Locational Determinants for Wood Pellet Plants: A Review and Case Study of North and South America

Damien Singh,[a] Frederick Cubbage,[a] Ronalds Gonzalez,[b] and Robert Abt [a]

The European Union's Renewable Energy Directive has led many electricity producers in Europe to use wood pellets in place of fossil fuels. North America has become one of the primary suppliers of wood pellets to Europe. This paper critically examines literature, economic models and data, as well as the supply chain and country risk factors, related to wood pellet production to anticipate where North and South American pellet mills should be built to meet Europe's demand. Canada, the United States, and Brazil maintain the largest natural forest area, planted forest area, and industrial roundwood production; however, South American countries achieve faster plantation growth rates. The World Bank's Logistic Procurement Index and IHS's Country Risk Index were used to score and rank countries' investment climates, based on their supply chain and risk factors. In this regard, the United States, Canada, and Chile performed best, in contrast to Venezuela, Bolivia, and Ecuador. When considering both wood supply and investment climates, the United States, Canada, and Chile were the most attractive countries to build a pellet mill, while countries, such as Argentina, Brazil, Colombia, Paraguay, and Peru present significant trade-offs between having significant wood resources and riskier investment climates.

Keywords: Wood pellet mill; North America; South America; Wood supply; Supply chain; Country risk; Investment climate

*Contact information: a: Department of Forestry and Environmental Resources, North Carolina State University, Raleigh, NC 27695-8008 USA; b: Department of Forest Biomaterials, North Carolina State University, Raleigh, NC 27695-8008 USA; *Corresponding author:dasinghb@ncsu.edu*

INTRODUCTION

Environmental and natural resource policies can have widespread social, political, and economic implications. The European Union (EU) recently implemented various programs, including the Renewable Energy Directive (RED) and the Emission Trading System (ETS), which mandates its member states to meet a minimum of 20% of their energy needs from renewable and carbon-neutral sources by 2020. In addition, these programs are mandating that by 2030, greenhouse gases (GHG) are to be reduced by 40% and the share of energy from renewable sources should increase to 27%, along with an 80% to 95% reduction in GHG by 2050 (European Commission 2016; European Union 2016; Lamers *et al*. 2014). While these are European-wide objectives, member states maintain their own mandatory targets and are able to design policies suitable to their circumstances, resulting in credit programs and feed-in-tariffs (FiT) that have led to an increase in wood pellet consumption (Table 1). While there are variations in policy design, electricity producers are awarded credits based on how much energy they generate from renewable and/or carbon neutral sources. These are sold to either suppliers, who are required by law to meet specific quotas, or government agencies that provide rebates. Penalty fees are commonly applied if quotas are not met. In contrast, FiTs represent direct subsidies to electricity producers based on the quantity of renewable and carbon neutral sources.

Table 1. Major European Wood Pellet Importers and their Incentive Policies

Country	Wood pellet imports (tons)	Policy	Description
United Kingdom	5,197,497	Renewables Obligation Certificate Program	Renewable Obligation Credits (ROC) are issued by the Office of Gas and Electricity Markets (Ofgem). Suppliers use the ROC's pay-into or buy-out-of-fund (currently set at €44.33/ROC) or a combination of both to meet their obligations (DECC 2015, Ofgem 2015).
Denmark	2,337,764	Feed-in-Tariff	The Danish Energy Agency (DEA) provides subsidies of €20/MWh for electricity produced from wood pellets (USDA 2013).
Italy	2,134,033	Green Certificates	Green Certificates (GC) are issued by Gestore Servizi Energetici (GSE) and their prices are set as the average cost of the electricity purchased by GSE from CIP6 plants minus the average revenue of CIP6 electricity sold by GSE to the market. The reference price in 2010 was €113.1/MWh (Bimbo 2013; GSE 2012).
Belgium	725,209	Green Certificate Scheme	This credit scheme is managed on a regional basis for Flanders, Wallonia, and the Brussels-Capital area. Credit prices are €65 for Wallonia and Brussels regions, and the price varies based on supply chain considerations and fossil fuel usage (during transport) for Flanders (Elia 2016; USDA 2013).
Sweden	574,970	The Electricity Certificate System	Credits are allocated by the Swedish Energy Agency (SEA), and quota obligation fees for not meeting the assigned quota in 2013 were $39.91/certificate (SEA 2015).
The Netherlands	422,422	Stimulation of Sustainable Energy Production (Feed-in-Tariff)	The Netherlands Enterprise Agencies (NEA) provides subsidies at a maximum of $15/MWh for electricity and $41.67/GJ of renewable heat produced from renewable resources (IEA 2016; NEA 2016).
Germany	408,083	Renewable Energy Sources Act (Feed-in-Tariff)	The German government provides subsidies for renewable energy sources at an average of $12/MWh (FMEAE 2014).
Import data from International Trade Administration Fuels Top Market Report (2015) http://trade.gov/topmarkets/pdf/Renewable_Fuels_Biomass_Wood_Pellets.pdf			

