calculations performed and Section 4.5 presents the results. Section 4.6 summarizes the chapter.

4.2 Background

Scenario analysis for disaster planning has been gaining attention on an international scale. In 2012, the President of the G20 (a group of finance ministers and central bank), Felipe Calderón Hinojosa describes, "Climate change-related events are becoming more frequent and intense. As a consequence, … the cumulative cost of disasters was more than 25 billion dollars, and the number of people directly affected was approximately 8 million" between 2000 and 2010 (Government of Mexico and the World Bank Group 2012). Specifically the needs of Brazil were recognized by Frederico Pedroso, a disaster risk management consultant at the World Bank, who describes, "Only recently has the importance of disaster risk management gained visibility in

Brazil. Setting preventive measures takes urban and financial planning, and a long-term commitment" (The World Bank 2012).

Awareness of disaster preparedness and response operations has increased dramatically in the aftermaths of the Boston marathon bombings, Japan earthquake and tsunami, hurricane Katrina, the 9/11 attacks, and other high profile disaster events. High-level coordination among large, independent organizations including police, military, and transportation agencies is critical for evacuation and relief efforts following an emergency. As there are a growing number of complexities in the disaster response operations, there is opportunity to advance research to improve emergency response efforts (Kovács & Spens 2007). In particular, there is need for strategic prioritization of investment initiatives for disaster response supply chain operations, with recognition of the wide array of uncertainties and criteria influencing decisions of emergency response agencies.

Emergency plans can be rendered ineffective or become unrealistic when they fail to address associated uncertainties stemming from emergent and future disaster scenarios. For example, distribution of critical aid resources is vulnerable to uncertain population behaviors, climate factors, integrity of the transportation network, public perception concerns, and other factors. It is also critical for emergency response agencies to analyze their supply chain investments with consideration of multiple and possibly conflicting criteria. For example, consideration of diverse criteria such as health, safety, cost, environmental impacts, and other factors greatly influence the complex decision making process.

In particular, there is critical need for scenario-based prioritization of Brazilian emergency response efforts. In 2012, the United Nations International Strategy for Disaster Reduction announced the opening of a Centre of Excellence for Disaster Risk Reduction. The decision to locate the Centre in Rio de Janeiro, Brazil was in part due to the occurrence of landslides that resulted in 900 fatalities and economic losses exceeding one billion dollars from 2010-2011. Losses due to floods in recent years have approached 10% of the GDP of the entire nation (Salim 2012). The establishment of the Centre is harmonious with Brazil's participation in the Hyogo Framework for Action.

The "Hyogo Framework for Action: 2005-2015" (UN/ISDR 2005) was a resultant publication of the World Conference on Disaster Reduction, where the more than 150 countries participating agreed on the objective to significantly reduce the social, economic, and environmental losses due to disasters. The document highlighted the goals of prioritizing disaster risk reduction, reducing underlying risk factors, and strengthening disaster preparedness for effective response. Table 3 summarizes the five priorities for action described in the document.

Table 3. Hyogo Framework for Action: 2005-2015 Priorities for Action (UN/ISDR 2005)

Priority	Description
HFA-1	Ensure that disaster risk reduction is a national and a local priority with a strong institutional basis for implementation
HFA-2	Identify, assess and monitor disaster risks and enhance early warning.
HFA-3	Use knowledge, innovation and education to build a culture of safety and resilience at all levels
HFA-4	Reduce the underlying risk factors.
HFA-5	Strengthen disaster preparedness for effective response at all levels.

Several follow-up documents have been published by or in collaboration with the United Nations secretariat of the International Strategy for Disaster Reduction (UN/ISDR). Among these documents are “Disaster Preparedness for Effective Response: Guidance and Indicator Package for Implementing Priority Five of the Hyogo Framework” (UN/ISDR & UN/OCHA 2008), “Let Our Children Teach Us! A Review of the Role of Education and Knowledge in Disaster Risk Reduction” (UN/ISDR 2006), and “Words Into Action: A Guide for Implementing the Hyogo Framework” (UN/ISDR 2007). The publication “Let Our Children Teach Us! A Review of the Role of Education and Knowledge in Disaster Risk Reduction” lists three key areas relevant to HFA-3: i) knowledge management, ii) education, and iii) risk awareness. The publication discusses current practices in disaster risk reduction and concludes by identifying gaps and opportunities in the field. The author concludes with the following priorities for disaster preparedness: i) teach about hazards and risk reduction, ii) make schools into centers for community disaster risk reduction, and iii) protect schools.

Another focus of risk reduction efforts has been on decreasing the vulnerability of the *favela*, or slum, populations. Uncontrolled population expansion in these urban areas has led to the crowding of low-income individuals in houses built on sloping land that is subject to flooding and landslides. Figure 3 shows *favela* neighborhoods characterized by crowded, cheaply built houses. Despite more than 80 *favelas* indicated, Figure 3 does not represent a comprehensive map of Rio de Janeiro *favelas*. As of 2001, about 20 percent of the population of Brazil lives in a Rio *favela* (OCHA/IRIN & UN-HABITAT 2007). In the past, Brazil has experienced problems with efficiently allocating resources to reduce the vulnerability of these poor urban dwellers (Preece 1992). Thus, natural disasters affecting *favelas* should be part of scenario planning and analysis for aiding emergency preparedness decision makers.

Figure 3. Map of favela locations in the state of Rio de Janeiro with a star indicating a favela neighborhood as listed by Google (2011).

This case study will integrate scenario planning with multi-criteria analysis for the prioritization of emergency disaster planning initiatives relevant to Brazil and in line with the goals of the ISDR. The study will enable emergency planners to understand which investment initiatives have the highest priority as well as which initiatives are the most robust across a variety of emergency scenarios. Changes in the prioritization of initiatives will reveal the most critical scenarios for emergency planners in Brazil. The results of this case study will enable decision makers to address uncertainties and bridge existing knowledge gaps to systematically prioritize investment initiatives under various disaster scenarios.

4.3 Demonstration of Methods

The following section will apply the methods to evaluate investments for supply chain performance in response to disaster scenarios in Brazil.

To recognize the plurality of viewpoints for disaster preparedness, ten criteria are used for this analysis. The set $S_c=\{c_1,\ldots,c_m\}$ represents the set of m criteria used for disaster preparedness decision-making. Table 4 describes the performance criteria, which are adapted from those used by Parlak et al. (2012) for radiological disaster preparedness. The criteria include health and safety, cost, environmental considerations, and coordination and planning of the government and private sector. The criteria also address the need for innovative and adaptive emergency plans in the face of unforeseeable disaster scenarios.

The set $S_x=\{x_1,\ldots,x_n\}$ represents the set of n disaster preparedness initiatives being considered for protective action. Table 5 describes the investment initiatives included in this case study. The thirty-seven listed initiatives are derived in part from those established by Parlak et al. (2012) for radiological preparedness and planning in the United States, various publications on Brazilian emergency and natural disaster preparedness (CARE Brasil 2010; Costa 2012; Government of Brazil 2012; Szlafsztein 2012), and international disaster risk reduction strategies (ISDR & OCHA 2008; UN/ISDR 2006). The investment initiatives include increasing the supply of food, water, sheltering, and medical supplies, improving coordination among responders, and building infrastructure for distributing information prior to (for educational purposes) and following an emergency, among others.

Table 4. Criteria used to evaluate the investment initiatives for disaster preparedness of supply chains in Brazil

Criterion	Description
c_1	Public health and safety
c_2	Estimated cost
c_3	Information sharing
c_4	Public preparedness and planning
c_5	Environmental considerations
c_6	Coordination across states and municipalities
c_7	Coordination across emergency support functions
c_8	Capacities for mass sheltering and evacuation at multiple geographic and temporal scales
c_9	Effective role and performance of private sector
c_{10}	Innovation, learning, and adaption in emergency management
$\vdots$	Others

Table 5. Investment initiatives considered for disaster preparedness supply chain management in Brazil

Initiative	Description
x_1	Improve mobility options for disabled and special needs populations
x_2	Provide additional sheltering, care, and related resources for children of critical workers
x_3	Improve and revise assistance compacts between localities
x_4	Increase emergency public transportation options and capacities
x_5	Provide additional pet sheltering and related resources
x_6	Provide education and training for citizen emergency preparedness
x_7	Increase availability of real time public information and advisories
x_8	Improve interoperability of emergency communications among first responders
x_9	Increase stockpiles and availability of essential medical supplies
x_{10}	Increase stockpiles and availability of prescription medication
x_{11}	Improve communication channels for providing counseling and psychiatric care
x_{12}	Increase stockpiles of drinking water
x_{13}	Increase number and capacities of distributed electricity generation
x_{14}	Increase stockpiles of ready-to-eat meals
x_{15}	Increase shelter availability
x_{16}	Improve planning that facilitates citizen evacuation
x_{17}	Improve planning that facilitates sheltering in place
x_{18}	Improve capabilities for contra flow on major transportation routes
x_{19}	Increase traveler information resources along major transportation routes
x_{20}	Increase availability of fuel at critical locations
x_{21}	Increase number of first aid locations along transportation routes

x_{22}	Increase availability of temporary and long term housing for people in need
x_{23}	Increase availability of food and essential personal items along transportation routes
x_{24}	Increase capability for door-to-door outreach by emergency responders
x_{25}	Increase number of volunteers to help in case of emergency
x_{26}	Increase capabilities for radiological decontamination at shelters or along transportation routes
x_{27}	Increase availability of emergency kits to be distributed in case of an emergency
x_{28}	Increase availability of public information on the real time conditions of critical infrastructures
x_{29}	Improve real time collection and dissemination of the behaviors and movements of citizens in an emergency
x_{30}	Increase number of first responders
x_{31}	Improve coordination of search and rescue efforts
x_{32}	Improve efforts to minimize environment degradation that can cause and/or magnify damages from disasters
x_{33}	Promote the model of cascading training of trainers to increase teachers' expertise in disaster risk reduction
x_{34}	Integrate disaster-relevant curriculum into schools
x_{35}	Increase community-based disaster management efforts
x_{36}	Increase the use of participatory geographical information systems for mapping disaster-related areas
x_{37}	Integrate natural hazard education into ongoing programs targeting the homeless and working children and youth
$\vdots$	Others

Table 6 describes the agencies responsible for protective investment for disaster preparedness within the Brazilian government. The supporting agencies include the key military branches, i.e. Brazilian Army (EB), Brazilian Navy (MB), and Brazilian Air Force (FAB). Other national and regional agencies and organizations responsible for rescue efforts include the Department of Civil Defense, Regional Coordination of Civil Defense, state firefighters, state police, and the Brazilian Red Cross. Additionally, there are various agencies involved in planning for emergencies affecting the transportation infrastructure (DETRO, DNIT), environment (SEA), and energy infrastructure (CNEN, ONS).

Table 7 describes the relationship between the supporting agencies for disaster preparedness and the thirty-seven investment initiatives. For instance, the Secretary for the State of the Environment should play a major role in the initiatives related to informing the public and integrating natural disaster-related curriculum into schools (x_7, x_{34}, x_{37}), mapping disaster prone areas using GIS (x_{36}), and implementing policies that would minimize environmental degradation (x_{32}).

Table 8 describes qualitative ratings assigned to investment initiatives based on how well they address categories of criteria. The ratings given are the result of expert elicitation with key users of this decision support system, and remain customizable for evolving leadership needs. Rating choices for the initiatives consist of a *strongly addresses*, *addresses, somewhat addresses*, and *does not address* each criterion. For example, the investment initiative x_8*: improve interoperability of emergency communications among first responders*, is rated as *strongly addressing* the criteria corresponding to providing information and facilitating communication, *addressing* the criteria related to improving planning and coordination, and *somewhat addressing* the criteria associated with providing human support.

Table 6. Brazil agencies responsible for protective investment initiatives for disaster preparedness supply chain management

Acronym	**Agency**
CBMERJ	Corpo de Bombeiros Militar do Estado do Rio de Janeiro
DGDEC	Departamento Geral de Defesa Civil
EB	Exército Brasileiro
CNEN	Comissão Nacional de Energia Nuclear
DETRO	Departamento de Transportes Rodoviários
MB	Marinha do Brasil
DNIT	Departamento Nacional de Infra-Estrutura de Transporte
ONS	Operador Nacional do Sistema Elétrico
SEA	Secretaria de Estado de Ambiente
PCERJ	Polícia Civil do Estado do Rio de Janeiro
REDEC	Coordenação Regional de Defesa Civil
FAB	Força Aérea Brasileira
CVB	Cruz Vermelha Brasileira
UNISDR	United Nations International Strategy for Disaster Reduction

Table 7. Responsibilities of agencies for protective investment for disaster preparedness supply chain management in Brazil, where the check marks describe a sample of roles of the agencies

Initiative	CBMERJ	DGDEC	EB	CNEN	DETRO	MB	DNIT	ONS	SEA	PCERJ	REDEC	FAB	CVB	UNISDR
x_1					✓		✓							
x_2	✓	✓	✓			✓				✓	✓		✓	
x_3	✓	✓	✓	✓						✓	✓			
x_4	✓	✓	✓		✓	✓	✓			✓	✓	✓		
x_5		✓									✓		✓	
x_6		✓		✓						✓	✓		✓	✓
x_7		✓		✓					✓	✓	✓			
x_8	✓	✓	✓	✓		✓				✓	✓	✓		
x_9	✓	✓	✓	✓		✓					✓		✓	
x_{10}		✓	✓								✓		✓	
x_{11}		✓	✓								✓		✓	
x_{12}		✓	✓								✓		✓	
x_{13}				✓				✓						
x_{14}		✓	✓								✓		✓	
x_{15}		✓	✓								✓		✓	
x_{16}	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓		✓
x_{17}		✓									✓			✓

x_{18}					✓		✓							
x_{19}		✓								✓	✓			
x_{20}		✓									✓			
x_{21}		✓	✓								✓		✓	
x_{22}		✓	✓								✓		✓	
x_{23}		✓					✓				✓		✓	
x_{24}	✓	✓	✓							✓	✓			
x_{25}	✓	✓	✓							✓	✓		✓	
x_{26}		✓	✓	✓						✓	✓			✓
x_{27}	✓	✓	✓							✓	✓		✓	✓
x_{28}	✓	✓	✓	✓	✓		✓			✓	✓			
x_{29}		✓	✓								✓			
x_{30}	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓
x_{31}	✓	✓	✓			✓				✓	✓	✓	✓	
x_{32}									✓					✓
x_{33}														✓
x_{34}		✓							✓		✓			✓
x_{35}		✓									✓			✓
x_{36}		✓							✓		✓			✓
x_{37}		✓							✓		✓			✓

Table 8. Fulfillment of criteria for each initiative, with ● indicating the initiative *strongly addresses* the criteria, ◑ indicating the initiative *addresses* the criteria, ○ indicating the initiative *somewhat addresses* the criteria, and omission indicating the initiative *does not address* the criteria.

Initiative	Provide Sheltering	Provide Health Services	Provide Food and Water	Provide Information and Facilitate Communication	Provide and Facilitate Transportation	Provide Human Support and Increase Volunteers	Improve Planning and Coordination	Provide Fuel and Electricity
x_1		○			◑		◑	
x_2	◑	○				○	○	
x_3	○	○	○	●	○	○	●	○
x_4					●		○	
x_5	◑							
x_6				◑		◑	●	
x_7				●			○	
x_8				●		○	◑	
x_9		●					○	
x_{10}		●					○	
x_{11}		●						
x_{12}			●					
x_{13}							○	●
x_{14}			●				○	
x_{15}	●						○	
x_{16}	◑			○	●	○	●	○
x_{17}	◑	◑					◑	○
x_{18}					●			
x_{19}				●		○		

x_{20}						○		●
x_{21}		●					◑	
x_{22}	●						○	
x_{23}			●			○	○	
x_{24}		○				●	◑	○
x_{25}						●	○	
x_{26}		●					◑	
x_{27}		●					◑	
x_{28}				●			○	
x_{29}				◑				
x_{30}		○				●	◑	
x_{31}				●		◑	◑	
x_{32}							◑	
x_{33}		○		○			◑	
x_{34}							○	
x_{35}						◑	◑	
x_{36}				◑			●	
x_{37}				◑			○	

The set $S_s=\{s_1,\ldots,s_q\}$ represents a variety of scenarios that represent future sources of uncertainty. Table 9 describes the set S_{ec} of emergent conditions included in each of six scenarios. The scenarios include three natural disaster scenarios, namely landslide, heavy rainfall, and drought, as well as one related to a radiological disaster. Additionally, there are two other scenarios concerning potential terrorist attacks or other emergencies during the 2014 World Cup and 2016 Summer Olympics, when increased tourism is likely to put a strain on Brazil resources. As an example, scenario s_4, a radiological disaster, is characterized by the emergent conditions relating to segments of the population becoming either "walking wounded" or "worried-well."

4.4 Calculations

The qualitative ratings given in Table 8 are translated to an assessment matrix of how well each investment initiative addresses the specific criteria (i.e. c_1-c_{10}). Table 10 describes the values of scores x_{ij} that are used to evaluate how each initiative x_i addresses each criterion c_j based on the qualitative ratings. Figure 4 describes the 10x37 matrix *A*, constructed using the quantitative scores, as described in Section 3.2.

Table 9. Emergent conditions included in the six scenarios used to evaluate investments for supply chain performance in response to disaster scenarios in Brazil.

Emergent Conditions		Scenarios					
		s_1: Featuring landslide	s_2: Featuring heavy rainfall	s_3: Featuring drought	s_4: Featuring radiological event	s_5: Featuring Olympics	s_6: Featuring World Cup
EC_1	Lack of confidence in public information sources						+
EC_2	Lack of accessibility to public information sources						
EC_3	Increased area tourism					+	+
EC_4	Increased *favela* population						
EC_5	Decreased *favela* population						
EC_6	Improved *favela* housing conditions						

EC $_{7}$	Drought			+			
EC $_{8}$	Flood affecting *favela* areas		+				
EC $_{9}$	Flood affecting non-*favela* areas						
EC $_{10}$	Landslide affecting *favela* areas	+					
EC $_{11}$	Landslide affecting non-*favela* areas						
EC $_{12}$	"Walking wounded"				+		+
EC $_{13}$	"Worried-well"				+		
EC $_{14}$	Power outages		+			+	
EC $_{15}$	Telephone systems overloaded						
EC $_{16}$	Emergency relief straining budget				+		
EC $_{17}$	Destruction of homes	+					
EC $_{18}$	Destruction of transportation infrastructure						
EC $_{19}$	Destruction of agriculture			+			
⋮							

Table 10. Translation of qualitative rating of the degree of agreement between preparedness initiatives and criteria to quantitative score.