Between 2012 and 2014, wood pellet exports from the United States were primarily shipped to the United Kingdom (73%), followed by Belgium (12%), the Netherlands (7%), and Europe (6%). Of those imported to the United Kingdom (UK), 82% went to the Drax

Group, the UK's largest electricity provider (ELIA 2016). Because the UK's electricity sector is largely powered by coal, energy providers, such as DRAX, have been forced to develop cost-efficient ways of meeting the new policy requirements. This has motivated large-scale suppliers either to fit existing coal plants to co-fire coal with wood pellets or to convert plants to dedicated biomass in order to utilize existing infrastructure (Lowenthal-Savy 2015). The UK government views the use of wood pellets as a short- to medium-term solution (10 to 30 years) to meet EU's renewable energy and carbon reduction targets, while energy providers develop and build solar and wind energy infrastructure (Renewables Financial Incentives Team 2014). Although estimates vary, the projected demand of wood pellet consumption in Europe is expected to increase from 25 to 70 million metric tons by 2020 (International Trade Administration 2015).

While Europe is currently the primary demand driver, some countries consume smaller amounts and others offer potential opportunities in the future. In North America, Canada maintains a small consumer market and lacks incentivizing policies. The United States consumes approximately 80% of its wood pellet production, which is supported by the Renewable Energy Production Incentive (REPI) and various state-led economic incentives. As environmental policies strengthen, it is expected that coal power plants will co-fire with wood pellets and thus increase its market potential. In Japan and South Korea, the Renewable Portfolio Standard (RPS) is forcing energy producers to source a required amount from renewables, including biomass. In addition, South Korea subsidizes the purchase of domestically produced pellet boilers. New Zealand administers the Wood Energy Grant Scheme to promote the use of wood residues for energy; however, its abundant wood resources may limit import opportunities. Finally, industrial growth in China and a push to resolve serious environmental issues will likely present opportunities in the future; however, current policy support and consumption are underdeveloped (Goh *et al*. 2013).

Wood pellets are an energy-dense fuel source derived from forest biomass, including logging and sawmill residues, pulpwood, roundwood, and other lignocellulosic sources. The European Union classifies these resources as renewable and carbon neutral (EPRS 2015). The southeast US region has become UK's biggest supplier of wood pellets (Canada is a distant second, followed by other European countries), due to an abundance of private forests, strong logistics capacity, and competitively priced feedstock (Goh *et at*. 2013; Dewitt 2015; Lowenthal-Savy 2015). Pellet mills range in production capacity from 10,000 to 650,000 metric tons (MT) annually; however, larger mills, owned or run by medium to large firms, such as Enviva LP and Georgia Biomass, are generally built to meet export demand because they can achieve greater economies of scale and ensure more consistent and abundant supply (Pirraglia *et al*. 2010; SELC 2015). While pellet mills may provide economic benefits to landowners, loggers, and various businesses, the substantial increase in wood pellet production in the southeast US presents concerns, such as loss in biodiversity and habitat destruction (Drouin 2015). Therefore, with the demand for wood pellets on the rise, there is a need to better understand where future pellet mills should be built.

Industrial location determinants, or factors that influence where a company builds a manufacturing plant, can be segmented into various levels including, but not limited to: quantity and quality of resources (infrastructure, raw materials, labor amount and productivity, and the environment); market conditions (access to and demand from consumer markets, exchange rates, input prices, and agglomeration effects); country risk (government policies, taxes, and incentives, level of corruption, and political stability), and company strategy (companies may select locations based on long term strategy, demand trends, and the ability to negotiate with local governments and labor organizations) (Hayter *et al*. 1997; Badri 2007). Existing literature in projecting future locations for pellet mills is scant. Young *et al*. (2011) utilize a logistic regression to identify factors influencing the locational choices of bioenergy and biofuel plants in the southern United States (US). Feedstock availability (expressed as the availability of thinnings, presence of wood using mills and unused mill residues) and high density railways had positive effects on the location of larger wood using bioenergy facilities, whereas median family income, population, low density of railway availability and harvesting costs for logging residues had negative.

Three articles compare the advantages of producing wood pellets in various countries for European consumption. Nunes *et al.* (2014a) evaluate the production potential of Portugal, Germany and Sweden and find only Portugal to be economically competitive in the global market due to lower resource and labor costs. Ehrig *et al*. (2014) estimate the cost of producing in and shipping wood pellets from Canada, Australia, and Russia. Their results suggest that Australia is not competitive due to high supply costs and Canada is risky due to extremely low profit margins. However, Russia was found to be economically viable due to its raw material and shipping costs. Using a multi-criteria decision model (MCDM), Smith and Junginger (2011) find that the comparative advantages of countries varies depending on different wood pellet demand scenarios. While the US, Brazil and Western Canada maintain abundant resources, they are not cost-competitive with high shipping rates. Overall, Austria, Estonia, Czech Republic, and Sweden faired consistently better under various scenarios.

This article attempts to summarize and report on literature that may be relevant to an investor in selecting a location to build a wood pellet mill. In addition, it applies several tools in a case study examining the comparative advantages of North and South American countries.

METHODS

Relevant research was divided into four categories. The first covers research that focused directly on identifying location decision factors related to the theoretical framework of identifying potential pellet mill locations. The next section identifies tools and reports that can be used to evaluate a country's wood supply and its potential for wood supply; this is sub-divided into three sections: wood supply and potential, forest plantations, and international bioenergy. A combination of forest and bioenergy economic and optimization models, annual reports, and literature were critically analyzed. The third section includes articles about the wood pellet supply chain, including its production, distribution, and consumption. The fourth section reviews performance indices that provide insight into the countries' social, political, and economic conditions. Indices were categorized according to their specific objective, and the countries' factors were evaluated. In addition, two indices were utilized to rank the countries, based on their risk and supply chain. The conclusion of this review included a brief summary and contextualizes within the broader scope of the location determinants of starting a wood pellet plant in North or South America.

NORTH AND SOUTH AMERICAN WOOD SUPPLY AND POTENTIAL

Measuring wood's supply and potential depends on the productive capacity of land and the decision process and objectives of their owners; thus, articles and models attempting to evaluate current and future resources must account for environmental, social, and economic situations (Kallio *et al*. 1987; Wear and Parks 1994; Buongiorno *et al*. 2003; Wear and Pattanayak 2003; Turner *et al*. 2006). Buongiorno *et al*. (2003) and Kallio *et al*. (2004 and 2006) review existing international trade models with forestry components, including the Global Trade Assessment Project, CINTRAFOR Global Trade Model, Timber Supply Model, Global Forest Product Supply Model, and the European Forest Institute - Global Trade Model. Incorporating various economic and biological assumptions, these models work to predict future patterns in forestry production, consumption and trade on a regional or country level basis. Several organizations collect and publish forest industry data for the public (Table 2). The Food and Agriculture Organization (FAO) leads in terms of the level of detail and years covered, followed by the International Tropical Timber Organization (ITTO) and the United Nations of Economic Commission for Europe (UNECE).

Table 2. List of Publicly Available Reports and Databases for International Wood Resources

Organization	Name	Reporting frequency	Description
Food and Agriculture Organization	Global Forest Resources Assessment (GFRA)	Every 5 years	Provides a comprehensive analysis on wood consumption, production, and projected trends, and has been released every 5 to 10 yrs since 1948 (MacDicken 2015). The latest report was published in 2015 and collected data for 234 countries and territories via remote sensing and surveys administered to governmental bodies. It consists of a summary report that is supported by individual country assessments (FAO 2015).
	State of the World's Forests (SWF)	Every 2 to 5 years	Reports on the status of forests and their contributions to people's livelihoods, including food, health, shelter, and energy needs to promote productive policy making. The latest report was published in 2014 (FAO, 2014).
	Global Forest Products Outlook Study (GFPOS)	Occurred only in 2000	Provides detailed information on the current and future status of forest plantation establishment, economic and policy issues associated with forest plantation establishment, and the outlook for potential wood supplies from forest plantations (FAO 2005).
	Global Fiber Supply Model (GFSM)	Occurred only in 1998	A comprehensive study that represents a first look at some of the major factors affecting supply for producer countries in Asia/Oceana, Latin America, and Africa. They found that non-wood fiber will increase in demand for developing and developed countries seeking to utilize it, and that policy development will depend on the actions taken by the government, industry, non-governmental organization (NGO), and the investment community (Bull *et al.*1998).