Qualitative rating	Symbol (from Table 8)	Quantitative rating
does not address		0
somewhat addresses	○	0.33
addresses	◑	0.67
strongly addresses	●	1

$$
A[1\text{-}18] = \left[\begin{array}{cccccccccccccccccc}
0.3 & 0.0 & 0.0 & 0.3 & 0.0 & 0.3 & 0.3 & 1.0 & 1.0 & 1.0 & 1.0 & 1.0 & 0.3 & 1.0 & 0.3 & 0.7 & 0.7 & 0.3 \\
0.3 & 0.3 & 0.0 & 0.0 & 0.0 & 0.7 & 0.0 & 0.7 & 0.3 & 0.0 & 0.3 & 0.3 & 0.0 & 0.3 & 0.0 & 0.0 & 0.7 & 0.0 \\
0.0 & 0.0 & 1.0 & 0.0 & 0.0 & 1.0 & 0.0 & 1.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.7 & 0.0 & 0.0 \\
0.7 & 0.3 & 0.7 & 0.3 & 0.0 & 0.3 & 0.3 & 0.3 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 1.0 & 1.0 & 0.0 \\
0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.3 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.3 & 0.3 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 \\
0.0 & 0.0 & 1.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.3 & 0.0 & 0.3 & 0.3 & 0.7 & 0.7 & 0.7 & 0.0 & 0.0 & 0.7 \\
0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 1.0 & 0.0 & 0.3 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.7 & 0.7 & 0.0 \\
0.3 & 0.7 & 0.0 & 0.7 & 0.7 & 0.0 & 1.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 1.0 & 1.0 & 0.7 & 1.0 \\
0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.3 & 0.3 & 0.7 & 0.0 & 0.0 & 0.0 & 0.3 & 0.0 & 0.0 & 0.0 & 0.0 \\
0.0 & 0.0 & 0.3 & 0.0 & 0.7 & 0.3 & 0.0 & 0.3 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.3
\end{array}\right]
$$

$$
A[19\text{-}37] = \left[\begin{array}{ccccccccccccccccccc}
0.3 & 0.0 & 1.0 & 0.0 & 0.7 & 1.0 & 0.7 & 1.0 & 0.7 & 1.0 & 0.3 & 0.3 & 1.0 & 0.0 & 0.3 & 0.3 & 1.0 & 0.3 & 0.3 \\
0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 1.0 & 0.7 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.7 & 0.0 & 0.7 & 0.0 & 0.0 \\
0.3 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.7 & 0.7 & 1.0 & 0.0 & 0.3 & 0.0 & 0.0 & 0.3 & 0.3 \\
0.0 & 0.0 & 0.0 & 0.0 & 0.3 & 0.7 & 0.0 & 0.7 & 0.0 & 0.3 & 0.0 & 0.0 & 0.7 & 0.3 & 0.7 & 0.3 & 0.7 & 0.3 & 0.3 \\
0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.7 & 0.0 & 0.0 & 0.0 & 0.0 & 1.0 & 0.0 & 0.0 & 0.0 & 0.7 & 1.0 \\
0.0 & 0.3 & 0.0 & 0.0 & 0.0 & 0.3 & 0.0 & 0.7 & 0.0 & 0.0 & 1.0 & 0.0 & 0.0 & 0.3 & 0.0 & 0.0 & 0.3 & 0.0 & 0.0 \\
0.0 & 0.0 & 0.7 & 0.0 & 0.0 & 0.3 & 0.0 & 1.0 & 0.7 & 0.7 & 0.0 & 0.0 & 0.7 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 \\
0.0 & 0.3 & 0.0 & 1.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 \\
0.0 & 0.3 & 0.3 & 0.0 & 0.3 & 0.3 & 0.3 & 0.3 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.3 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 \\
0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.3 & 0.0 & 0.3 & 0.0 & 1.0 & 1.0 & 0.0 & 0.3 & 1.0 & 1.0 & 0.3 & 0.3 & 0.3
\end{array}\right]
$$

Figure 4. Assessment matrix A where entry x_{ij} represents the degree to which initiative x_i addresses criterion c_j using the translated ratings described in Table 10. Numbers are rounded to the first decimal place for visibility in the figure, but not for calculations.

Each criterion is weighted to determine the relative influence of the criteria. The relative influence of each criterion may change during each of the six scenarios introduced in Table 9. Identifying whether the influence of the criteria *increases, increases somewhat, stays the same, decreases somewhat,* or *decreases*, the weight of the criteria is multiplied by a constant α as follows:

$$\alpha = \begin{cases} 9 & \text{if the influence of criterion i increases with scenario k} \\ 3 & \text{if the influence of criterion i increases somewhat with scenario k} \\ 1 & \text{if the influence of criterion i stays the same with scenario k} \\ 1/3 & \text{if the influence of criterion i decreases somewhat with scenario k} \\ 1/9 & \text{if the influence of criterion i decreases with scenario k} \end{cases}$$

Reassessing the weights under each scenario results in the 10x6 matrix *W*. The first column of *W* represents the weights in the *as-planned* baseline scenario. The other columns represent the reconsidered weights under scenarios 1, 2, 3, 4, 5, and 6 respectively. For the baseline scenario, three of the criteria are identified as major and assigned 45% combined weight, while the remaining supporting criteria are assigned 65% weight equally.

$$W = \begin{bmatrix} 15\% & 21\% & 10\% & 19\% & 46\% & 6\% & 7\% \\ 15\% & 7\% & 30\% & 2\% & 5\% & 1\% & 1\% \\ 8\% & 3\% & 5\% & 9\% & 3\% & 26\% & 3\% \\ 8\% & 3\% & 5\% & 9\% & 8\% & 3\% & 31\% \\ 15\% & 21\% & 30\% & 19\% & 5\% & 6\% & 7\% \\ 8\% & 3\% & 5\% & 9\% & 3\% & 3\% & 3\% \\ 8\% & 3\% & 5\% & 9\% & 23\% & 26\% & 3\% \\ 8\% & 31\% & 5\% & 3\% & 3\% & 3\% & 31\% \\ 8\% & 3\% & 1\% & 9\% & 3\% & 3\% & 10\% \\ 8\% & 3\% & 5\% & 9\% & 3\% & 26\% & 3\% \end{bmatrix}$$

The value score matrix is computed by multiplying the transpose of the weight matrix W^T by the assessment matrix *A*, as demonstrated in Table 11.

Table 11. Performance scores of the preparedness initiatives under each scenario. Scores are out of 100, with 100 representing the best performing initiative.

	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}	x_{13}	x_{14}	x_{15}	x_{16}	x_{17}	x_{18}
s_0	18	13	23	13	10	33	15	49	26	23	23	28	15	28	18	36	38	21
s_1	22	24	10	29	23	24	39	36	25	24	24	31	16	26	40	53	45	41
s_2	18	15	15	8	7	41	10	43	22	12	22	31	17	23	12	23	38	13
s_3	14	6	28	12	8	30	13	49	26	28	23	29	19	29	16	38	32	19
s_4	23	6	11	20	3	26	21	79	50	56	49	50	19	50	20	58	59	21
s_5	5	3	39	5	19	39	6	68	8	16	7	9	6	9	7	44	26	15
s_6	33	31	29	33	23	20	43	29	12	15	8	11	7	13	35	71	59	37
Median	18	13	23	13	10	30	15	49	25	23	23	29	16	26	18	44	38	21
Mean	17	11	21	14	12	32	17	54	26	27	25	30	15	28	19	42	40	22

	x_{19}	x_{20}	x_{21}	x_{22}	x_{23}	x_{24}	x_{25}	x_{26}	x_{27}	x_{28}	x_{29}	x_{30}	x_{31}	x_{32}	x_{33}	x_{34}	x_{35}	x_{36}	x_{37}
s_0	8	8	23	8	15	28	31	46	28	23	26	18	33	26	31	15	36	23	28
s_1	8	13	24	31	16	26	23	34	31	24	16	13	29	25	18	11	30	24	31
s_2	5	3	13	5	8	17	38	42	31	15	17	12	22	35	33	10	36	28	38
s_3	9	7	28	3	19	35	21	46	35	28	32	22	41	32	27	19	33	28	35
s_4	16	3	62	3	34	61	38	80	50	64	22	20	69	10	27	21	56	23	25
s_5	10	3	24	3	6	18	14	36	33	24	47	44	50	17	38	28	17	24	26
s_6	3	15	13	31	18	33	10	37	13	19	11	8	33	23	28	16	30	19	22
Median	8	7	24	5	16	28	23	42	31	24	22	18	33	25	28	16	33	24	28
Mean	9	6	29	9	16	31	27	47	35	30	27	21	41	24	29	17	35	25	30

4.5 Results

Table 12 illustrates the rank order of initiatives based on the value scores of each initiative for the six scenarios and the baseline *as-planned* scenario. Figure 5 demonstrates the range of rankings that each initiative is assigned under the scenarios. The following three initiatives were ranked highest under at least one scenario: (i) *Improve interoperability of emergency communications among first responders*, (ii) *Improve planning that facilitates citizen evacuation*, and (iii) *Increase capabilities for radiological decontamination at shelters or along transportation routes*. Figure 6 illustrates the robustness of preparedness initiatives for the initiatives with a median rank higher than 10. While initiative x_8*: Improve interoperability of emergency communications among first responders* has the highest median rank, x_{26}*: Improve planning that facilitates citizen evacuation* is more, in fact the most, robust to changes in rank under the scenarios considered for the analysis. Investment initiative x_{25}*: Increase number of volunteers to help in case of emergency*, on the other hand, is the least robust to emergency scenario, falling from rank of four in scenario s_2*: Heavy rainfall* to thirty-third in scenario s_6*: World Cup*.

Table 13 illustrates the absolute value of the change in prioritization of initiatives caused by the emergency scenarios relative to the *as-planned* scenario. In terms of average change in rank of initiatives, scenario s_6*: World Cup* is the most disruptive combination of emergent conditions. Scenario s_1*: Landslide*, however, causes the largest change in rank, causing x_{22}*: Increase availability of temporary and long term housing for people in need* to increase in priority from 35th in the *as-planned* scenario to 8th in the case of a landslide affecting favela regions and destroying homes.

Table 12. Performance rank of preparedness initiatives. The highest scoring initiative for each scenario is highlighted.

	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}	x_{13}	x_{14}	x_{15}	x_{16}	x_{17}	x_{18}
s_0	25	32	18	32	34	6	28	1	15	18	18	10	28	10	25	4	3	24
s_1	28	19	36	13	26	19	5	6	17	19	19	9	31	15	4	1	2	3
s_2	18	22	22	33	34	3	30	1	15	27	16	10	20	13	28	14	6	26
s_3	30	36	15	32	34	12	31	1	21	15	22	13	25	13	29	4	9	27
s_4	21	34	32	27	35	19	24	2	14	10	15	11	30	11	27	8	7	24
s_5	33	35	7	34	17	6	30	1	27	21	28	25	30	25	29	5	12	22
s_6	7	11	15	8	18	20	3	14	30	25	34	32	36	27	6	1	2	5
Median	25	32	18	32	34	6	28	1	15	18	18	10	28	10	25	4	3	24

	x_{19}	x_{20}	x_{21}	x_{22}	x_{23}	x_{24}	x_{25}	x_{26}	x_{27}	x_{28}	x_{29}	x_{30}	x_{31}	x_{32}	x_{33}	x_{34}	x_{35}	x_{36}	x_{37}
s_0	35	35	18	35	31	10	8	2	10	18	15	25	7	15	8	28	4	18	10
s_1	37	33	19	8	32	16	26	7	9	19	30	33	13	17	29	35	12	19	9
s_2	35	37	25	35	32	19	4	2	11	22	20	28	17	8	9	30	7	12	5
s_3	33	35	15	37	27	5	24	2	5	15	10	23	3	11	20	25	8	15	5
s_4	31	36	5	36	17	6	16	1	11	4	23	27	3	33	18	24	9	21	20
s_5	24	36	14	36	32	18	23	9	10	14	3	4	2	20	8	11	19	14	13
s_6	37	25	28	12	23	8	33	4	28	21	31	35	8	17	16	24	13	21	19
Median	35	35	18	35	31	10	8	2	10	18	15	25	7	15	8	28	4	18	10

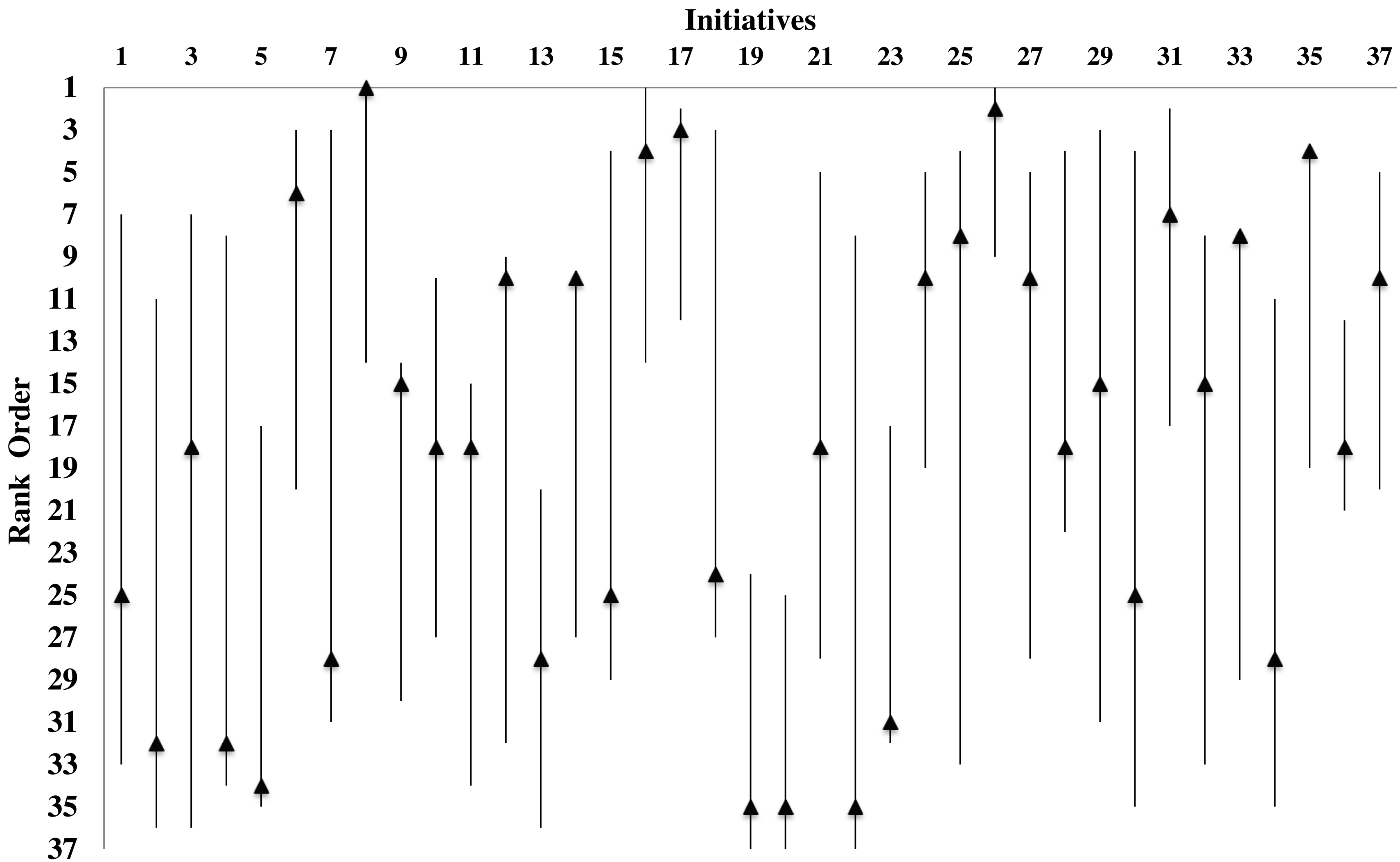

Figure 5. Comparison of rank order of initiatives and robustness to changes in rank. The triangle marks the rank in the baseline scenario with the lines indicating the robustness of the initiative under the set of scenarios analyzed.

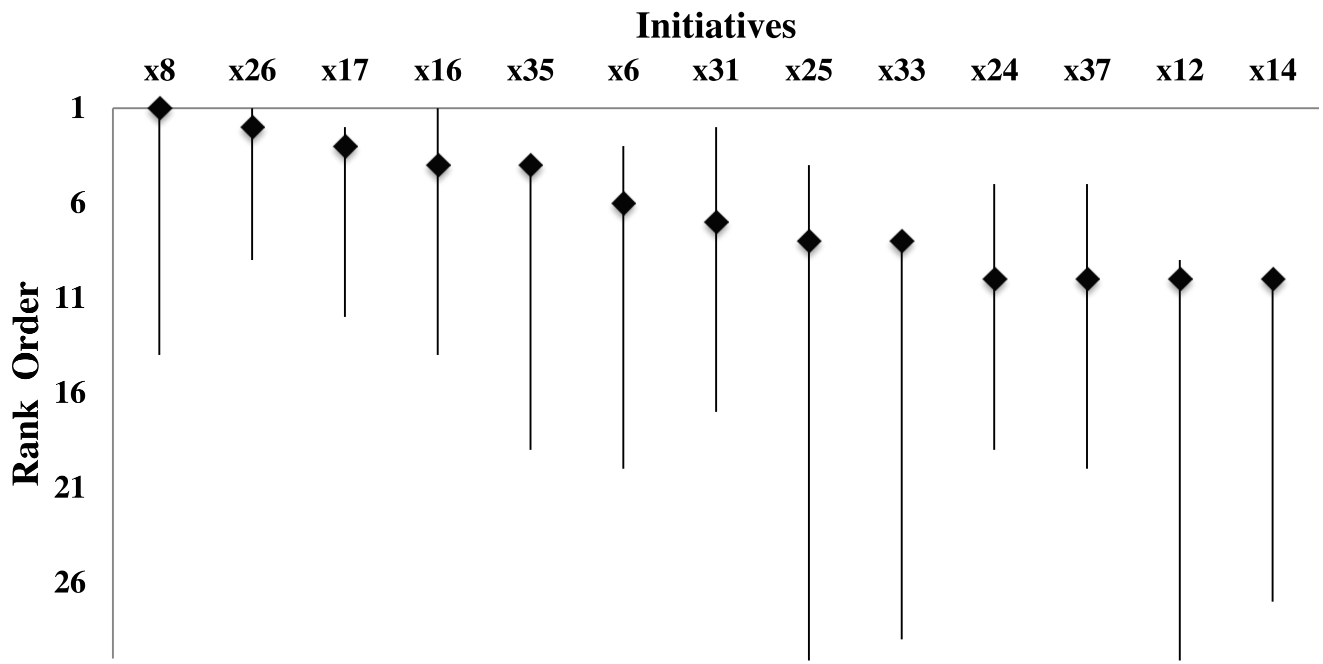

Figure 6. Comparison of initiatives with median rank (represented by the diamond) of 10 or better.

Table 13. Change in rank (in absolute terms) of initiatives in response to emergency scenario as compared to as-planned scenario.

	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}	x_{13}	x_{14}	x_{15}	x_{16}	x_{17}	x_{18}	x_{19}
s_1	3	13	18	19	8	13	23	5	2	1	1	1	3	5	21	3	1	21	2
s_2	7	10	4	1	0	3	2	0	0	9	2	0	8	3	3	10	3	2	0
s_3	5	4	3	0	0	6	3	0	6	3	4	3	3	3	4	0	6	3	2
s_4	4	2	14	5	1	13	4	1	1	8	3	1	2	1	2	4	4	0	4
s_5	8	3	11	2	17	0	2	0	12	3	10	15	2	15	4	1	9	2	11
s_6	18	21	3	24	16	14	25	13	15	7	16	22	8	17	19	3	1	19	2

	x_{20}	x_{21}	x_{22}	x_{23}	x_{24}	x_{25}	x_{26}	x_{27}	x_{28}	x_{29}	x_{30}	x_{31}	x_{32}	x_{33}	x_{34}	x_{35}	x_{36}	x_{37}	Avg
s_1	2	1	27	1	6	18	5	1	1	15	8	6	2	21	7	8	1	1	7.9
s_2	2	7	0	1	9	4	0	1	4	5	3	10	7	1	2	3	6	5	3.7
s_3	0	3	2	4	5	16	0	5	3	5	2	4	4	12	3	4	3	5	3.7
s_4	1	13	1	14	4	8	1	1	14	8	2	4	18	10	4	5	3	10	5.3
s_5	1	4	1	1	8	15	7	0	4	12	21	5	5	0	17	15	4	3	6.8
s_6	10	10	23	8	2	25	2	18	3	16	10	1	2	8	4	9	3	9	11.5

Table 14 provides a summary of the scenario analysis results. As scenario *s_6: World Cup* is the most disruptive scenario across all initiatives relative to the *as-planned* scenario, the results suggest initiatives for agencies preparing for the event. Agencies must also adapt emergency plans and prioritize efforts to address the three highest ranked initiatives across all scenarios (*Improve interoperability of emergency communications among first responders*, *Improve planning that facilitates citizen evacuation*, and *Increase capabilities for radiological decontamination at shelters or along transportation routes*). Although *s_2: Heavy Rainfall* was the least disruptive scenario across all initiatives relative to the *as-planned* scenario, agencies should further study the long-term implications of the scenario with regard to possibly changing climate conditions.

4.6 Chapter Summary

This chapter has described the application of the methods from Chapter 3 to disaster preparedness and emergency planning in Brazil. By translating qualitative assessments in Section 4.3 into quantitative scores in Section 4.4, the methodology was able to prioritize initiatives under a variety of future scenarios. The results were presented in Section 4.5. This demonstration serves to inform decision makers in Brazil as to which single scenario or combination of emergent conditions has the most impact on the prioritization of preparedness initiatives.

Table 14. Summary of results for the analysis of disaster preparedness initiatives.

Highest ranked initiatives	x_8: Improve interoperability of emergency communications among first responders x_{16}: Improve planning that facilitates citizen evacuation x_{26}: Increase capabilities for radiological decontamination at shelters or along transportation routes
Lowest ranked initiatives	x_{19}: Increase traveler information resources along major transportation routes x_{20}: Increase availability of fuel at critical locations x_{22}: Increase availability of temporary and long term housing for people in need
Greatest increase in rank relative to *as-planned* scenario	x_{22}: Increase availability of temporary and long term housing for people in need
Greatest decrease in rank relative to *as-planned* scenario	x_{25}: Increase number of volunteers to help in case of emergency
Most disruptive scenario across all initiatives relative to *as-planned* scenario	s_6: World Cup
Least disruptive scenario across all initiatives relative to *as-planned* scenario	s_2: Heavy Rainfall

5 APPLICATION TO BIOJET FUEL IN THE COMMONWEALTH OF VIRGINIA

5.1 Overview

This chapter will demonstrate the methodology described in Chapter 3 for biofuel production. The need for decision analysis in this area is described by Lisa Jackson, EPA Administrator, who describes, "Biofuels lifecycle and sustainability research will provide better information to decision makers on the trade-offs and opportunities associated with increased biofuels production" (Environmental Protection Agency 2011). Section 5.2 provides background for the case study. Section 5.3 adapts the notation described in Chapter 3 to apply the methods and Section 5.4 describes the calculations. Section 5.5 presents the results. Section 5.6 summarizes the chapter.

5.2 Background

Currently, the modern commercial and military aviation sector relies almost exclusively on petroleum-derived fuels (Miller et al. 2012). The most common type of fuel, kerosene or Jet A, is produced by petroleum refineries around the world and traded on commodities markets like other fossil fuels. Other jet fuel blends are used with different performance characteristics but Jet A is the most commonly encountered type of fuel. For a variety of reasons, including concerns about national security, long-term availability of crude oil feedstock, and environmental impacts like climate change, there is increasingly interest by commercial airlines, the US military, and other groups to identify alternatives to Jet A (Air Transport Action Group 2011b; H. Smith 2010). For example, in 2006, the Commercial Aviation Alternative Fuels Initiative (CAAFI) was established to promote the development of alternative jet fuel out of three major concerns: i) security of supply, ii) affordability and price stability, and iii) CO_2 emissions and other environmental concerns (CAAFI 2013). Efforts of CAAFI are sponsored by various stakeholders, including three trade associations (i.e. Airports Council International-North America, Aerospace Industries Association, and Airlines for America) and one government agency (i.e. the Federal Aviation Administration), who represent the interests of airports, manufacturers, airlines, and aviation energy and environmental policy.

Finding an adequate replacement for conventional jet fuel is difficult for a multitude of reasons. The replacement must be a liquid fuel since solid power sources and gaseous power sources are either too heavy or too big to be viable in a conventional airplane (SWAFEA 2011). There are several "do no harm" limitations that alternative aviation fuel should meet: i) does not compete for food or arable land used for food production, ii) does not rely on freshwater, iii) does not cause deforestation, other detrimental land use change, or environmental harm, iv) can be implemented on a level that assures a sustainable secure supply, v) can be competitive with conventional jet fuel, and vi) reduces carbon emissions by more than 50% compared to petroleum derived jet fuel (Hendricks et al. 2011).

There are five main categories of feedstocks being considered that meet these requirements: i) agricultural residues, ii) forest residues, iii) energy crops, iv) algae, and v) municipal solid waste (U.S. Department of Energy 2012).

There are a number of technical specifications (i.e. flash point, freezing point, combustion heat, viscosity, sulfur content and density) that make some alternatives less desirable than petroleum, particularly in mission critical military applications (Air Transport Action Group 2011a). Also, the logistical implications of developing a new energy infrastructure for delivering another kind of fuel to airplanes would represent a significant national investment (Milbrandt 2005).

To address some of these challenges, most aviation stakeholders have tended to focus on the development of alternative fuels that can be "dropped-in" to existing infrastructure (Miller et al. 2012). In practice this means that the alternative fuel have certain characteristics that allow it to be easily blended with conventional jet fuel during production, distribution, or in unmodified aircraft engines (Miller et al. 2012). There are several candidate drop-in fuels that can be produced using existing or developing technology and which have the possibility of i) meeting civil or military fuel specifications (e.g., ASTM standards) and ii) being produced at large enough scales to be both economically viable and to offset enough petroleum to help meet policy objectives associated with their deployment (e.g., such as achieving renewable energy portfolio standards).

The most common type of drop-in alternative jet fuel is synthetic paraffinic kerosene (SPK) (Miller et al. 2012). SPK resembles Jet A chemically but it can be made from a variety of feedstocks including waste biomass and coal (Miller et al. 2012). There are two conversion processes that produce SPK that have been approved by ASTM standard D7566: (1) Fischer-Tropsch (FT) process that can convert a variety of hydrocarbon feedstocks and (2) hydroprocessing of esters and fatty acids (HEFA) to produce hydrotreated renewable jet (HRJ) made form plant oils and animal fats (Miller et al. 2012). Appendix B contains a list of test flights that have been flown on SPK. Bio-crude can also be produced by either (1) pyrolysis or (2) hydrothermal liquefaction (HTL) and then upgraded into biojet fuel (Jena & Das 2011; de Miguel Mercader et al. 2010). Neither of these processes has been implemented on a large scale, however, and is yet to be certified for commercial use.

The production of biojet fuel in a general sense involves several key steps as outlined in Figure 7. Bio-based agricultural feedstocks are the raw materials for all biofuels. Transportation and logistics associated with moving the biomass and/or fuel and storing it are important given the large scale at which fuels are produced. Production, or conversion, steps are typically followed by blending processes wherein biofuels are combined with conventional petroleum-derived fuels. The blends are ultimately transported to their point of use at airports.

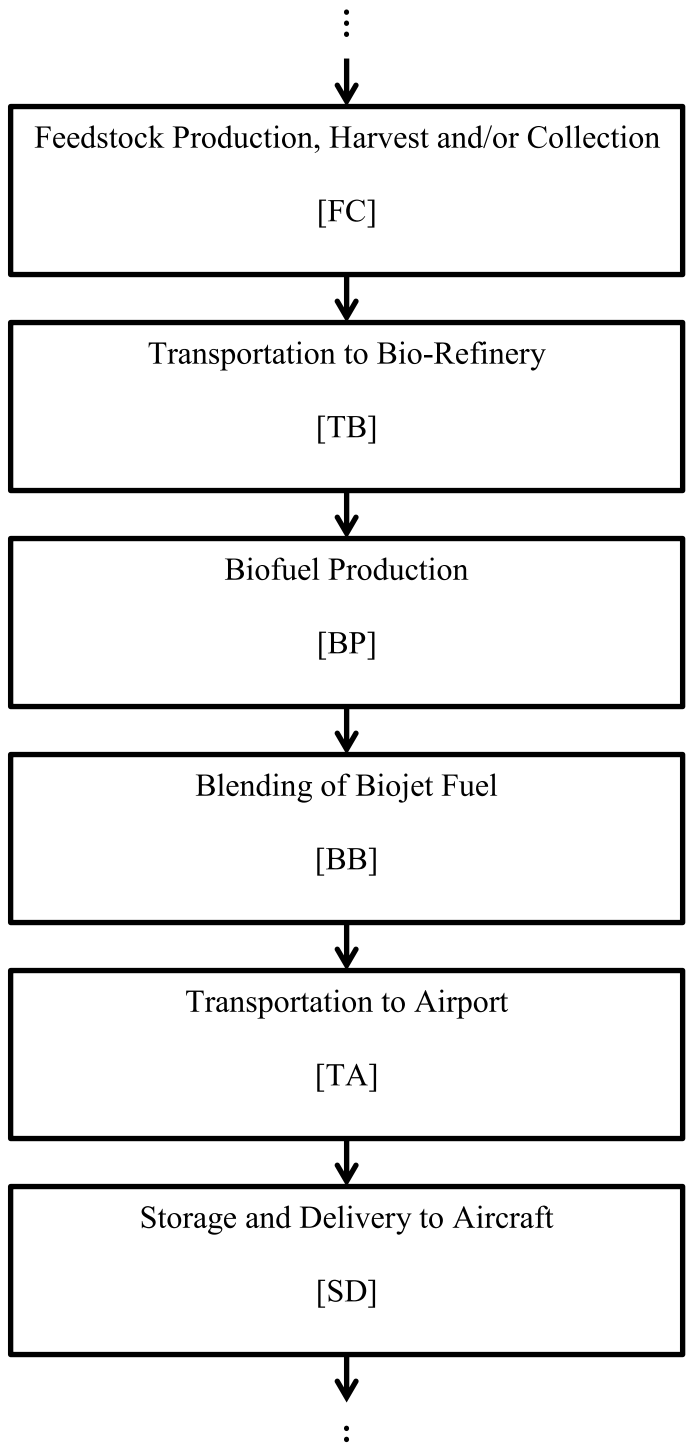

Figure 7. Conceptual supply chain for biojet fuel, adapted from Elgowainy, Han, Wang, Hileman, & Carter (2012).

In August 2012, the Virginia Department of Aviation (DOAV) requested that the Virginia Center for Transportation Innovation and Research (VCTIR) conduct a cost-benefit analysis of pursing biojet fuel industry in the Commonwealth of Virginia. The airports of the Commonwealth may need to supply this fuel in the coming years and opportunities may develop for the Commonwealth to be a producer and supplier of this fuel. Of particular concern to the stakeholders is losing airline hubs to airports in states that can provide a supply of biojet fuel if the Commonwealth fails to develop this emerging industry. A preliminary exploration of the logistics and economics of leveraging existing infrastructure and developing new infrastructure and agriculture capacity within Virginia to produce a "drop-in" biojet fuel that could be used in the airports in the Commonwealth was completed in January 2013. This paper uses those motivations and findings to propose a multi-criteria course of action analysis to support associated decision-making.

5.3 Demonstration of Methods

The following section will identify emergent conditions that most influence prioritizations of diverse initiatives for the regional development of a biojet fuel industry.

We define $S_c=\{c_1,\ldots,c_m\}$ as the set of *m* criteria. The criteria are adapted from several sources, including from the Federal Aviation Administration (FAA) vision for the future of the U.S. aviation system (Federal Aviation Administration 2011) and The White House (2011) Blueprint for Energy Security. Appendices F and G contain the executive summaries from these two documents from which the criteria were identified. The criteria are:

(i) *reliability* of supply of jet fuel by considering the sufficiency and sustainability of quantity of biojet fuel (U.S. Department of Energy 2012);

(ii) *safety* of air travel by considering the appropriateness of the quality of biojet fuel (e.g., flash point, freeze point, combustion heat, viscosity, sulfur content, density, etc.) (Air Transport Action Group 2011a);

(iii) *environmental sustainability* of producing biojet fuel (e.g., greenhouse gas emissions, land use change, freshwater use, pesticides, fertilizers, threats to biodiversity, deforestation, etc.) (Hendricks et al. 2011; Macfarlane et al. 2011; Air Transport Action Group 2011a; U.S. Department of Energy 2012);

(iv) *employment and economic development* (U.S. Department of Energy 2012);

(v) *costs* across system lifecycles, to both airport owners, carriers, and passengers (U.S. Department of Energy 2012);

(vi) *regulatory compliance* in meeting international standards, certifications, and regulations; and

(vii) *security* of supply that could be vulnerable to willful attacks by terrorists or other adversaries.

Table 15 summarizes the criteria to be used to prioritize among initiatives that support the development of a biojet fuel industry.

Table 15. Criteria used to evaluate the courses of action for regional biojet fuel industry development, based on the FAA mission and vision for the future (Federal Aviation Administration 2011) and the White House goals for energy security (The White House 2011).

Criterion	Description	FAA (2011)	The White House (2011)
c_1	Production quantity	✓	
c_2	Production quality	✓	
c_3	Environmental quality	✓	✓
c_4	Economic development		✓
c_5	Life-cycle costs		✓
c_6	Regulatory compliance and global collaboration	✓	
c_7	Safety and security	✓	✓
⋮	Others		

The set $S_x=\{x_1,\ldots,x_n\}$ represents the set of *n* alternative initiatives being considered for enhancing the biojet fuel industry. Table 16 summarizes the initiatives that are being considered in the analysis. The initiatives relate to one or more of the stages of the biojet fuel supply chain shown in Figure 7, as indicated by the two letter code in the third column of the table. Table 17 summarizes the initiatives that are relevant to each stage in the supply chain. These initiatives address decisions related to feedstock selection, production, and transportation, conversion technology, facility siting, fuel distribution, and political and regulatory actions. This list will be extended into the future as more initiatives are identified to support the development of a biojet fuel industry. The list is based on research papers and reports from academic researchers, interest groups, and government agencies, among others, as indicated in the last column of the table. Initiatives include the cultivation of various feedstocks, collection of waste or residue feedstocks, location decisions for bio-refineries, investment in conversion technologies, fuel transportation infrastructure, and supportive legislation and policies all of which are relevant to developing a biojet fuel industry.

Table 16. Initiatives for biojet fuel industry development. Two letter codes indicate one or more corresponding stages in the supply chain (Figure 7), with FC representing *Feedstock Production, Harvesting, and/or Collection*, TB representing *Transportation to Bio-Refinery*, BP representing *Biofuel Production*, BB representing *Blending of Biojet Fuel*, TA representing *Transportation to Airport*, and SD representing *Storage and Delivery to Aircraft*.