	Global Forest Resource Assessment Database (FLUDE)	Periodically (2015)	Includes forestry data collected as part of the GFRA, including land characteristics, production, and deforestation (FAO 2016).
	Statistics Database (FAOSTAT)	Periodically (2014)	The FAO's core database includes information on the economic, social, and political dimensions of the agriculture and forestry industries (FAO 2016).
International Tropical Timber Organization	Biennial Review and Assessment of the World Timber Situation (WTS)	Biennial (2014)	Provides international statistics available on global production and trade of timber, with an emphasis on the tropics (ITTO 2014).
	Tropical Timber Market Report (TTMR)	Bi-weekly (March 1 - 15, 2016)	Provides global market trends, trade news, and prices on more than 400 tropical timber and added-value products (ITTO 2016).
	Tropical Forest Update (TFU)	Quarterly (4th Quarter in 2015)	Provides quarterly news and updates related to global tropical forests.
	Annual Review Statistics Database	Annually (2014)	Provides historical data on the international production and trade of primary wood products (ITTO 2016)
United Nations Economic Commission for Europe	Forest Products Annual Market Review (AMR)	Annually (2015)	Provides general and statistical information on the forest products markets in the United Nations Economic Commission for Europe (UNECE) region of Europe, North America, and the Commonwealth of Independent States (UNECE 2015).

FAOSTAT is the most robust database for forestry trade and production data, as it includes the most countries and the widest variety of forest products, including wood pellets. In addition, the database goes back as far as 1961, depending on the specific variable (FAO 2016). ITTO's Annual Review Statistics Database has the advantage of disaggregating non-coniferous from non-coniferous tropical species for sawn wood, veneer and plywood products; however, it provides data only for its member countries going back to 1980 (ITTO 2016). The GRFA, WTS, and AMR serve similar purposes in that they try to explain, both through qualitative and statistical analysis, international forest production, consumption, trade, and policy trends. From a wood pellet mill investor's perspective, the GRFA would likely be the most relevant as it provides detailed reports for nearly every country, covers all wood species and was published most recently in 2015 (FAO 2015). The WTS focuses only on primary and secondary products for tropical hardwood species and the latest report was released in 2014 (ITTO 2014). The AMR, provides reports annually (the latest in 2015), though its focus is only on the UNECE region of Europe, North America, and the Commonwealth of Independent State (UNECE 2015). In contrast to the GRFA, WTS and AMR, the SWF largely focuses on the role forests play in contributing to the livelihood of people all over the world; however, Chapter 3 of the latest report maintains a section on the role of wood energy and provides some basic consumption statistics (FAO 2014). Finally, the GFPOS and GFSM occurred only once in 1998 and 2000, and would thus likely be too outdated for current investment purposes (Bull *et al.* 1998; FAO 2005).

Table 3 lists the top-rated North and South American countries for wood resources (along with their wood pellet production and export quantities), as measured by forest area, planted forest area, roundwood production, and the total export value of forest products. Data from FAOSTAT was used because it combines wood pellet as well as forest area and production data. Roundwood production was included to anticipate the potential supply of sawdust, a common input for wood pellet mills. With the exception of Canada, Brazil, and the US, there is no clear association between abundant forested land and roundwood production. This could be attributed to several factors, including the political infrastructure or business environment circumstances.