Initiative	Description	Stage	Reference
$\mathbf{x_{01}}$	Invest in R&D of more productive feedstocks (i.e., higher yielding per area of land)	FC	Rosillo-Calle et al. 2012; Air Transport Action Group 2011b; U.S. Department of Energy 2012
$\mathbf{x_{02}}$	Cultivate lignocellulosic feedstocks (e.g., switchgrass, miscanthus, etc.)	FC	Bauen et al. 2009; SWAFEA 2011; Rosillo-Calle et al. 2012
$\mathbf{x_{03}}$	Cultivate oilseed crops as feedstock (e.g., camelina, jatropha, soybean, canola, pennycress, etc.)	FC	Air Transport Action Group 2011a; Hendricks et al. 2011; Rosillo-Calle et al. 2012
$\mathbf{x_{04}}$	Cultivate halophyte feedstocks (e.g., seashore mallow, salicornia, etc.)	FC	Hendricks et al. 2011; Air Transport Action Group 2011b
$\mathbf{x_{05}}$	Cultivate algae as feedstock	FC	Air Transport Action Group 2011a; Rosillo-Calle et al. 2012; Haddad 2011
$\mathbf{x_{06}}$	Develop collection infrastructure for woody residue biomass as feedstock (e.g., wood chips)	FC/TB	U.S. Department of Energy 2011; JI Hileman et al. 2009; Swanson et al. 2010
$\mathbf{x_{07}}$	Develop collection infrastructure for agricultural residue biomass as feedstock (e.g., corn stover, wheat straw)	FC/TB	Air Transport Action Group 2011a; Rosillo-Calle et al. 2012; Swanson et al. 2010
$\mathbf{x_{08}}$	Develop collection infrastructure for municipal solid waste (MSW) as feedstock	FC/TB	Air Transport Action Group 2011a; Macfarlane et al. 2011; Rosillo-Calle et al. 2012

x_{09}	Provide long-term contracts for feedstock supply (volume and price)	FC	Miller et al. 2013; U.S. Department of Energy 2011; Stratton et al. 2010
x_{10}	Develop workforce	FC/BP	Macfarlane et al. 2011; Stubbins 2009; U.S. Department of Energy 2012
x_{11}	Locate bio-refinery in close proximity of feedstock cultivation	TB/BP	Melin & Hurme 2011; T. J. Skone et al. 2011; Miller et al. 2012
x_{12}	Locate bio-refinery in close proximity of city or metropolitan area	TB/BP	Gerber et al. 2013; Macfarlane et al. 2011; Miller et al. 2012
x_{13}	Distribute preprocessing depots with transportation infrastructure to bio-refineries	TB/BP	U.S. Department of Energy 2012
x_{14}	Invest in hydroprocessing (HEFA) bio-refining technologies	BP	Air Transport Action Group 2011a; Miller et al. 2013; Pearlson et al. 2013
x_{15}	Invest in Fischer-Tropsch (FT) bio-refining technologies	BP	Miller et al. 2013; Air Transport Action Group 2011b; Liu et al. 2013
x_{16}	Invest in alcohol-to-jet (ATJ) bio-refining technologies	BP	Air Transport Action Group 2011a; Miller et al. 2013; Macfarlane et al. 2011
x_{17}	Invest in fermentation renewable jet (FRJ) bio-refining technologies	BP	Miller et al. 2013; Miller et al. 2012; Hendricks et al. 2011
x_{18}	Invest in pyrolysis bio-refining technologies	BP	Miller et al. 2013; Air Transport Action Group 2011a; Hendricks et al. 2011
x_{19}	Invest in hydrothermal liquefaction (HTL) bio-refining technologies	BP	Young & Heimlich 2010; Bauen et al. 2009; Biddy et al. 2013
x_{20}	Develop market for co-products (e.g., chemicals)	BP	Macfarlane et al. 2011; U.S. Department of Energy 2012; Agusdinata et al. 2011

x_{21}	Diversify demand for biofuels (e.g., marine shipping, railroad, avgas, etc.)	BP	Macfarlane et al. 2011; Rye & Batten 2012; Miller et al. 2012
x_{22}	Provide low-cost financing for bio-refineries	BP	Miller et al. 2013; Air Transport Action Group 2011b; U.S. Department of Agriculture 2012
x_{23}	Provide tax credits for biofuels	BP	Miller et al. 2013; Air Transport Action Group 2011b; U.S. Department of Agriculture 2010
x_{24}	Commit to biojet fuel purchase agreements	BP	Hammel 2013; Pearlson 2011; Macfarlane et al. 2011; Air Transport Action Group 2011b
x_{25}	Establish airports as biofuel fueling stations for non-aircraft vehicles	BP	Miller et al. 2013; T. Skone & Gerdes 2008
x_{26}	Encourage user-friendly biofuel accounting methods	BP	International Air Transport Association 2013; Air Transport Action Group 2011b
x_{27}	Co-locate bio-refinery with petroleum refinery	BP/BB	Gutierrez et al. 2007; Miller et al. 2012; de Miguel Mercader et al. 2010
x_{28}	Locate bio-refinery in proximity of pipeline access	BP/BB/TA	Miller et al. 2012; U.S. EPA 2010; Shonnard et al. 2010
x_{29}	Locate bio-refinery in close proximity of sea port for biofuel distribution via barge	BP/TA	Miller et al. 2012; Shonnard et al. 2010; T. J. Skone et al. 2011
x_{30}	Locate bio-refinery in close proximity of rail line for biofuel distribution via train	BP/TA	Miller et al. 2012; Shonnard et al. 2010; T. J. Skone et al. 2011
x_{31}	Site blending facility on airport grounds	BB	Macfarlane et al. 2011; Air Transport Action Group 2011a
x_{32}	Site blending facility at bio-refinery	BB	Macfarlane et al. 2011; Air Transport Action Group 2011a

x_{33}	Site blending facility at existing fuel terminal	BB	Macfarlane et al. 2011; Air Transport Action Group 2011a
x_{34}	Convert petroleum pipeline to biofuel pipeline for biofuel distribution	TA	Macfarlane et al. 2011; JI Hileman et al. 2009
x_{35}	Establish trucking infrastructure for fuel distribution	TA	Miller et al. 2012; Shonnard et al. 2010; T. J. Skone et al. 2011
x_{36}	Increase number of storage tanks on airport grounds	SD	Watson 2011; Hendricks et al. 2011
x_{37}	Establish coalitions encompassing all parts of the supply chain	FC-SD	Air Transport Action Group 2011b; Hammel 2013
⋮	Others		

Table 17. Initiatives grouped by corresponding stage in the biojet fuel supply chain.

Stage	Relevant Initiatives
Feedstock Production, Harvest, and/or Collection	x_{01}: Invest in R&D of more productive feedstocks
	x_{02}: Cultivate lignocellulosic feedstocks
	x_{03}: Cultivate oilseed crops as feedstock
	x_{04}: Cultivate halophyte feedstocks
	x_{05}: Cultivate algae as feedstock
	x_{06}: Develop collection infrastructure for woody residue biomass as feedstock
	x_{07}: Develop collection infrastructure for agricultural residue biomass as feedstock
	x_{08}: Develop collection infrastructure for municipal solid waste (MSW) as feedstock
	x_{09}: Provide long-term contracts for feedstock supply
	x_{10}: Develop workforce
	x_{37}: Establish coalitions encompassing all parts of the supply chain
Transportation to Bio-Refinery	x_{06}: Develop collection infrastructure for woody residue biomass as feedstock
	x_{07}: Develop collection infrastructure for agricultural residue biomass as feedstock
	x_{08}: Develop collection infrastructure for municipal solid waste (MSW) as feedstock
	x_{11}: Locate bio-refinery in close proximity of feedstock cultivation
	x_{12}: Locate bio-refinery in close proximity of city or metropolitan area
	x_{13}: Distribute preprocessing depots with transportation infrastructure to bio-refineries
	x_{37}: Establish coalitions encompassing all parts of the supply chain

Biofuel Production	x_{10}: Develop workforce
	x_{11}: Locate bio-refinery in close proximity of feedstock cultivation
	x_{12}: Locate bio-refinery in close proximity of city or metropolitan area
	x_{13}: Distribute preprocessing depots with transportation infrastructure to bio-refineries
	x_{14}: Invest in hydroprocessing (HEFA) bio-refining technologies
	x_{15}: Invest in Fischer-Tropsch (FT) bio-refining technologies
	x_{16}: Invest in alcohol-to-jet (ATJ) bio-refining technologies
	x_{17}: Invest in fermentation renewable jet (FRJ) bio-refining technologies
	x_{18}: Invest in pyrolysis bio-refining technologies
	x_{19}: Invest in hydrothermal liquefaction (HTL) bio-refining technologies
	x_{20}: Develop market for co-products
	x_{21}: Diversify demand for biofuels
	x_{22}: Provide low-cost financing for bio-refineries
	x_{23}: Provide tax credits for biofuels
	x_{24}: Commit to biojet fuel purchase agreements
	x_{25}: Establish airports as biofuel fueling stations for non-aircraft vehicles
	x_{26}: Encourage user-friendly biofuel accounting methods
	x_{27}: Co-locate bio-refinery with petroleum refinery
	x_{28}: Locate bio-refinery in proximity of pipeline access
	x_{29}: Locate bio-refinery in close proximity of sea port for biofuel distribution via barge
	x_{30}: Locate bio-refinery in close proximity of rail line for biofuel distribution via train

	x_{37}: Establish coalitions encompassing all parts of the supply chain
Blending of Biojet Fuel	x_{27}: Co-locate bio-refinery with petroleum refinery
	x_{28}: Locate bio-refinery in proximity of pipeline access
	x_{31}: Site blending facility on airport grounds
	x_{32}: Site blending facility at bio-refinery
	x_{33}: Site blending facility at existing fuel terminal
	x_{37}: Establish coalitions encompassing all parts of the supply chain
Transportation to Airport	x_{28}: Locate bio-refinery in proximity of pipeline access
	x_{29}: Locate bio-refinery in close proximity of sea port for biofuel distribution via barge
	x_{30}: Locate bio-refinery in close proximity of rail line for biofuel distribution via train
	x_{34}: Convert petroleum pipeline to biofuel pipeline for biofuel distribution
	x_{35}: Establish trucking infrastructure for fuel distribution
	x_{37}: Establish coalitions encompassing all parts of the supply chain
Storage and Delivery to Aircraft	x_{36}: Increase number of storage tanks on airport grounds
	x_{37}: Establish coalitions encompassing all parts of the supply chain

Table 18 describes qualitative ratings assigned to investment initiatives based on how well they address categories of criteria. The ratings given are the result of stakeholder analysis, and remain customizable for other decision makers and into the future. Rating choices for the initiatives consist of a *strongly addresses*, *addresses, somewhat addresses*, and *does not address* each criterion. For example, initiative x_{01}*: Invest in R&D of more productive feedstocks*, is rated as *strongly addressing* criteria c_{01}*: Production quantity* and c_{05}*: Life-cycle costs*, *addressing* criteria c_{03}*: Environmental quality* and c_{06}*: Regulatory compliance and global collaboration*, *somewhat addressing* criterion c_{04}*: Economic development*, and *not addressing* criteria c_{02}*: Production quality* and c_{07}*: Safety and security*.

Table 18. Fulfillment of criteria for each initiative, with ● indicating the initiative *strongly addresses* the criteria, ◑ indicating the initiative *addresses* the criteria, ○ indicating the initiative *somewhat addresses* the criteria, and omission indicating the initiative *does not address* the criteria.

		c_1 Production quantity	c_2 Production quality	c_3 Environmental quality	c_4 Economic development	c_5 Life-cycle costs	c_6 Regulatory compliance and global collaboration	c_7 Safety and security
x_{01}	Invest in R&D of more productive feedstocks	●		◑	○	●	◑	
x_{02}	Cultivate lignocellulosic feedstocks	◑			●			○
x_{03}	Cultivate oilseed crops as feedstock	◑			●			○
x_{04}	Cultivate halophyte feedstocks	◑		○	◑		●	○
x_{05}	Cultivate algae as feedstock	●		○	◑			○
x_{06}	Develop collection infrastructure for woody residue biomass as feedstock	○		◑			○	○
x_{07}	Develop collection infrastructure for agricultural residue biomass as feedstock	○		◑				○
x_{08}	Develop collection infrastructure for municipal solid waste (MSW) as feedstock	●		◑				◑
x_{09}	Provide long-term contracts for feedstock supply	●					○	
x_{10}	Develop workforce	○			●			◑
x_{11}	Locate bio-refinery in close proximity of feedstock cultivation			○		◑		
x_{12}	Locate bio-refinery in close proximity of city or metropolitan area			○		◑		

		c_1 Production quantity	c_2 Production quality	c_3 Environmental quality	c_4 Economic development	c_5 Life-cycle costs	c_6 Regulatory compliance and global collaboration	c_7 Safety and security
x_{13}	Distribute preprocessing depots with transportation infrastructure to bio-refineries	◑						◑
x_{14}	Invest in hydroprocessing (HEFA) bio-refining technologies	○	●		○		◑	○
x_{15}	Invest in Fischer-Tropsch (FT) bio-refining technologies	○	●		○		◑	○
x_{16}	Invest in alcohol-to-jet (ATJ) bio-refining technologies	○	◑		○			○
x_{17}	Invest in fermentation renewable jet (FRJ) bio-refining technologies	○	○		○			○
x_{18}	Invest in pyrolysis bio-refining technologies	○	○		○			○
x_{19}	Invest in hydrothermal liquefaction (HTL) bio-refining technologies	○	○		○			○
x_{20}	Develop market for co-products				◑	●		
x_{21}	Diversify demand for biofuels	○			◑			
x_{22}	Provide low-cost financing for bio-refineries				◑			
x_{23}	Provide tax credits for biofuels				◑	●		
x_{24}	Commit to biojet fuel purchase agreements	○						
x_{25}	Establish airports as biofuel fueling stations for non-aircraft vehicles				◑			

		c_1 Production quantity	c_2 Production quality	c_3 Environmental quality	c_4 Economic development	c_5 Life-cycle costs	c_6 Regulatory compliance and global collaboration	c_7 Safety and security
x_{26}	Encourage user-friendly biofuel accounting methods				○			
x_{27}	Co-locate bio-refinery with petroleum refinery					◑		
x_{28}	Locate bio-refinery in proximity of pipeline access			●		◑		
x_{29}	Locate bio-refinery in close proximity of sea port for biofuel distribution via barge			○		◑		
x_{30}	Locate bio-refinery in close proximity of rail line for biofuel distribution via train			○		◑		
x_{31}	Site blending facility on airport grounds							
x_{32}	Site blending facility at bio-refinery							
x_{33}	Site blending facility at existing fuel terminal					◑	◑	
x_{34}	Convert petroleum pipeline to biofuel pipeline for biofuel distribution					◑		
x_{35}	Establish trucking infrastructure for fuel distribution					◑		
x_{36}	Increase number of storage tanks on airport grounds	◑				◑		○
x_{37}	Establish coalitions encompassing all parts of the supply chain						●	◑

Table 19 describes a set S_{ec} representing emergent conditions with potential importance to the development of a biofuel industry. The emergent conditions address potential threats and opportunities of concern to airports (Kincaid et al. 2012), airlines (Air Transport Action Group 2011b), feedstock and biofuel producers (Rosillo-Calle et al. 2012), among other stakeholders. These emergent conditions include uncertainties in airline actions, competition between airports, air travel and jet fuel demand, and changes in the price of biojet fuel and petroleum jet fuel.

Select emergent conditions are combined to form scenarios in the set $S_s=\{s_1,\ldots,s_q\}$, representing scenarios to address future uncertainties related to developing a regional biojet fuel industry. Tables 20-25 describe these scenarios. The first scenario takes into consideration the recent RINs issued by the U.S. EPA for biojet fuel (H. Wang & Kolhman 2013) by which biojet fuel can qualify for credits that can be traded under the Renewable Fuel Standard (RFS) program. The other scenarios consider emergent conditions related to the application of the European Union Emissions Trading Scheme (EU ETS) to U.S.-originating flights, airport competition, changes in passenger preferences and travel patterns, and supply restrictions.

Table 19. Emergent conditions used to build scenarios for biojet fuel industry development, organized into categories of market forces and competition, regulations and tariffs, and technologies and resources.

Category	Emergent Condition	Description	Reference
Market Forces and Competition	EC_{01}	Competition between airports	Kincaid et al. 2012
	EC_{02}	Shift in customer preferences to favor biofuel-powered flights	Kincaid et al. 2012
	EC_{03}	Change in air traffic mix (e.g., decrease in international trips)	Kincaid et al. 2012
	EC_{04}	Entry or expansion of a low-cost carrier	Kincaid et al. 2012
	EC_{05}	Relocation of airline hub	Kincaid et al. 2012
	EC_{06}	Restructuring or failure of an incumbent airline	Kincaid et al. 2012
	EC_{07}	Long-term change in demand for air travel	Kincaid et al. 2012; Rosillo-Calle et al. 2012; Penner et al. 2001
	EC_{08}	Change in demand for jet fuel	Rosillo-Calle et al. 2012; Penner et al. 2001
	EC_{09}	Change in the price of petroleum jet fuel	Rosillo-Calle et al. 2012; Air Transport Action Group 2011b
	EC_{10}	Competition for biofuel feedstock from other industries	Rosillo-Calle et al. 2012; Penner et al. 2001
	EC_{11}	Alteration of airline service agreement	Kincaid et al. 2012
	EC_{12}	Shock event (e.g., terrorist attack, severe weather event, etc.)	Kincaid et al. 2012

	EC_{13}	Development or expansion of market for co-products	Macfarlane et al. 2011; U.S. Department of Energy 2012
	EC_{14}	Biofuel market conditions shift to favor production of biojet fuel	Macfarlane et al. 2011; Air Transport Action Group 2011b
Regulations and Tariffs	EC_{15}	Implementation of carbon taxes and/or emissions cap and trade system	Kincaid et al. 2012
	EC_{16}	Introduction of biofuel-related legislation (e.g., tax exemptions, subsidies, etc.)	Rosillo-Calle et al. 2012
	EC_{17}	Political factors impede commercial-scale biojet fuel refining	Macfarlane et al. 2011
	EC_{18}	Increase in the strictness of emission standards	Kincaid et al. 2012; Young & Heimlich 2010
	EC_{19}	Certification of additional biojet fuel conversion techniques (e.g., ATJ, FRJ, HTL, pyrolysis, etc.) and/or higher blend levels	Penner et al. 2001; Rosillo-Calle et al. 2012
	EC_{20}	Policy or legislation requiring set amount of biofuel use in aviation sector	Air Transport Action Group 2011b
Technologies and Resources	EC_{21}	Change in supply or availability of feedstock	U.S. Department of Energy 2011; Air Transport Action Group 2011b
	EC_{22}	Advances in conversion technology	Macfarlane et al. 2011; JI Hileman et al. 2009; Air Transport Action Group 2011b
	EC_{23}	Development in aircraft technology, air traffic control, and/or passenger facilitation	Kincaid et al. 2012
	EC_{24}	Change in cost of growing and/or harvesting feedstock	Rosillo-Calle et al. 2012; Air Transport Action Group 2011b; U.S. Department of Energy 2011
	EC_{25}	Change in cost of producing (i.e. refining) biojet fuel	Macfarlane et al. 2011; Air Transport Action Group 2011b; U.S. Department of Energy 2012
	⋮	Others	

Table 20. Description of baseline scenario, s_{00}.

Scenario
s_{00}: Baseline
Description
Absence of regulations related to a biojet fuel industry
Emergent Conditions
None
Influences
Commercialization of biojet fuel is slow to stagnant, relying only on existing market forces.

Table 21. Description of scenario of expected regulations, s_{01}.

Scenario
s_{01}: Expected regulations
Description
U.S. regulations or policies offer tax credits or other incentives that effectively make biojet fuel more cost competitive with conventional jet fuel.
Emergent Conditions
EC_{16}: Introduction of biofuel-related legislation (e.g., tax exemptions, subsidies, etc.)
Influences
The cost of biojet fuel to the consumer decreases. Thus, airlines are more willing to buy biojet fuel (demand increases), signaling for producers to increase biojet fuel production.

Table 22. Description of European Union Emissions Trading Scheme scenario, s_{02}.

Scenario
s_{02}: EU ETS
Description
EU ETS is expanded to include U.S.-originating flights to Europe.
Emergent Conditions
EC_{15}: Implementation of carbon taxes and/or emissions cap and trade system
Influences
Flights to Europe using conventional jet fuel increase in price. The demand for biojet fuel thus increases in order to keep these international flights affordable, even if the biojet fuel is more expensive (per gallon) than biojet fuel.

Table 23. Description of airport competition scenario, s_{03}.