Table 3. Forest Characteristics and Wood Pellet Production by Country (2014)

Country	Wood pellet production (tons)	Wood pellet export (tons)	Forest area* (000 ha)	Planted forest area (000 ha)	Roundwood production (000 m^3)	Industrial roundwood production** (000 m^3)
United States	6,503,637	4,414,820	245,332	26,364	398,693	356,812
Canada	1,910,672	1,804,917	323,145	15,784	154,259	149,934
Brazil	54,013	7,341	287,311	7,736	267,653	149,530
Chile	33,069	875	14,038	3,044	58,712	42,590
Argentina	12,125	6,438	25,176	1,202	18,261	13,666
Mexico	4,409	924	37,991	87	44,204	5,353
Honduras	4,409	924	2,257	0	478	478
Uruguay	4,409	1,609	1,532	1,062	12,424	9,668
Costa Rica	1,102	237	1,402	18	4,593	1,263
Peru	0	0	54,299	1,157	8,785	1,402
Colombia	0	0	47,978	71	12,145	3,841
Bolivia	0	0	44,084	26	3,367	943
Venezuela	0	0	22,370	557	5,514	1,317
Guyana	0	0	14,646	0	1,461	623
Suriname	0	0	13,442	13	542	492
Paraguay	0	0	12,824	98	11,062	4,044
Ecuador	0	0	7,559	55	7,432	2,440
Guatemala	0	0	1,700	185	654	654
Nicaragua	0	0	1,085	48	118	118
Dominican Republic	0	0	780	119	978	35
El Salvador	0	0	233	16	4,885	682
*Forest area does not include forest under conservation/protection						
**Roundwood production minus that for wood fuel						

FAO 2014

Research shows that forest plantations will increasingly play a significant role in roundwood production because they provide environmental, social, and economic benefits, such as reducing pressure on natural ecosystems and replacing marginal agriculture lands (Sedjo *et al*. 1999; Carle *et al*. 2002). Meanwhile, the total global forest area decreased from 4.28 to 3.99 billion ha from 1990 and 2015 and the planted forests increased from 167.5 to 277.9 million ha (4.06% to 6.95%), primarily in temperate zones and comprising approximately 88% native species (Payn *et al*. 2015). A comprehensive literature review found that the global timber harvest has increased over time and will likely continue to do so; illegal logging has increased in emerging economies, and planted forests will play a larger role in satisfying this increased demand (Nilsson and Bull 2005).

Table 4. Common Plantation Species for Selected Countries (2011)

Country	Species	Rotation age (yrs)	Mean annual increment (m^3/ha/yr)
Argentina	*Pinus taeda* – Misiones	18	25
	Eucalyptus grandis – Corrientes	12	40
Brazil	*Pinus taeda* pulpwood/sawtbr	15	30
	Pinus taeda sawtimber	25	25
	Eucalyptus urophylla pulpwood, S.P.	6	40
	Eucalyptus grandis sawtimber	16	40
Chile	*Pinus radiata* sawtimber - Good Site	22	30
	Pinus radiata pulpwood - Poor Site	16	20
	Eucalyptus globulus pulpwood	16	25
	Eucalyptus nitens pulpwood	14	30
Colombia	*Eucalyptus grandis*	20	25
	Pinus tecunumanii	20	25
	Pinus maximinoi	20	24
	Pinus patula	20	18
Costa Rica	*Gmelina arborea*	12	31
Ecuador	Balsa	5	40
	Pinus radiata	20	20
Mexico	*Pinus greggii*	20	15
	Eucalyptus grandis	8	30
Paraguay	*Eucalyptus* sp. clones	14	30
	Eucalyptus sp. seedlings	14	26
Uruguay	*Eucalyptus globulus*	9	22
	Eucalyptus grandis pulp	10	28
	Pinus taeda	22	18
	Eucalyptus grandis sawtimber	16	25
United States	*Pinus taeda* South*	25	10 - 17.1*
	Pseudotsuga menziesii Site II	40	13
	Pseudotsuga menziesii Site I	40	17
Venezuela	*Pinus caribaea*	12	18
	Eucalyptus urophylla	7	25
	Gmelina arborea	5	25

*Range based on management intensity
Cubbage *et al*. (2014)

The productive capacity of forest plantations varies regionally. Table 4 summarizes data collected by Cubbage *et al*. (2014) on common plantation species for North and South American countries and their respective growth rates. Argentina, Brazil, Chile, Colombia, Mexico, Uruguay, and Venezuela host both eucalyptus and pine species, with Argentina and Brazil achieving the highest mean annual increment yields. In addition to pine, Douglas fir is grown in the US, balsa wood is grown in Ecuador, and gahmar wood is grown in Costa Rica and Venezuela. As previously mentioned, the US and Canada are the largest producers of wood pellets. In South America, Brazil, and Chile are the largest producers (primarily for domestic markets) and are characterized by smaller mills that rely on sawmill residues as inputs (Goh *et al*. 2013). This may be subject to change because in Brazil, Suzano plans to produce 2 million tons of pellets per year and Tanac plans to produce 441,000 ton/yr for the Drax Group in 2016 (Nielsen 2011; TANAC 2014). Both Suzano and Tanac mills would source their raw materials from forest plantations.