Scenario
s_{03}: Airport competition
Description
Select airports have a competitive advantage in terms of access to biojet fuel.
Emergent Conditions
EC_{01}: Competition between airports
EC_{05}: Relocation of airline hub
EC_{15}: Implementation of carbon taxes and/or emissions cap and trade system
Influences
Because only certain airports can provide biojet fuel, thus offering cheaper flights to Europe (due to the EU ETS), airlines relocate their international hubs from less competitive airports.

Table 24. Description of consumer green preference scenario, s_{04}.

Scenario

s_{04}: Green preferences

Description

Environmental awareness causes a change in consumer preferences, favoring domestic flights flown on biojet fuel.

Emergent Conditions

EC_{02}: Shift in customer preferences to favor biofuel-powered flights

EC_{13}: Change in air traffic mix (e.g., decrease in international trips)

Influences

Consumers choose to fly less frequently, especially staying away from long international flights. Preference is given to flights powered by biojet fuel, asymmetrically increasing demand for these flights while overall demand decreases.

Table 25. Description of insufficient biojet fuel supply scenario, s_{05}.

Scenario

s_{05}: Insufficient supply

Description

Supply of biojet fuel cannot meet demand due to lack of commercial scale bio-refineries and/or availability of feedstock

Emergent Conditions

EC_{17}: Political factors impede commercial-scale biojet fuel refining

EC_{21}: Change in supply or availability of feedstock

Influences

Supply of biojet fuel cannot meet demand, driving prices up. Increased demand for viable feedstocks and increasing benefit for retrofitting or converting existing refineries to bio-refineries.

5.4 Calculations

The qualitative ratings of how well each initiative addresses each criterion given in Table 18 are translated to a quantitative assessment matrix. Table 26 describes the values of score x_{ij} that are used to evaluate how each initiative x_i addresses each criterion c_j based on the qualitative ratings. These scores are used to populate the 7x37 matrix *A* (Figure 8) as it is described in Section 3.2.

Table 26. Translation of qualitative rating of the degree of agreement between biojet fuel initiatives and criteria to quantitative scores.

Qualitative rating	Symbol (from Table 18)	Quantitative rating
does not address		0
somewhat addresses	○	0.33
addresses	◑	0.67
strongly addresses	●	1

$$A[1\text{-}18] = \begin{bmatrix}
1.0 & 0.7 & 0.7 & 0.7 & 1.0 & 0.3 & 0.3 & 1.0 & 1.0 & 0.3 & 0.0 & 0.0 & 0.7 & 0.3 & 0.3 & 0.3 & 0.3 & 0.3 \\
0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 1.0 & 1.0 & 0.7 & 0.3 & 0.3 \\
0.7 & 0.0 & 0.0 & 0.3 & 0.3 & 0.7 & 0.7 & 0.7 & 0.0 & 0.0 & 0.3 & 0.3 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 \\
0.3 & 1.0 & 1.0 & 0.7 & 0.7 & 0.0 & 0.0 & 0.0 & 0.0 & 1.0 & 0.0 & 0.0 & 0.0 & 0.3 & 0.3 & 0.3 & 0.3 & 0.3 \\
1.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.7 & 0.7 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 \\
0.7 & 0.0 & 0.0 & 1.0 & 0.0 & 0.3 & 0.0 & 0.0 & 0.3 & 0.0 & 0.0 & 0.0 & 0.0 & 0.7 & 0.7 & 0.0 & 0.0 & 0.0 \\
0.0 & 0.3 & 0.3 & 0.3 & 0.3 & 0.3 & 0.3 & 0.7 & 0.0 & 0.7 & 0.0 & 0.0 & 0.7 & 0.3 & 0.3 & 0.3 & 0.3 & 0.3
\end{bmatrix}$$

$$A[19\text{-}37] = \begin{bmatrix}
0.3 & 0.0 & 0.3 & 0.0 & 0.0 & 0.3 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.7 & 0.0 \\
0.3 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.7 & 0.7 & 0.7 & 0.0 & 0.0 & 0.0 & 0.0 \\
0.0 & 0.0 & 0.0 & 0.0 & 0.7 & 0.0 & 0.0 & 0.0 & 0.0 & 1.0 & 0.3 & 0.3 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 \\
0.3 & 0.7 & 0.7 & 0.7 & 0.7 & 0.0 & 0.7 & 0.3 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 \\
0.0 & 1.0 & 0.0 & 0.0 & 1.0 & 0.0 & 0.0 & 0.0 & 0.7 & 0.7 & 0.7 & 0.7 & 0.0 & 0.0 & 0.0 & 0.7 & 0.7 & 0.7 & 0.0 \\
0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.7 & 0.0 & 0.0 & 1.0 \\
0.3 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.3 & 0.7
\end{bmatrix}$$

Figure 8. Assessment matrix *A* where entry i,j represents the degree to which initiative x_i addresses criterion c_j using the translated ratings described in Table 26. Numbers are rounded for visibility in the figure, but not for calculations.

Each criterion is weighted to determine the relative influence of the criteria. The relative influence of each criterion may change during each of the five scenarios introduced in Tables 21-25. For the baseline scenario s_{00}, each criterion is considered to have equal influence. Thus, for the baseline, each criterion is assigned a weight of approximately 14.3%. Identifying whether the influence of the criteria *increases, increases somewhat, stays the same, decreases somewhat,* or *decreases*, under other scenarios, the weight of the criteria is multiplied by a constant α:

$$\alpha = \begin{cases} 9 & \text{if the influence of criterion i increases with scenario k} \\ 3 & \text{if the influence of criterion i increases somewhat with scenario k} \\ 1 & \text{if the influence of criterion i stays the same with scenario k} \\ 1/3 & \text{if the influence of criterion i decreases somewhat with scenario k} \\ 1/9 & \text{if the influence of criterion i decreases with scenario k} \end{cases}$$

Reassessing the weights under each scenario results in the 7x6 matrix *W*. The first column of *W* represents the weights in the baseline scenario. The other columns represent the reconsidered weights under scenarios 1, 2, 3, 4, and 5 respectively.

$$W = \begin{bmatrix} 14\% & 41\% & 43\% & 25\% & 20\% & 48\% \\ 14\% & 1\% & 1\% & 3\% & 27\% & 1\% \\ 14\% & 41\% & 1\% & 19\% & 27\% & 1\% \\ 14\% & 7\% & 5\% & 25\% & 3\% & 1\% \\ 14\% & 1\% & 1\% & 0\% & 1\% & 1\% \\ 14\% & 1\% & 43\% & 25\% & 3\% & 1\% \\ 14\% & 7\% & 5\% & 3\% & 20\% & 48\% \end{bmatrix}$$

The value score matrix is computed by multiplying the transpose of the weight matrix W^T by the assessment matrix *A*, as demonstrated in Table 27.

Table 27. Performance scores of the biojet fuel initiatives under each scenario. Scores are out of 100, with 100 representing the best performing initiative.

	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}	x_{13}	x_{14}	x_{15}	x_{16}	x_{17}	x_{18}
s_{00}	52	29	29	43	33	24	19	33	19	29	14	14	19	38	38	24	19	19
s_{01}	73	37	37	50	62	44	44	74	42	25	14	14	32	20	20	19	19	19
s_{02}	75	36	36	78	49	31	17	47	58	23	1	1	32	48	48	19	18	18
s_{03}	63	43	43	65	49	30	22	39	33	35	6	6	19	37	37	20	19	19
s_{04}	41	23	23	34	38	32	31	51	21	23	9	9	27	43	43	32	23	23
s_{05}	50	49	49	50	64	33	32	80	48	49	1	1	63	34	34	33	32	32
Median	60	37	37	50	49	32	29	50	40	26	7	7	31	38	38	21	19	19
Mean	59	36	36	53	49	32	27	54	37	31	8	8	32	37	37	24	22	22

	x_{19}	x_{20}	x_{21}	x_{22}	x_{23}	x_{24}	x_{25}	x_{26}	x_{27}	x_{28}	x_{29}	x_{30}	x_{31}	x_{32}	x_{33}	x_{34}	x_{35}	x_{36}	x_{37}
s_{00}	19	24	14	10	33	5	10	5	10	24	14	14	10	10	10	19	10	24	24
s_{01}	19	5	18	5	33	14	5	2	1	42	14	14	1	1	1	1	1	31	6
s_{02}	18	5	18	4	5	14	4	2	1	2	1	1	1	1	1	29	1	31	47
s_{03}	19	17	25	17	29	8	17	8	0	19	6	6	2	2	2	17	0	18	27
s_{04}	23	3	9	2	20	7	2	1	0	27	9	9	18	18	18	3	0	20	17
s_{05}	32	2	17	1	2	16	1	0	1	2	1	1	1	1	1	1	1	48	33
Median	19	5	18	4	23	12	4	2	1	20	7	7	1	1	1	6	1	29	26
Mean	22	9	17	6	21	11	6	3	2	19	8	8	5	5	5	12	2	29	25

5.5 Results

Table 28 illustrates the rank order of initiatives based on the value scores of each initiative for the five scenarios and the baseline scenario. Figure 9 demonstrates the range of rankings that each initiative is assigned under the scenarios. The following three initiatives were ranked highest under at least one scenario: (i) *Invest in R&D of more productive feedstocks*, (ii) *Cultivate halophyte feedstock*, and (iii) *Develop collection infrastructure for municipal solid waste (MSW) as feedstock*. Figure 10 illustrates the robustness of initiatives for the initiatives with a median rank higher than 10. While initiative x_{08}*: Develop collection infrastructure for municipal solid waste (MSW) as feedstock* ranks the highest under the most scenarios (s_{01}, s_{04}, and s_{05}), initiative x_{01}*: Invest in R&D of more productive feedstocks* has the highest median rank. Further, initiative x_{01} is robust in that the largest change in rank from the baseline scenario is 3, which is also true only of initiative x_{05}*: Cultivate algae as feedstock*. In terms of average change in rank from the baseline scenario, initiatives x_{05}*: Cultivate algae as feedstock*, x_{17}*: Invest in fermentation renewable jet (FRJ) bio-refining technologies*, x_{18}*: Invest in pyrolysis bio-refining technologies*, and x_{19}*: Invest in hydrothermal liquefaction (HTL) bio-refining technologies* are the most robust.

Table 29 illustrates the absolute value of the change in prioritization of initiatives caused by the scenarios relative to the baseline scenario. In terms of average change in rank of initiative, scenario s_{04}*: Green preferences* is the most disruptive combination of emergent conditions. And, it also accounted for the largest change in rank, causing initiative x_{20}*: Develop market for co-products* to decrease in priority from 11th in the baseline scenario to 31st in the case of the "greening" of consumer preferences. Scenario s_{05}*: Insufficient supply*, on the other hand, is the least disruptive scenario in terms of the prioritization of biojet fuel initiatives.

Table 28. Performance rank of biojet fuel initiatives. The highest scoring initiative for each scenario is highlighted.

	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}	x_{13}	x_{14}	x_{15}	x_{16}	x_{17}	x_{18}
s_0	1	8	8	2	5	11	17	5	17	8	24	24	17	3	3	11	17	17
s_1	2	9	9	4	3	5	6	1	8	14	22	22	12	15	15	17	18	18
s_2	2	9	9	1	4	12	21	7	3	15	29	29	11	5	5	16	17	17
s_3	2	4	4	1	3	11	15	6	10	9	29	29	18	7	7	16	18	18
s_4	4	12	12	6	5	7	9	1	18	12	25	25	11	2	2	7	12	12
s_5	4	6	6	5	2	13	16	1	10	6	26	26	3	11	11	13	16	16
Median	2	9	9	3	4	11	16	3	10	11	26	26	12	6	6	15	17	17

	x_{19}	x_{20}	x_{21}	x_{22}	x_{23}	x_{24}	x_{25}	x_{26}	x_{27}	x_{28}	x_{29}	x_{30}	x_{31}	x_{32}	x_{33}	x_{34}	x_{35}	x_{36}	x_{37}
s_0	17	11	24	29	5	36	29	36	29	11	24	24	29	29	29	17	29	11	11
s_1	18	28	21	29	11	26	29	31	36	7	22	22	33	33	33	32	36	13	27
s_2	17	24	20	25	23	22	25	27	33	28	29	29	33	33	33	14	33	12	8
s_3	18	23	14	25	12	27	25	27	36	17	29	29	33	33	33	24	36	22	13
s_4	12	31	29	33	19	30	33	35	36	10	25	25	21	21	21	32	36	20	24
s_5	16	23	20	30	22	21	30	37	30	23	26	26	30	30	30	25	30	9	13
Median	17	24	21	29	16	27	29	33	35	14	26	26	32	32	32	25	35	13	13

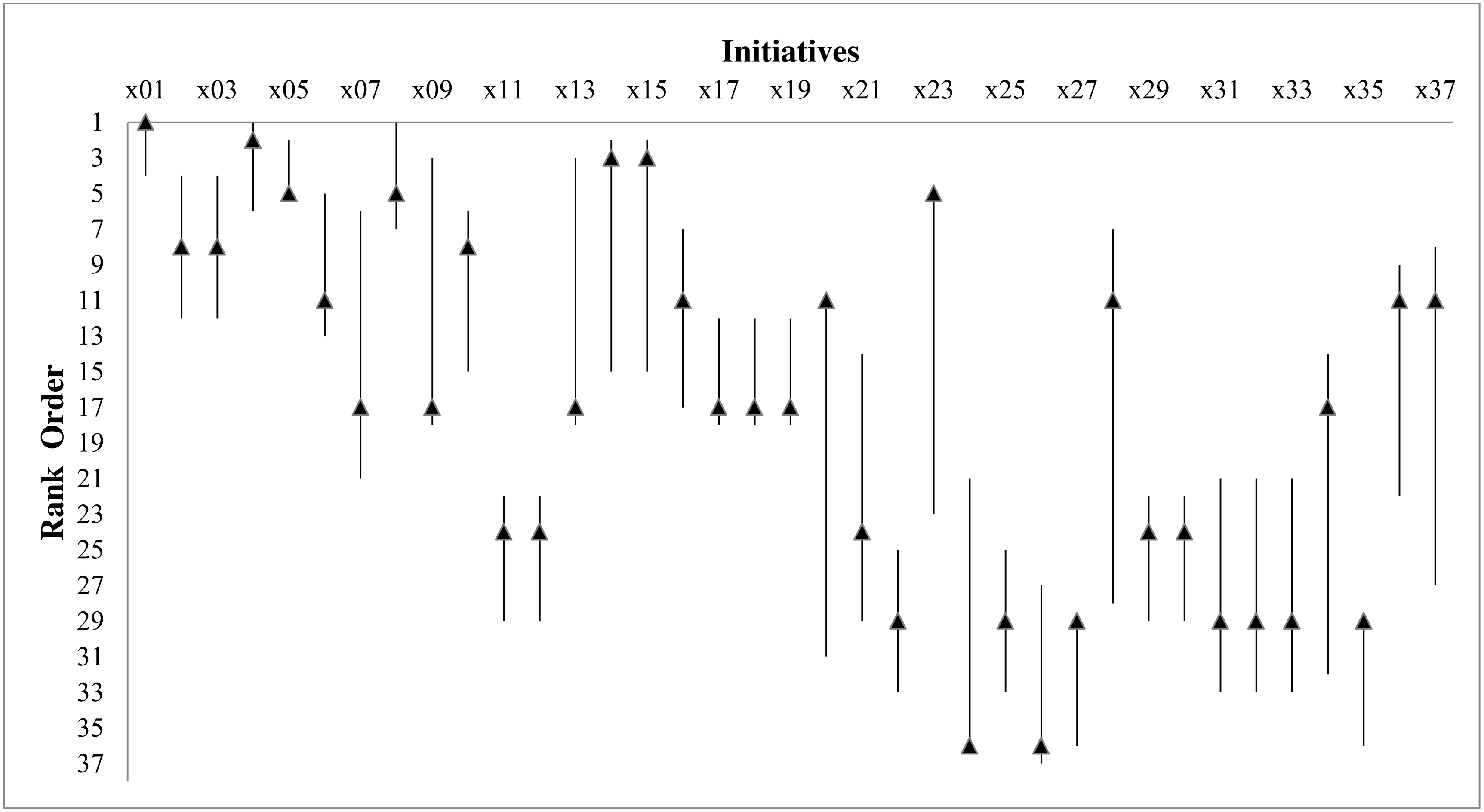

Figure 9. Comparison of rank order of biojet fuel initiatives and robustness to changes in rank. The triangle marks the baseline scenario rank, with the lines indicating the range of rank orders under the set of scenarios.

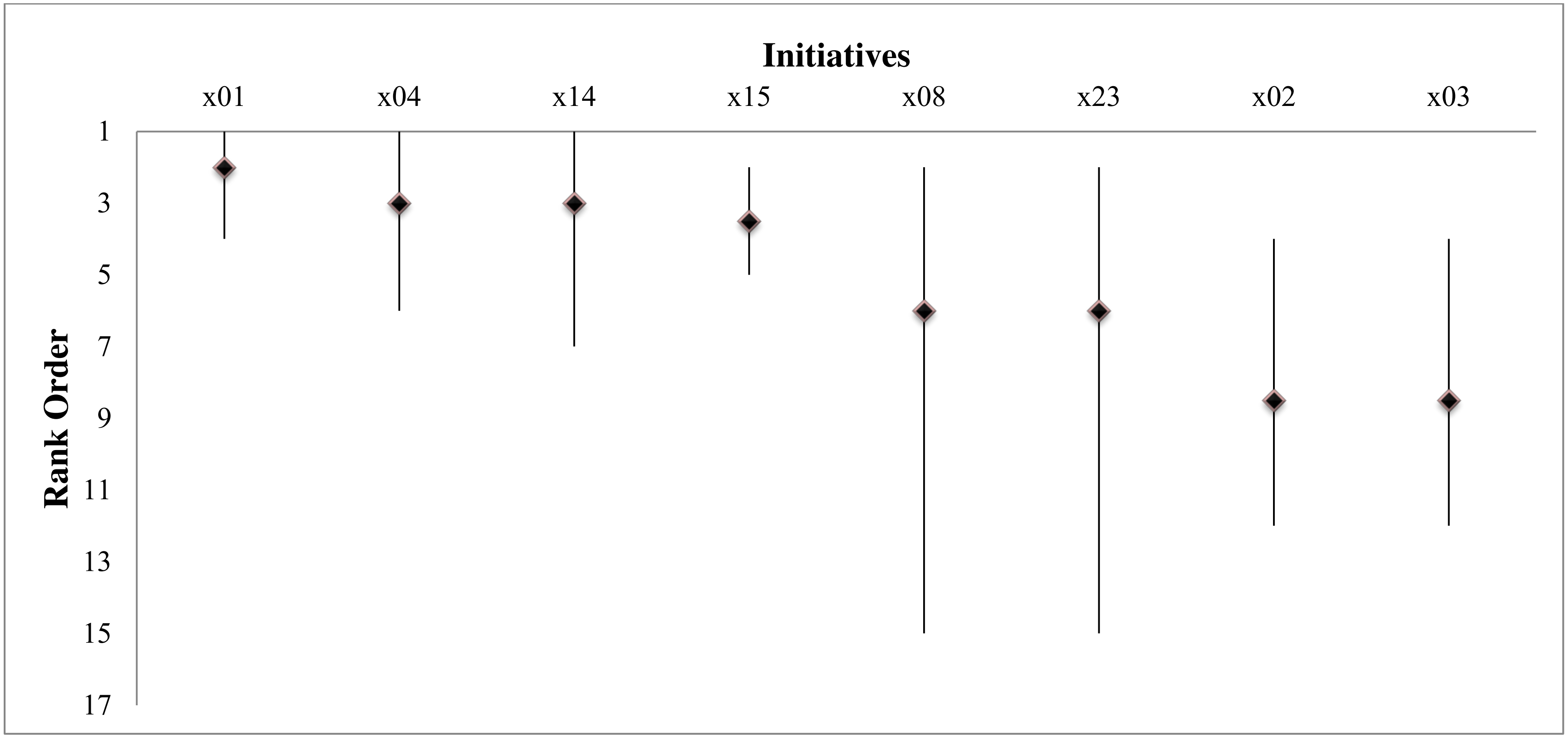

Figure 10. Comparison of biojet fuel initiatives with median rank (represented by the diamond) of 10 or better.

Table 29. Change in rank (in absolute terms) of biojet fuel initiatives in response to the set of scenarios s_{01}-s_{05} as compared to the baseline scenario.

	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}	x_{13}	x_{14}	x_{15}	x_{16}	x_{17}	x_{18}	x_{19}
s_1	1	1	1	2	2	6	11	4	9	6	2	2	5	12	12	6	1	1	1
s_2	1	1	1	1	1	1	4	2	14	7	5	5	6	2	2	5	0	0	0
s_3	1	4	4	1	2	0	2	1	7	1	5	5	1	4	4	5	1	1	1
s_4	3	4	4	4	0	4	8	4	1	4	1	1	6	1	1	4	5	5	5
s_5	3	2	2	3	3	2	1	4	7	2	2	2	14	8	8	2	1	1	1

	x_{20}	x_{21}	x_{22}	x_{23}	x_{24}	x_{25}	x_{26}	x_{27}	x_{28}	x_{29}	x_{30}	x_{31}	x_{32}	x_{33}	x_{34}	x_{35}	x_{36}	x_{37}	**Avg**
s_1	17	3	0	6	10	0	5	7	4	2	2	4	4	4	15	7	2	16	5.2
s_2	13	4	4	18	14	4	9	4	17	5	5	4	4	4	3	4	1	3	4.8
s_3	12	10	4	7	9	4	9	7	6	5	5	4	4	4	7	7	11	2	4.5
s_4	20	5	4	14	6	4	1	7	1	1	1	8	8	8	15	7	9	13	5.3
s_5	12	4	1	17	15	1	1	1	12	2	2	1	1	1	8	1	2	2	4.1

Table 30 provides a summary of the scenario analysis results. As scenario s_{04}*: Green preferences* is the most disruptive scenario across all initiatives relative to the baseline scenario, the results suggest initiatives for expanding the supply of certain feedstocks (e.g., MSW, halophytes, and algae) and investing in proven and certified conversion technologies, as these initiatives remain relatively highly ranked under all scenarios analyzed. These initiatives are top priorities under scenario s_{04}*: Green preferences* because they are expected to be the least harmful to the environment in addition to the least technically risky. For the most part, the top initiatives under the most disruptive scenario also tend to be those that are ranked highly overall. This would suggest that there should be an emphasis on producing and harvesting feedstock, as well as investing in R&D to increase the productivity of these feedstocks. Although other innovative conversion technologies might prove to be more efficient and cost effective in the future, based on the five future scenarios selected for this analysis, investing in the certified technologies, initiatives x_{14} and x_{15}, are high ranking and robust decisions. Although s_2*: Insufficient supply* is the least disruptive scenario across all initiatives relative to the baseline scenario, agencies should further study the long-term implications of the scenario with regard to possibly diminishing amount of available land for feedstock production.

Table 30. Summary of results for the analysis of biojet fuel initiatives.

Highest ranked initiatives	x_{01}: Invest in R&D of more productive feedstocks
	x_{04}: Cultivate halophyte feedstocks
	x_{08}: Develop collection infrastructure for municipal solid waste (MSW) as feedstock
Lowest ranked initiatives	x_{24}: Commit to biojet fuel purchase agreements
	x_{26}: Encourage user-friendly biofuel accounting methods
	x_{27}: Co-locate bio-refinery with petroleum refinery
	x_{35}: Establish trucking infrastructure for fuel distribution
Greatest increase in rank relative to baseline scenario	x_{24}: Commit to biojet fuel purchase agreements
Greatest decrease in rank relative to baseline scenario	x_{20}: Develop market for co-products
Most disruptive scenario across all initiatives relative to baseline scenario	s_{04}: Green preferences
Least disruptive scenario across all initiatives relative to baseline scenario	s_{05}: Insufficient supply

5.6 Chapter Summary

This chapter has described the application of the methods from Chapter 3 to establishing a biojet fuel industry, with particular consideration given to the concerns of stakeholders in the Commonwealth of Virginia. Section 5.2 has provided the background for this case study. Section 5.3 and 5.4 qualitatively and quantitatively have applied the methodology. Section 5.5 has discussed the results of the case study. The results of this demonstration can inform decision-makers as to which single scenario or combination of emergent conditions has the most influence on the relative attractiveness of biojet fuel initiatives.

6 DISCUSSION

6.1 Overview

This chapter will discuss the results and findings from the two case studies described in the previous chapters, highlighting surprising combinations of emergent conditions and future scenarios that affect decision maker priorities. This chapter will also discuss weaknesses or issues revealed during the analysis.

6.2 Findings and Considerations

For both case studies, this methodology considers scenarios based on behavior, infrastructure, and economic development, among others. Systems engineering is unique in integrating these viewpoints and scenarios into a single decision-aiding tool that can inform a variety of decision-makers. Table 31 describes the elements that are similar to both of the case studies.

The first case study, of emergency preparedness initiatives, highlighted the need for the Brazilian government to plan for the 2014 FIFA World Cup, as this scenario cause the most disruption to the prioritization of initiatives. Interestingly, the World Cup scenario was more influential in prioritization of initiatives than the 2016 Olympics, possibly due to the inclusion of the emergent condition characterizing a lack of trust in public information. One might consider investigating how other scenarios including that same emergent condition would influence the prioritization of planning initiatives.

The ranking of biojet fuel initiatives appears to be more robust than those in the emergency preparedness case study. The five scenarios considered in the second case study all showed similar average disruptions to the prioritization of initiatives. Further investigation of combinations of emergent conditions could reveal disruptive scenarios on par with those considered for disaster preparedness.

One can consider the effect of the choice of weights used in the case studies. The choices of weights made for these two applications were based on similar works (Parlak et al. 2012; Karvetski et al. 2011a; Karvetski et al. 2011b). This thesis focuses on investigating the influence of scenarios of combinations of emergent conditions, thus emphasizing the development of criteria, initiatives, emergent conditions, and future scenarios. As such, the methodology is applied using one set of weights, but weights can be varied according to stakeholder preference. Using a different set of weights can effect priorities and robustness of initiatives, and hence the disruptiveness of scenarios.

One can also consider the robustness of the technical approach. Roy (2010) describes the robustness of decision aiding models. The instability of the system of values used to create and exploit decision aiding models causes a gap between the formal representation of a model or tool and the “real-life context” of the results. Without the pretense of exhaustivity, the criteria, initiatives, and emergent conditions described for each case study in Chapters 4 and 5 are adaptable for different stakeholder values. Thusly, the results of both case studies are not assumed, or intended, to be robust to changes in the system of values.

[Planned expansion as a result of discussion with committee.]

6.3 Chapter Summary

This chapter has commented on the findings from the case studies, pointing out the difference in degree of influence of scenarios between the two case studies. This chapter has also discussed weaknesses or limitations regarding the analysis.

Table 31. Comparison of the elements of methodology for two case studies

Elements of Methodology	Case Study I	Case Study II
Criteria	Performance criteria used for disaster preparedness decision-making, as established by Parlak et al. (2012)	Vital elements that must be considered for a biojet fuel industry to be technically feasible and economically viable
Initiatives	Investment alternatives for building a more robust disaster preparedness supply chain	Courses of action related to investment decisions on feedstock, technology, and infrastructure investment to develop a biojet fuel industry
Scenarios	Disaster scenarios that result from a combination of emergent conditions related to possible states of the environment, population, and infrastructure.	Future scenarios that result from a combination of emergent conditions related to uncertain economic, regulatory, behavioral and agricultural changes and conditions

7 CONCLUSIONS

7.1 Overview

This chapter will provide a summary of accomplishments, the intellectual contributions, and the recommendations for future work.

7.2 Summary of Accomplishments

This thesis has demonstrated the identification of impactful scenarios for two case studies, emergency preparedness and biofuel industry. It provides a scenario-based supply chain management for (i) disaster preparedness and response and (ii) establishing a biofuel industry.

The methods are applied to the preservation of disaster response investment initiatives for emergency management agencies in Brazil. With safety concerns related to the upcoming 2014 FIFA World Cup and the 2016 Olympics, scenario-based prioritization is necessary to promote security of emergency management supply chain operations in Brazil. This analysis results in revealing which emergent conditions have the greatest, or least, impact on the prioritization of disaster preparedness initiatives.

The methods are also applied to the development of a biofuel, specifically biojet fuel, industry. Due to concerns about the future of petroleum fuel supply and associated pricing in addition to climate change implications, scenario-based prioritization is necessary for the future of civil and military aviation. The analysis reveals the future scenarios that matter the most to biofuel development.

7.3 Contributions

The integration of scenario analysis and multi-criteria analysis allows decision makers to assess how priorities change as a result of various scenarios, identify scenarios that are most impactful to priorities, identify scenarios that are least impactful to priorities, and identify decision alternatives that are most robust to scenarios.

The contributions of this thesis are:

- Refined and tested an existing method of scenario-based preferences analysis to identify scenarios of particular concern for two new application areas: biojet fuel industry in Virginia, and disaster planning in Brazil (Chapters 4 and 5)
- Identified ten criteria for which agencies and organizations in Rio de Janeiro can evaluate emergency planning initiatives and policies (Sections 4.2 and 4.3)
- Identified thirty-seven preparedness initiatives for emergency and disaster planning in Rio de Janeiro (Section 4.3, Appendix E)
- Identified nineteen emergent conditions of importance to emergency planning (Sections 4.2 and 4.3)
- Tested the priorities for the preparedness initiatives via scenario-based preferences with six scenarios that are combinations of the emergent conditions (Sections 4.3 and 4.4)

- Identified six criteria by which stakeholders in the Commonwealth of Virginia can evaluate actions, decisions, and other initiatives to develop a regional biojet fuel industry (Sections 5.2 and 5.3, Appendices F and G)
- Identified thirty-seven initiatives for building a biojet fuel industry, considering six stages of the supply chain (Sections 5.2 and 5.3)
- Identified twenty-five emergent conditions of importance to farmers, fuel producers, airlines, airports, and travelers, among others (Sections 5.2 and 5.3, Appendices A and D)
- Constructed five future scenarios of concern to these stakeholders (Section 5.3, Appendix D)
- Tested the priorities for the biofuel initiatives with scenario-based preferences for the five scenarios that are combinations of the emergent conditions (Section 5.4)
- Discovered for each case study which scenarios have the most influence on prioritization of initiatives, and suggested that investigation of these scenarios could be of relatively high value going forward (Sections 4.5 and 5.5)
- Performed a systematic comparison of elements of the two case studies and thereby accumulated important new experience for the application of an existing method that applies scenario-based preferences to a process of risk identification (Section 6.2)

This effort provides decision support for emergency management agencies to preserve supply chain operations in response to disaster scenarios. The methods are adaptable for humanitarian relief organization investment, regional disaster analysis, and private sector supply chain protection.

This effort provides decision support for the DOAV and other stakeholders to preserve aviation operations in response to scenarios of emergent future conditions. The methods are adaptable for other development of other alternative liquid fuels and in other regions or countries.

7.4 Future Work

Future related research will include: (1) Decision-making methods to utilize advancements in information-sharing for increased coordination and recognition of shared objectives, (2) Methods to promote the protection of vulnerable infrastructure through big-data analytic techniques, and (3) Methods for coordinating public dissemination of research on the benefits from innovative technologies. These three general areas can be applied to the two case studies presented in this thesis or to other areas of study that can benefit from integrating scenarios based on behavior, infrastructure, and economic development, among others, into a single decision-aiding tool that can inform a variety of decision makers. In particular, integration of multi-criteria decision analysis with life-cycle assessment could further aid decision makers in the biofuel industry, among others, by moving beyond a strictly deterministic analysis.

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APPENDIX A: DIAGRAM OF APPROVED BIOJET CONVERSION PROCESSES

This appendix contains process diagrams of Fischer-Tropsch and HEFA conversion processes, which have been approved by ASTM standard D7566 as a 50:50 biojet fuel to conventional jet fuel blend.

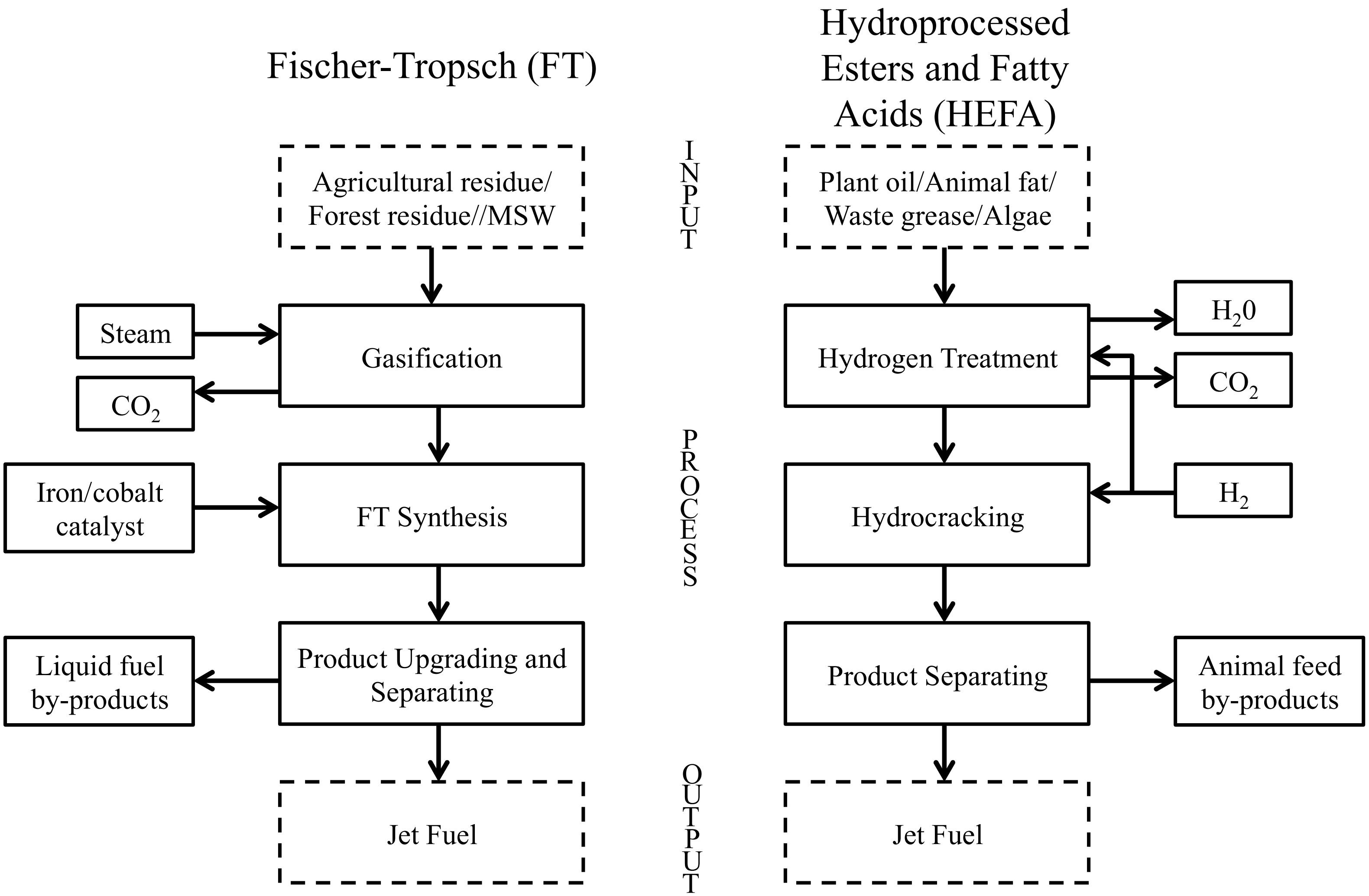


Figure 11. Diagram of feedstock inputs, processes, and outputs from Fischer-Tropsch and hydroprocessed esters and fatty acids (HEFA) biojet conversion processes.

APPENDIX B: LIST OF BIOJET FUEL TEST FLIGHTS

This appendix contains a table listing major test flights using some percentage of biojet fuel. The table lists the organization(s) responsible and the feedstock for the biojet fuel.

Table 31. Chronology of notable biojet fuel test flights. Sources: Rosillo-Calle et al. 2012; Fan et al. 2013; Zhi 2013.