International Bioenergy

The current estimates of the potential bioenergy supply vary significantly according to the type of model (statistical *vs*. remote sensing and geographic information science), method (biomass availability based on inventory *vs*. economic conditions), and assumption (alternative land uses, land/crop productivity, biodiversity, water availability, commodity market conditions, food, forest, and energy production, prices and demand amounts, and varying inclusion/definitions of bioenergy categories) (Gronowska *et al*. 2008; Dornburg *et al*. 2010; Offerman *et al*. 2010; Long *et al*. 2013; Slade *et al*. 2014). Research shows that bioenergy resources are sufficient to meet increasing global demand without competing with food production, and that the short-rotation plantation systems could play a major sourcing role (Carle and Holmgren 2008; Pleguezuel *et al*. 2014). In addition, woody biomass has become major sources of supply and certification would be the most suitable instrument for developing sustainable bioenergy systems (Ladanai and Vinterbäck 2009). However, a recent study suggests there is a need to better understand the drivers of competition, technical strategies, and participatory approaches for improving biomass utilization, and integrated approaches for optimizing bioeconomic value chain networks (Lewandowski 2015).

It appears that the demand for bioenergy should be met by the current supply of wood resources without sacrificing food production. Plantations will likely play a more prominent role, especially across South America, where these growers alleviate the demand on natural ecosystems and provide income from marginal agriculture land. However, natural forests will supply the majorities of the resources because of the expanse of forested land in North and South America. Canada, the US, and Brazil, followed by Chile and Uruguay, appear the most capable of supplying Europe with wood pellets, based on their large supply of natural and plantation forests, significant roundwood production, and high growth rates. In contrast, Peru, Colombia, Bolivia, and Mexico lack the necessary resources for extensive plantations and industrial roundwood production. The remaining countries are not strong candidates for supplying wood pellets because of limited forested land and underdeveloped industries.

WOOD PELLET SUPPLY CHAIN

The supply chain of a product or raw material describes the network of buyers and sellers that connect its production, processing, distribution, and eventual sales in the target market. With regards to bioenergy, this includes landowners, forest loggers, agriculture harvesters, land transportation agents (in home and target markets), manufacturing/ biorefinery plants, storage facilities, ports, shippers, and consumers. In contrast, the value chain describes those processes and activities within each component of the supply chain that adds value to the products. For instance, this can occur at the manufacturing level, where factories convert biomass feedstock into bioenergy, or at the distribution level, where truckers provide value by making the raw material and/or goods available to users (Qian and McDow 2013; Seebaluck and Leal 2015).

The wood pellet sector can be broken into four primary components:

1. Feedstock sourcing (harvesting, inland transportation, forest consulting, and finance);
2. Pellet production (storage, pelletizing, inland transportation, and financing);
3. Distribution (ocean transportation, harbor storage, loading/unloading, and financing);
4. Consumption (inland transportation and consumption for heat and electricity) (Sikkema *et al*. 2010; Qian and McDow 2013).

With respect to bioenergy value/supply chains in general, there are various types of decision-making levels (strategic, tactical, and operational), uncertainties (feedstock supply and logistics capacity, production/operation and demand/pricing, *etc*.), different methods in which uncertainties are addressed (analytical and simulation), and sustainability concepts and models (Balaman and Selim 2015; Seebaluck and Leal 2015). Management approaches have been devised according to their logistics capacity, uncertainty, leanness, agility, managerial involvement, demand driven strategies, demand forecasting, and models utilized, by mathematical and simulation processes (Hughes *et al*. 2014).

Of the biomass feedstock types, wood pellets from southern yellow pine present minimum processing issues and are more economical than alternatives; also the torrefied pellets from yellow pine have higher energy density and are thus ideal for displacing coal (Pirraglia *et al*. 2012). Research related specifically to wood pellet production have identified a range of typical product characteristics, such as density, moisture, and ash content, their associated production processes, including drying, grinding, conditioning, pelletizing, screening for fine separation, and packaging/sorting (less common production aspects include bonding, adhesive mechanisms, and thermal treatments), as well as their financial cost characteristics (Stelte *et al*. 2012; Hughes *et al*. 2014). Torrefaction, the thermochemical process of heating biomass to above 390 °F in an oxygen-deprived environment, has recently garnered attention for its capability to increase the energy density of wood pellets. This additional step in the pelletization process could present significant market opportunities to co-fire in coal plants (Pirraglia *et al*. 2013; Nunes *et al*. 2014b).