Airline	Partner	Date	Feed	Blend
Virgin Atlantic	Boeing, GE	Feb 23, 2008	Coconut & Babassu	20% (one engine)
Air New Zealand (ANZ)	Honeywell/UOP, Boeing, Rolls Royce, Terasol	Dec 30, 2008	Jatropha	50% (one engine)
Continental Airlines (CAL)	Honeywell/UOP, Boeing, CFM, Sapphire	Jan 7, 2009	Jatropha & Algae	50% (one engine)
Japan Airlines (JAL)	Honeywell/UOP, Boeing, Pratt & Whitney, Sustainable Oils	Jan 30, 2009	Jatropha & Algae	50% (one engine)
KLM	Honeywell/UOP, Boeing, GE	Nov 23, 2009	Camelina	50% (one engine)
TAM, Brazil	Honeywell/UOP, Airbus, CFM	Nov 23, 2010	Jatropha	50%
Interjet, Mexico	Honeywell/UOP, Airbus, CFM	Apr 01, 2011	Jatropha	30%
Honeywell, USA (Corporate Jet)	Honeywell/UOP, Gulfstream, Sustainable Oils	Jun 17, 2011	Camelina	50%
Boeing, USA	Honeywell/UOP, Boeing, Sustainable Oils	Jun 19, 2011	Camelina	50%

Interjet, Mexico	Honeywell/UOP, Airbus,	Jul 21, 2011	Jatropha	50%
Aeroméxico	Honeywell/UOP, Boeing, GE	Aug 2, 2011	Jatropha	30%
National Research Council of Canada	Applied Research Associates, Chevron Lummus Global and Agrisoma Biosciences Inc.	Oct 29, 2012	Agrisoma Resonance™	100%
China Eastern Airlines	Sinopec	Apr 24, 2013	Palm oil & cooking oil	50%

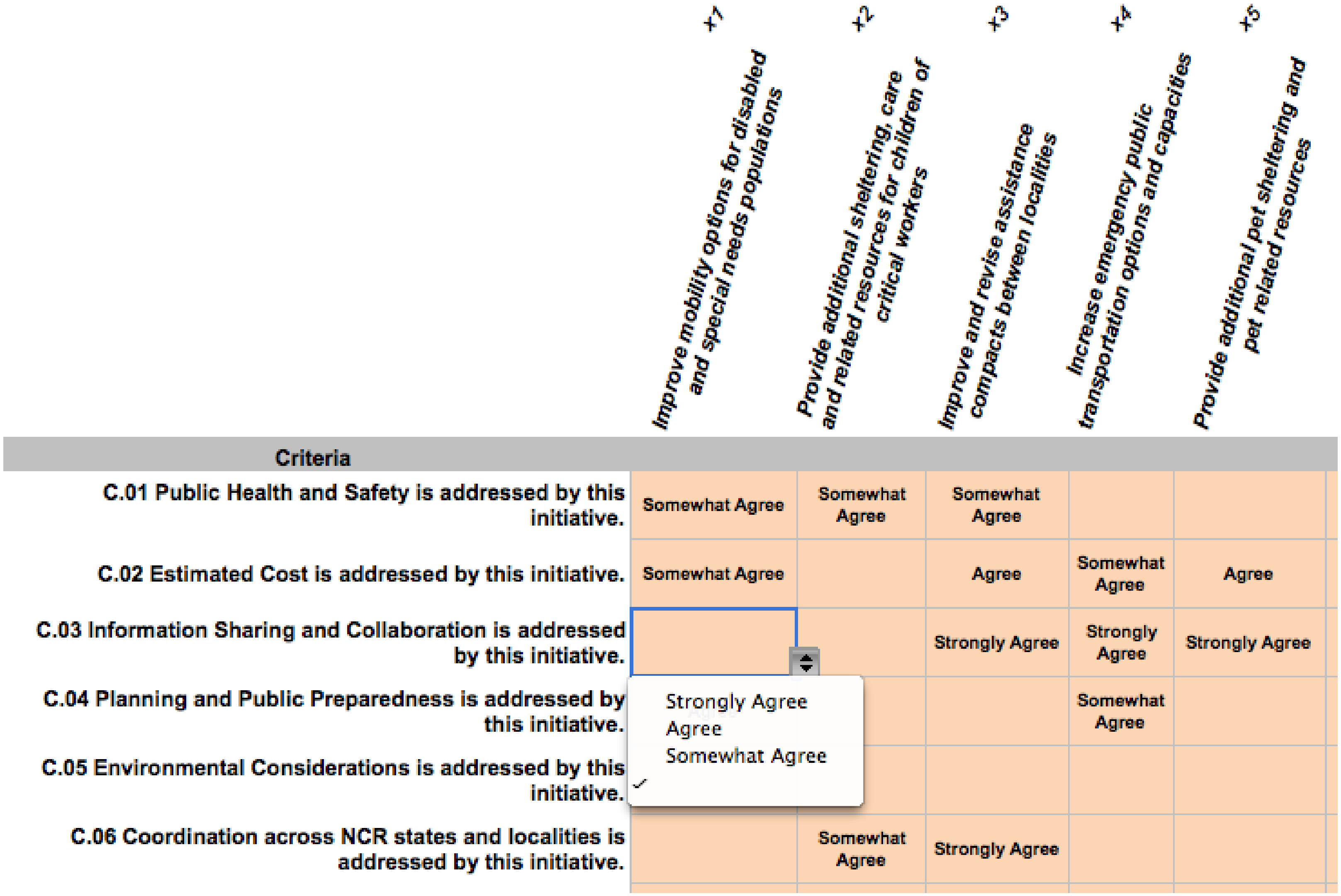
APPENDIX C: DESIGN FEATURES OF A WORKBOOK IMPLEMENTING SCENARIO ANALYSIS

This appendix contains figures from an Excel workbook applying the methodology described in Chapter 3 to Brazil disaster preparedness, as a preliminary analysis for the case study in Chapter 4. The same features are also used for the analysis of the biojet fuel case study in Chapter 5.

		100%	
The criterion C.01 Public Health and Safety has	***high importance***	**15%**	***among the other criteria.***
The criterion C.02 Estimated Cost has	***high importance***	**15%**	***among the other criteria.***
The criterion C.03 Information Sharing and Collaboration has	***medium importance***	**7%**	***among the other criteria.***
The criterion C.04 Planning and Public Preparedness has	***medium importance***	**15%**	***among the other criteria.***
The criterion C.05 Environmental Considerations has	***high importance***	**15%**	***among the other criteria.***
The criterion C.06 Coordination across NCR states and localities has	***low importance***	**7%**	***among the other criteria.***
The criterion C.07 Coordination across emergency support functions has	***low importance***	**7%**	***among the other criteria.***
The criterion C.08 Capacities for mass sheltering and evacuation at multiple geographic and temporal scales has	***medium importance***	**7%**	***among the other criteria.***
The criterion C.09 Effective role and performance of the private sector has	***medium importance***	**7%**	***among the other criteria.***
The criterion C.10 Innovation, learning, and adaptation in emergency management has	***medium importance***	**7%**	***among the other criteria.***
The criterion C11. tbd has		**0%**	***among the other criteria.***
The criterion C12. tbd has		**0%**	***among the other criteria.***

high importance
medium importance
low importance
no importance

Figure 12. Worksheet assessing the influence of criteria in the *as-planned* scenario. The normalized weight is based on the selection of influence from the pull-down options of *high*, *medium*, *low*, or *no* influence.

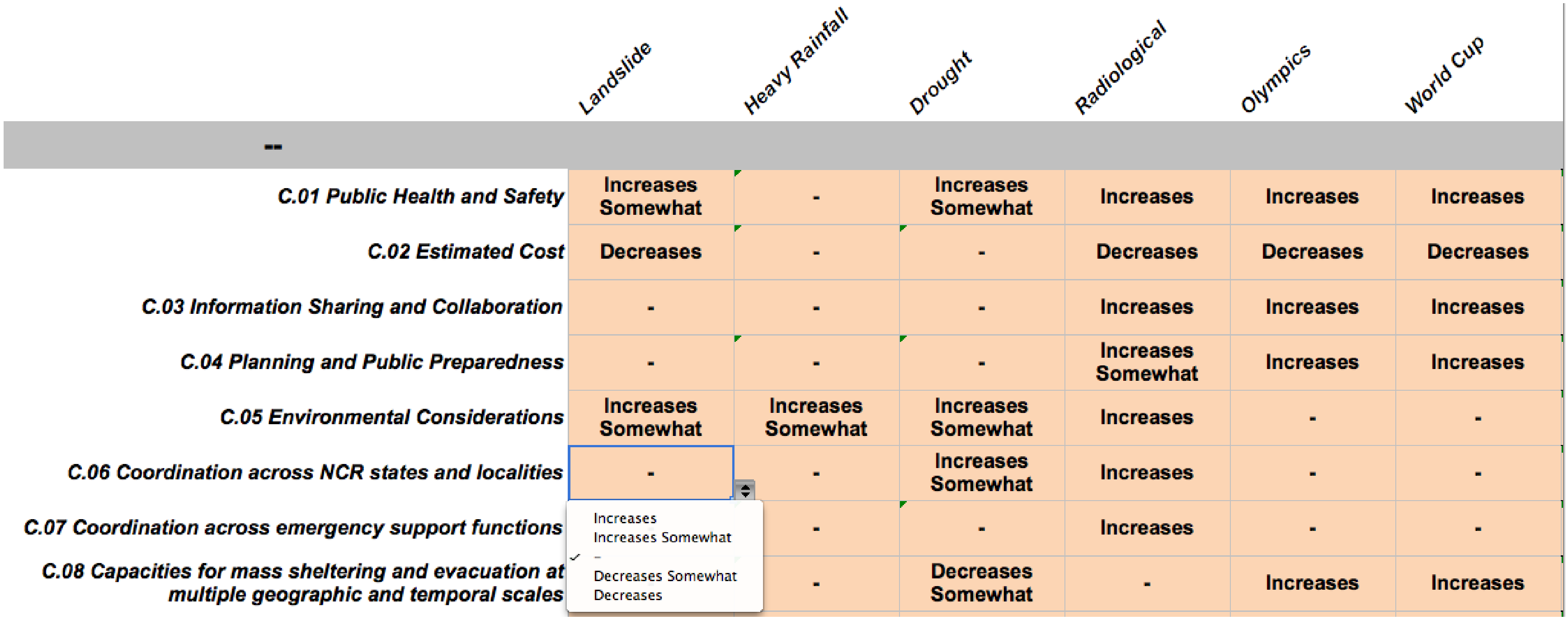


Criteria	x1 Improve mobility options for disabled and special needs populations	x2 Provide additional sheltering, care and related resources for children of critical workers	x3 Improve and revise assistance compacts between localities	x4 Increase emergency public transportation options and capacities	x5 Provide additional pet sheltering and pet related resources
C.01 Public Health and Safety is addressed by this initiative.	Somewhat Agree	Somewhat Agree	Somewhat Agree		
C.02 Estimated Cost is addressed by this initiative.	Somewhat Agree		Agree	Somewhat Agree	Agree
C.03 Information Sharing and Collaboration is addressed by this initiative.			Strongly Agree	Strongly Agree	Strongly Agree
C.04 Planning and Public Preparedness is addressed by this initiative.				Somewhat Agree	
C.05 Environmental Considerations is addressed by this initiative.					
C.06 Coordination across NCR states and localities is addressed by this initiative.		Somewhat Agree	Strongly Agree		

Figure 13. Worksheet evaluating how each initiative x_i addresses each criterion c_j. The selection of strongly agree, agree, somewhat agree, or no agreement are used to create the *A* matrix described in Chapter 3.

Emergent Conditions		Landslide	Heavy Rainfall	Drought	Radiological	Olymipics	World Cup
		Scenarios					
EC.01	Lack of confidence in public information sources	☐	☐	☐	☐	☐	☑
EC.02	Lack of accessibility to public information sources	☐	☐	☐	☐	☐	☐
EC.03	Increased area tourism	☐	☐	☐	☐	☑	☑
EC.04	Increased favela population	☐	☐	☐	☐	☐	☐
EC.05	Decreased favela population	☐	☐	☐	☐	☐	☐
EC.06	Improved favela housing conditions	☐	☐	☐	☐	☐	☐
EC.07	Drought	☐	☐	☑	☐	☐	☐
EC.08	Flood affecting favela areas	☐	☑	☐	☐	☐	☐
EC.09	Flood affecting non-favela areas	☐	☐	☐	☐	☐	☐
EC.10	Landslide affecting favela areas	☑	☐	☐	☐	☐	☐
EC.11	Landslide affecting non-favela areas	☐	☐	☐	☐	☐	☐
EC.12	"Walking wounded"	☐	☐	☐	☑	☐	☑
EC.13	"Worried-well"	☐	☐	☐	☑	☐	☐
EC.14	Power outages	☐	☑	☐	☐	☑	☐
EC.15	Telephone systems overloaded	☐	☐	☐	☐	☐	☐
EC.16	Emergency relief straining budget	☐	☐	☐	☑	☐	☐
EC.17	Destruction of homes	☑	☐	☐	☐	☐	☐

Figure 14. Worksheet combining emergent conditions to create future scenarios. The scenarios correspond to the set evaluated in Chapter 4.



--	Landslide	Heavy Rainfall	Drought	Radiological	Olympics	World Cup
C.01 Public Health and Safety	Increases Somewhat	-	Increases Somewhat	Increases	Increases	Increases
C.02 Estimated Cost	Decreases	-	-	Decreases	Decreases	Decreases
C.03 Information Sharing and Collaboration	-	-	-	Increases	Increases	Increases
C.04 Planning and Public Preparedness	-	-	-	Increases Somewhat	Increases	Increases
C.05 Environmental Considerations	Increases Somewhat	Increases Somewhat	Increases Somewhat	Increases	-	-
C.06 Coordination across NCR states and localities	-	-	Increases Somewhat	Increases	-	-
C.07 Coordination across emergency support functions	[illegible]	-	-	Increases	-	-
C.08 Capacities for mass sheltering and evacuation at multiple geographic and temporal scales	[illegible]	-	Decreases Somewhat	-	Increases	Increases

Figure 15. Worksheet reassessing the influence of each criterion under each scenario.

APPENDIX D: VIRGINIA DEPARTMENT OF AVIATION DRAFT "SCOPE OF WORK" FOR RESEARCH PROJECT ON BIOJET FUEL INDUSTRY IN VIRGINIA

This appendix contains the draft scope of work from the DOAV to the Virginia Center for Transportation Innovation and Research (VCTIR). This request for the “Analysis of the Commercial Viability of the Bio-Jet Fuel Industry in Virginia” is the purpose and motivation of the case study in Chapter 5 of this thesis.

Draft Scope of Work
Analysis of the Commercial Viability of the Bio-Jet Fuel Industry in Virginia

August 28, 2012

Request

The Virginia Department of Aviation (DOAV) requests the Virginia Center for Transportation Innovation and Research (VCTIR) to conduct a cost/benefit analysis to determine if there is a sufficient commercial business case and return on investment for Virginia to support and potentially financially invest in the development of the bio-jet fuels industry in the Commonwealth.

Background

Virginia's system of 66 public-use airports provides the Commonwealth with safe and efficient means of transportation as well as stimulates economic growth and development. Virginia's airports contributed $28.8 billion in economic activity to the Virginia economy, which represents 4.4 percent of the state's total economic output. Much of this activity ($20.5B economic activity /209K jobs) is generated by the Commonwealth's nine commercial service airports where more than 69,000 people each day board commercial aircraft. In order for Virginia to continue to benefit from the economic activity its commercial service airports produce the commercial service airports must remain competitive domestically and internationally. To this end, it is imperative that Virginia remain on the leading edge of new technologies, including enhancement of energy security and environmental sustainability in order to foster the growth of the air transport industry in Virginia and the country.

The future success and growth of the air transport industry is directly tied to the control of operating costs--- with fuel costs, supply concerns and environmental policies being at the forefront. For some time there has been a desire globally to develop and deploy sustainable alternative fuels for commercial aviation. In recent years the air transport industry has moved alternative fuels as an aspirational concept to operational reality. With the approval by the U.S. government of airlines (United Airlines and Alaska Airlines) to use "drop-in" bio-jet fuels the airline industry is on the cusp of a major expansion of operational use of sustainable alternative jet fuels in the U.S. and globally.

By "drop-in," the air transport industry means their bio-jet fuel is indistinguishable from current (fossil) fuels and can be mixed with Jet-A (which civil aviation uses) in any ratio and the mixture can then flow through the same delivery infrastructure and used in existing aircraft without modification. The feedstock for the drop-in bio-jet fuel can range from switch-grass, one of the favored feedstock crops that will, we believe, grow on old tobacco fields, to Municipal Solid Waste, i.e. MSW or trash. Production to date has been in small pilot quantities. The air transport industry now is working to stimulate large scale availability between major gateway airports.

With the demonstrated success by the airline industry, the viability of the "drop-in" bio-jet fuel is not an issue. The commercial viability of its production and distribution in the Virginia business environment is the question. In short, for the Commonwealth to support the development of bio-jet fuel industry in Virginia and potentially make a substantial financial commitment the return on investment for the agriculture and transportation sectors, prospective investors and taxpayers needs to be better understood.

Methodology and Scope

The requirement is to provide the administration a cost/benefit analysis with key decision information prior to the beginning for the 2013 General Assembly. DOAV is requesting VCTIR to conduct the appropriate level of research to answer the questions denoted below. Because of the challenging short research period it is understood VCTIR will have to rely on exiting research for bio-jet fuels and input from individuals currently working in the bio-jet fuels industry.

To assist VCTIR, it is proposed a study advisory group (SAG) be formed consisting of industry, academic and government professionals conducting work in the field to help guide the research and serve as a resource for VCTIR. In developing this scope of work several professionals have volunteered to serve on the proposed SAG.

Tasks

The principal focus of this research request is a cost/ benefit analysis that gives the Commonwealth decision makers the detail necessary to make wise business decisions regarding the Commonwealth's investment in this new capability for the aviation community and potential new opportunity for Virginia's agriculture and waste management communities.

1. Would the production of "drop-in" bio-jet fuel be commercially attractive in the Virginia business environment?
   a) What is the commercially viable price range for the air carriers?
   b) What is the range for production costs?
   c) Therefore, what can the processing company pay for:
      - Crops/biomass
      - Municipal solid waste
   d) Does Virginia have any usable production capacity which may be well sized to meet the initial demand for example? There is an unused ethanol refinery (Osage bio energy) at Hopewell, for example.
   e) What is the civil aviation market demand:
      - At Washington Dulles International Airport
      - Within the Commonwealth
      - Along the pipeline corridor, which passes through Virginia
   f) What is the capability of the fuel handling companies for storage of bio jet fuel and the capacity in the existing transport systems (colonial / plantation pipelines) to move bio jet fuel?
   g) Where are the sources of raw materials (switch grass, trash, cottonwood trees etc) for bio jet fuel within the Commonwealth first and out of state secondary sources?
   h) What loan guarantees or other risk reduction programs are available from the Federal Government?

2. What are the economics of production, and would the price that could be charged for Virginia-produced Jet-A be commercially attractive for the air transport industry?

3. Is there a substantial commercial business case for Virginia to purse investment in bio-jet fuels at this time?

4. What is the potential to create new Virginia Jobs?

5. What are the down side risks?

APPENDIX E: EXCERPT FROM BRAZIL PROGRESS REPORT ON THE IMPLEMENTATION OF THE HYOGO FRAMEWORK FOR ACTION

This appendix contains an excerpt from the *National progress report on the implementation of the Hyogo Framework for Action* prepared by the SEDEC. The report addresses to what extent Brazilian policies have met the priorities for action in the *Hyogo Framework*. The following excerpt describes the challenges Brazil faces in improving in three strategic goal areas.

Future outlook

Area 1

The more effective integration of disaster risk considerations into sustainable development policies, planning and programming at all levels, with a special emphasis on disaster prevention, mitigation, preparedness and vulnerability reduction.

Overall Challenges:
Realização de eventos técnicos para elaborar e aperfeiçoar planos de contingências para o enfrentamento da maior frequência e intensidade de desastres naturais provocados pelas mudanças climáticas . Análise de estudos e pesquisas concentrados no âmbito federal (SINDEC) e difusão das informações pertinentes para órgãos de Defesa Civil estaduais e municipais, com o objetivo de apoiar o estudo e o mapeamento das áreas nas quais há riscos de desastres e de elaborar mapas temáticos sobre as vulnerabilidades dessas áreas em relação às mudanças climáticas.

Future Outlook Statement:
Promover o conhecimento dos efeitos das Mudanças Climáticas aos Órgãos Estaduais, Municipais e comunitários de Defesa Civil, com vistas a orientá-los e assessorá-los sobre os impactos dessas mudanças, avaliando os riscos e a conseqüente minimização dos desastres relacionados.

Area 2

The development and strengthening of institutions, mechanisms and capacities at all levels, in particular at the community level, that can systematically contribute to building resilience to hazards.

Overall Challenges:
: Apoiar a realização de ações de caráter preventivo destinadas a reduzir a ocorrência e a intensidade dos desastres com ações estruturais e não estruturais. Essas medidas referem-se ao planejamento da ocupação do espaço geográfico e à execução de obras e serviços, principalmente relacionados com intervenções em áreas de risco, tais como, dentre outras: aquisição e instalação de equipamentos, infraestrutura urbana e rural; estabilização de encostas, contenção de erosões, relocação de famílias de áreas de risco, prestação de serviços essenciais, proteção do patrimônio público e demais ações que visem diminuir a vulnerabilidade da população aos desastres, em complementação à atuação Municipal e Estadual.

Future Outlook Statement:
Evitar e/ou reduzir perdas e danos provocados por desastres, com ações estruturantes e não estruturantes, visando a minimização de recursos alocados como decorrência de demandas emergenciais, bem como o acompanhamento e avaliação da aplicação destes recursos na verdadeira diminuição da vulnerabilidade das populações beneficiadas.

Area 3

The systematic incorporation of risk reduction approaches into the design and implementation of emergency preparedness, response and recovery programmes in the reconstruction of affected communities.

Overall Challenges:
: Auxílio Emergencial Financeiro para pessoas afetadas por desastres, além de: ações de socorro, como: evacuação das populações em risco, combate aos sinistros, busca e salvamento, primeiros

APPENDIX F: EXECUTIVE SUMMARY FROM THE WHITE HOUSE (2011)

BLUEPRINT FOR A SECURE ENERGY FUTURE

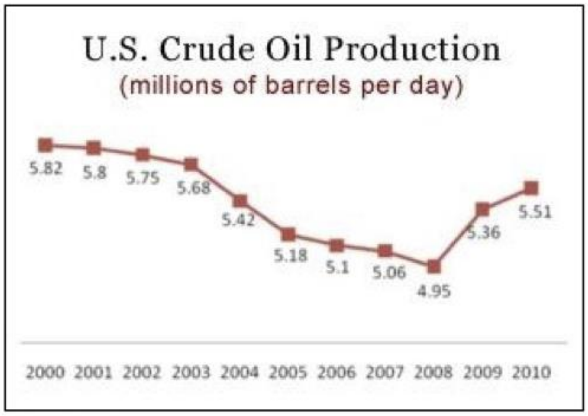
This appendix contains the executive summary from The White House (2011) *Blueprint for a Secure Energy Future* which was used for the biojet fuel criteria in Chapter 5. The report outlines a three-part strategy to meet the goal of energy independence, with an emphasis on clean energy technologies.

Executive Summary: *Blueprint for a Secure Energy Future*

Develop and Secure America's Energy Resources

Expand Safe and Responsible Domestic Oil and Gas Development and Production

Even as we develop next generation energy technologies, we will continue to rely on oil and gas.



Source: EIA

Last year, U.S. crude production reached its highest level since 2003. But we must ensure that production is safe, responsible, and efficient. In the wake of *Deepwater Horizon*, the Administration has reformed safety and environmental standards for oil and gas exploration, making structural reforms within the Department of the Interior to improve oversight. At the same time, we are encouraging exploration, development, and production—rewarding industry for effectively and responsibly utilizing resources that belong to the American people. Additionally, we are encouraging the exploration of new frontiers of production and of new ways to safely make use of domestic assets like our vast reserves of natural gas.

Lead the World Towards Safer and More Secure Energy Supplies

We know that markets are global. The recent crude oil price increases, which translate into higher prices at the pump, have many causes, including the global economic recovery and unrest in the Middle East. But a major cause of the recent price rise is the concern that global oil demand will outpace supply over the next few years. The dependence of the global vehicle fleet on oil makes this problem especially acute. That's why we are working to reduce oil demand and increase reliable supplies of oil around the world in the years ahead, as we also work to diversify the fuel mix in our vehicle fleets. We have already taken, and will take more, steps at home both to reduce oil demand through efficiency, technology, and conservation and to increase domestic production in a manner that is safe and protects our environment. We are also acting in the international arena to moderate global oil demand and secure additional supplies of liquid fuels.

Provide Consumers with Choices to Reduce Costs and Save Energy

Reduce Consumer Costs at the Pump with More Efficient Cars and Trucks

Transportation is the second costliest expense for most American households, and it's responsible for more than 70 percent of our petroleum consumption. So, one of the best ways to make our economy less dependent on oil – and save consumers money – is simply to make our transportation more efficient. Since taking office, President Obama has taken bold steps to transform these challenges into opportunities across the transportation sector. These efforts include the historic investments in advanced vehicle and fuel technologies, public transit, and high speed rail under the Recovery Act, as well as the ambitious new fuel economy standards put into place for cars and trucks – which will raise average fuel economy to 35.5 miles per gallon by 2016, and save 1.8 billion barrels of oil over the lifetime of the vehicles covered. These actions are already helping to lower transportation costs by reducing our dependence on oil, provide more transportation choices to the American people, and revitalize the U.S. manufacturing sector.

But we need a sustained effort, which is why the President set an ambitious goal that by 2015 we would have 1 million electric vehicles on the road, becoming the world's leader in advance vehicle technologies. To help reach this goal, the President is proposing bold steps to improve the efficiency of all modes of transportation, from air to highways to rail to water, and to develop alternative fuels. He is continuing to push forward on fuel economy standards for cars and trucks. He has proposed to speed the adoption of electric vehicles with new more effective tax credits for consumers and support for communities that create an environment for widespread adoption of these advanced vehicles in the near term. And he is taking steps to encourage increased use of biofuels.

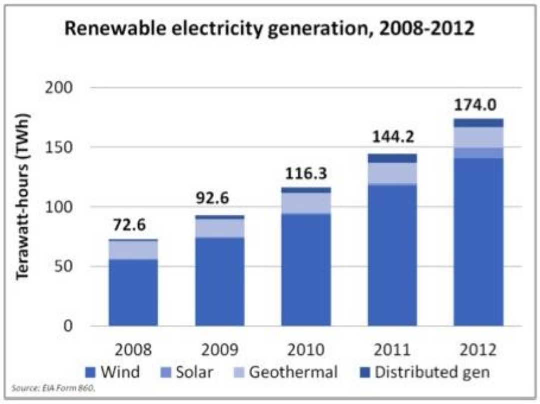
Cut Energy Bills with More Efficient Homes and Buildings

Our homes, businesses and factories account for more than 70 percent of the energy we consume, and we need to invest in energy efficiency in the residential, commercial, and industrial sectors to improve U.S. competitiveness, lower electricity bills, and protect our environment. This is why the President has laid out a bold vision for sparking a new home-grown industry in making our homes, buildings, and factories more energy efficient. The President's plan lays a foundation for the private sector to dramatically scale up investments and reap the enormous benefits that come with greater energy efficiency. Because there is no "one size fits all" solution, the Administration is supporting a variety of programs that are tailored to the unique challenges of each sector and will leverage public dollars to encourage private sector investment and job creation. Building on efficiency investments in the Recovery Act , which have already led to the weatherization of about 350,000 projects that are helping lower income Americans reduce energy bills, the Administration's ongoing efficiency agenda crosses sectors. It includes an ongoing commitment to passing HOMESTAR legislation to will help homeowners finance retrofits, a "Better Buildings Initiative" to make commercial facilities 20 percent more efficient by 2020, and a range of steps to promote industrial efficiency.

Innovate Our Way to a Clean Energy Future

Harness America's Clean Energy Potential

A global race is underway to develop and manufacture clean energy technologies, and China and other countries are playing to win. To rise to this challenge, we need to tap into the greatest resource we have: American ingenuity. We have the most dynamic economy in the world, and there is no reason we can't lead the world. But clean energy innovation, and the jobs that come with it, don't just happen. That's why, in his State of the Union address, President Obama proposed an ambitious but achievable standard for America: By 2035, we will generate 80 percent of our electricity from a diverse set of clean energy sources – including renewable energy sources like wind,



solar, biomass, and hydropower; nuclear power; efficient natural gas; and clean coal. A Clean Energy Standard (CES) will provide the signal investors need to move billions of dollars of capital off of the sidelines and into the clean energy economy, creating jobs across the country and reducing air pollution and greenhouse gas emissions.

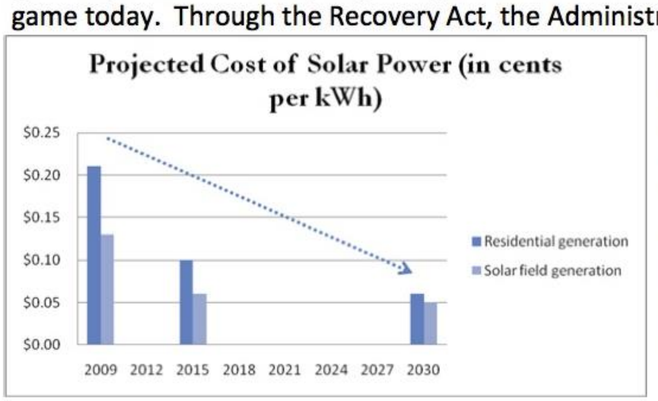
We're already making great strides in this direction. Agencies across the Federal government, including the Departments of Energy, Agriculture, and the Interior, are working to promote clean energy deployment by offering grants under the Recovery Act to renewable energy manufacturers and developers; funding cutting-edge R&D; modernizing our rural energy infrastructure; siting the world's largest solar power plants on public lands; and opening a new frontier for offshore wind development. Thanks to these concerted efforts, we are on track to double renewable energy generation by 2012.

Looking ahead, meeting the President's target will position the United States as a global leader in developing and manufacturing cutting-edge clean energy technologies. It will ensure continued growth in the renewable energy sector, building on the progress made in recent years. And it will spur innovation and investment in our nation's energy infrastructure, creating American jobs.

Creating a market for new technologies will be central to charting a path to a clean energy future – but there is more we need to do. For that reason, the Administration is also advancing policies that will help to modernize the electric power grid while ensuring a safe and reliable power plant fleet.

Win the Future Through Clean Energy Research and Development

Maintaining our leadership in research and development is critical to winning the future and deploying innovative technologies that will create quality jobs and move towards clean energy economy that reduces our reliance on oil. But as we aspire to achieve new breakthroughs – a battery that will take a car 300 miles on a single charge or a way to turn sunlight into fuel like gasoline, we area already beginning to see how our investments in the future are changing the game today. Through the Recovery Act, the Administration has invested in a host of clean energy



Source: DOE

programs and ultimately supported thousands of projects across the country targeted at the demonstration of clean energy projects in every state. The Recovery Act investments include funding the Advanced Research Project Agency-Energy (ARPA-E) for the first time ever, a program that helps projects move from idea to implementation. Today, some of these aspirations have penetrated the market – like "1366 Technologies," a small Massachusetts startup that received a $4 million ARPA-E grant to develop solar panel components for 80 percent less than the current cost, and which has since secured $33.4 million in private investment. These kinds of innovations can help us to achieve a "Sunshot" – making new solar technologies cost-competitive and achieving dreams of a clean energy future.

Lead by Example: Clean Energy and the Federal Government

As new technologies emerge, the Federal government has a responsibility to lead by example. Our government owns and manages approximately 500,000 buildings and operates more than 600,000 fleet vehicles. The electricity used for its buildings, the fuel used in its cars and trucks, and the energy required in military operations make it the largest energy consumer in the US economy. That's why President Obama signed an Executive Order that made it the responsibility of every Federal agency to help move the nation towards a clean energy economy by leading by example, practicing what we preach, and improving the government's energy efficiency while expanding our use of clean energy. And that's why the *Blueprint* announces new steps, to improve the Federal fleet's performance so that it is composed entirely of alternative fuel vehicles, is fuel-efficient.

APPENDIX G: EXECUTIVE SUMMARY FROM THE FEDERAL AVIATION ADMINISTRATION (2011) *DESTINATION 2025*

This appendix contains an excerpt from the FAA *Destination 2025* report on the visionary future of aviation with the following aspirations: i) move to the next level of safety, ii) create our workplace of the future, iii) deliver aviation access through innovation, iv) sustain our future, and v) advance global collaboration. The report was used in developing the biojet fuel criteria listed in Chapter 5.

Destination 2025

Executive Summary

The Destination 2025 vision captures the ideal future we strive toward – a transformation of the Nation's aviation system in which air traffic will move safely, swiftly, efficiently, and seamlessly around the globe. Flights will take off and land on time, every time, without delay and there will be no fatal accidents. Air travel will be routine and uneventful for everyone involved: passengers, crews, ground support, and communities. Costs will be contained for both operators and passengers, and there will be no negative impact to the environment. Manned and unmanned flights will each achieve safe flight, as will commercial launches to space. This is a vision that captures the future we will strive to achieve – to transform the Nation's aviation system by 2025.

The Federal Aviation Administration's mission is to provide the safest, most efficient aviation system in the world. What sets us apart is the size and complexity of our infrastructure, the diversity of our user groups, our commitment to safety and excellence, and our history of innovation and leadership in the world's aviation community. Now we are working to develop new systems and to enhance a culture that increases the safety, reliability, efficiency, capacity, and environmental performance of our aviation system. To meet our vision will require enhanced skills, clear communication, strong leadership, effective management, innovative technology, new equipment, advanced system oversight, and global integration.

Our primary focus in the past was increasing the safety of the aviation system and providing the necessary capacity. Working together with our industry counterparts, we have been very successful. Since the mid-1990s, the number of commercial air carrier fatal accidents has decreased nearly 80 percent. Since 2000, new runways have opened at 16 large and medium hub airports, providing these airports with the potential to accommodate more than 2 million annual operations. We have enhanced our own performance, putting in place internal acquisition, planning, and financial systems and processes that have helped us account for and save taxpayers' money. We have also helped shape the growth of the global aviation system and the access and opportunity afforded U.S. citizens. Yet, there is still more to be done.

The Federal Aviation Administration's mission is to provide the safest, most efficient aviation system in the world.

Building on this solid foundation, the FAA is heading into a time of unprecedented challenges as we work to adapt to a rapidly changing aviation system in the presence of changing economic, social, environmental, and energy needs of both our nation and our global partners. Like the rest of the federal government, the FAA faces significant budget pressures that will shape our ability to maintain today's system and respond to tomorrow's demands. The FAA must see the opportunities within these challenges that will enable aviation to be a transportation choice that provides the traveling public, U.S. business and our global partners with safe, secure, reliable, and environmentally sustainable air travel. Our vehicle for providing opportunities during this transformation is the Next Generation Air Transportation System (NextGen).

NextGen is a series of inter-linked programs, systems, and policies that implement advanced technologies and capabilities to dramatically change the way the current aviation system is operated. NextGen is satellite-based and relies on a network to share information and digital communications so all users of the system are aware of other users' precise locations. It will make U.S. aviation safer, reduce delays, and mitigate impacts on the environment. The system responds quickly as the types and performance of aircraft change and as weather and routes change and congestion occurs. Hazards are identified and their associated risk mitigated before they result in incidents or accidents. NextGen combines changes to the way aircraft are routed, with new, more fuel-efficient technology and improved fuels to reduce aviation's environmental "footprint." NextGen must also extend beyond our domestic airspace and be an integral part of the global aviation system. This will require partnership and collaboration within the FAA, across government, with industry, both domestic and international, and with the International Civil Aviation Organization (ICAO) and its contracting states.

The next 15 years promise to be a pivotal time in the history of air transportation, as the face of aviation is transformed around the world. This is occurring even as we face challenging budget pressures that will shape every aspect of FAA's operations, plans, and workforce. Key components of NextGen programs are already improving access to airports during inclement weather and are providing tangible improvements for passengers and aviation stakeholders today. Setting metrics at 2018 provides us with a waypoint for measuring our progress towards achieving our goals. From flight decks to control towers, our system is already changing. The FAA is committed to ensuring America has the safest, most advanced and efficient, and sustainable aviation system in the world. We must also work to make air transportation safe and efficient wherever U.S. citizens travel.

Our aspirations:

Move to the Next Level of Safety

Safety is FAA's top priority. We will transform the way we assure safety by expanding our safety culture to enhance standards and oversight. We will take action to manage risk by proactively identifying hazards and risk based on continuous analysis of data.

Create Our Workplace of the Future

We can only create the future we envision through the people of the FAA. NextGen will require not only new technology and tools, but a skilled and dedicated workforce. Our continued success depends on creating a workplace of choice with integrity, fairness, diversity, and innovation as our professional hallmarks. We will train and enable our high performance workforce with the adaptive skills and abilities required to reach and sustain the NextGen levels of safety, efficiency, and sustainability.

Deliver Aviation Access through Innovation

We must serve the needs of the traveling public and the aviation industry to provide unencumbered access to the aviation system, whether the destination is domestic or international. We will enhance aviation's value to the public by improving travel throughout the National Airspace System, and beyond. This includes reducing costs and energy use, minimizing delays, preserving and securing needed infrastructure, and matching capacity to demand to increase the economic effectiveness of aviation.

Sustain Our Future

We will advance aviation in an environmentally responsible and energy efficient manner. We will minimize noise and emission impacts on communities, reduce aviation's carbon footprint, invest in new technology, foster sustainable alternative fuels research, and advance other innovations that promote environmentally friendly solutions.

Advance Global Collaboration

We will work with ICAO and other international partners to improve global aviation safety and environmental performance around the world. We will encourage innovation while we work with our international partners to deploy seamless and efficient global air navigation through interoperable standards, procedures, and technologies, and harmonization of certification and regulation.