Financial analysis of wood pellet production is scant; however, existing research identifies biomass feedstock (made up of harvesting cost, stumpage price, and transportation) as the most important cost component, followed by labor, energy (electricity and natural gas), consumables, depreciation, and taxes (Pirraglia *et al*. 2010, 2012; Uasuf and Becker 2011; Stelte *et al*. 2012; Trømborg *et al*. 2013; Qian and McDow 2013). With regards to servicing international markets, transportation and supply chain logistics play significant roles (Thek and Obernberger 2004; Hoque *et al*. 2006; Gonzalez *et al*. 2011). The April, 2016 freight on board (FOB) current market prices for wood pellets from southeastern US and southwestern Canada were approximately $123/ton and $118.00/ton, respectively (Argus Media 2016). Initial data concerning the labor and energy costs show considerable variation among countries. In Guyana, industrial electricity costs $.30/kWh, as opposed to $.0642/kWh in the US (Climate Scope 2015; Energy Information Administration 2016). The average manufacturing wage is $21.23 per hour in Canada and $1.39 in Mexico (ILO, 2016). Understanding the competitive advantages is important for future research.

Although the supply chain characteristics vary among countries, common issues often include an evolving nature of supplier markets, varying weight standards when transporting wood, and a lack of research and worker training (at least when comparing the southern US to other countries) (Siry *et al*. 2006). To address market deficiencies and aid with biomass sourcing and conversion decision-making for selling biomass-based products in the European market, Black *et al.* (2015) developed a database system that includes physical characteristics of biomass, the necessary technology to process it, and relevant policies and risk factors to assist with business decisions.

The development of standardized environmental and technical requirements in the EU may influence future potential wood pellet supply locations. For instance, Canadian forests, largely publicly owned, will likely have greater traceability than forests owned by small landowners in the US (Goetzl 2015). While the EU lacks uniform obligatory requirements, member states have adopted certification systems and/or sustainability criteria of their own, including the Green Gold Label, NTA 8080 certification, Laborelec-SGS Solid Biomass Sustainability Scheme, Drax Biomass Sustainability Implementation Process, UK's Timber Standard, Germany's GINPlus, Austria's Önorm M 7135, France's NF Granules Biocombustibles, and Italy's Pellet Gold. Various industry participants are working towards establishing consistent certification systems such as ENPlus (wood pellet technical standards), ISO 13065 (environment, social and economic sustainability) and Sustainable Biomass Partnership (sustainability standards for industrial wood pellet buyers) (Hiegl *et al*. 2009; Goetzl 2015).

Given the complex nature of and rich literature covering the environmental implications of wood pellets, a comprehensive review is beyond the scope of this paper. However, a brief overview may be relevant to investors. The environmental impacts of substituting coal for wood pellets vary throughout the supply chain and depend on forest management practices, types of biomass sourced, product specifications, production processes, transportation modes and on the proximity of the pellet mill to biomass resources and final consumer markets. Such processes lead to various levels of emissions, including CO, CO_2, CH_4, N_2O, NO_2, VOC, PM and SO_x, Aldehyde, and NH_3, that can contribute to global warming, acid rain, and smog. Energy consumed throughout the supply chain varies, and includes propane, gasoline, diesel, and bunker oil for harvesting and transportation and natural gas, wood waste, electricity, and steam for pellet production. In a Canadian study, marine transportation was found to be the highest environmentally impacting activity, followed by harvesting and pellet production (Magelli *et al*. 2009; Pa *et al*. 2012).

Forest plantations have been proposed as one means to produce pellets, with less adverse impacts to native forests. Their active management would provide economic incentives that could increase wood fiber supply and increase sustainability of wood pellet use. Forest plantations require active management, and they present some concerns about intensive chemicals, water quality, and biodiversity. However, planted forest use can offset native forest harvests, which take longer to regenerate and restore their carbon losses (Abt *et al*. 2012). Forest management practices relating to harvesting, species composition, site-preparation, and tending can be adjusted to reduce their use and consequences of intensive forest management impacts (Hartley 2002). There is a vast literature on life cycle analysis of wood pellets and biomass. One example of a cradle to gate analysis by Katers *et al*. (2012) found that processing whole logs into wood pellets used less energy than dry and wet co-products. Another found that using wood pellets instead of coal to produce electricity in Europe reduces greenhouse gas emissions by approximately 74% to 85% (Wang *et al*. 2015).

Current research is insufficient to truly compare the costs and benefits of building a large-scale wood pelleting mills in North and South America. Qian and McDow (2013) and Hoque *et al.* (2006) directly address the different wood pellet supply chain components (feedstock inputs, production, inland and shipping transportation, port usage, and final consumption in Europe), accounting for their associated costs; however, their scope was limited to southern US and Canadian producers. The analyses conducted by Sikkema *et al*. (2010) and Lamers *et al*. (2015) were global; although detailed information on individual North and South American countries was absent. Given price volatility in the wood sector and the current rise of the US dollar in comparison with other currencies, it will be important to understand how Central and South American countries can contribute in European markets. In addition, those analyses which primarily examine the pellet production processes and costs assume plant capacities of less than 120,000 MT/year. Pirraglia *et al*. (2010 and 2012) assumed that production and consumption would take place in the US; while Thek and Obernberger (2004) assumed that production and consumption would be located primarily in Europe. While these analyses are robust, pellet mills designed to meet demand from export markets can produce up to 650,000 MT/year of pellets in bulk SELC 2015). Furthermore, our research found no previous analyses that used one cost and production model to evaluate the competitive advantages among North and South American, making it difficult to appreciate their various differences. Thus, much work remains with regards to conducting financial analyses of wood pellet production across various countries.

COUNTRY INDICES

There is extensive research on country risk and investment climate analyses dating back to the 1960s. While various methodologies have been developed, it is beyond the scope of this article to cover them all. This section will review performance indices developed by large organizations, companies, banks, and government entities (sources likely to be used by international investors).

Performance indices can provide effective means of evaluating countries based on social, political, economic, environmental, and health-related issues; also the UN's

Development Programme (UNDP) conducted a comprehensive survey of performance indices in 2008 (Bandura 2008). For example, The Economist's Big Mac index measures the status of currencies, Freedom House's Countries at Crossroads measures government accountability and civil liberties, and the Standard and Poor's Sovereign Credit Rating measures the ability of governments to service debt. Other indices have a broader scope: The Economist Intelligence Unit's (EIU) Country Risk Rating evaluates political, economic, and industry specific risk factors, and the Forbes' Capital Hospitality Index evaluates the macroeconomic and social indicators, including GDP growth, international trade, poverty, *etc*. Generally, an index is made up of several categories and subcategories that are averaged together (weighting schemes are sometimes applied). For example, the World Bank's Ease of Doing Business Index (WBEDB), one of the most widely-used indices, is subdivided into the following 10 categories: Starting a Business, Dealing with Construction Permits, Getting Electricity, Registering Property, Getting Credit, Protecting Minority Investors, Paying Taxes, Trading Across Borders, Enforcing Contracts, and Resolving Insolvency (World Bank 2016). Each is scored separately and then pooled to arrive at a total country score, from which countries are then ranked. There are a large number of indices designed to rank countries based on specific goals.

Performance indices have been used in evaluating international forestry investments. Gonzalez *et al*. (2008) used indices from Global Edge, Coface, and the Organization for Economic Cooperation and Development (OECD) in assessing the future of the global forest products sector. Cubbage *et al*. (2010, 2014) utilized the Belgium Export Credit Agency's (listed under Ducrioire in Appendix 1) risk index and the World Bank Ease of Doing Business (WBEDB) to better understand current and future investments in timber.

Selecting the location for a large, export-oriented wood pellet mill requires suitable social, political, economic, and supply chain conditions and institutions. This analysis utilizes two comprehensive indices: World Bank's Logistic Performance Index (LPI) and IHS Connect Country Risk Index (IHS Risk). LPI was selected because it is the only index fully dedicated to measuring countries' supply chain factors. IHS Risk was selected because it provides a comprehensive look at the countries' social, political and economic risks and is updated on a quarterly basis. In addition, many of the indices reviewed by Bandura (2008) are limited in several ways, including being updated less frequently (or not at all in many cases) and covering fewer countries and social, political and/or economic conditions separately. Table 5 provides the definitions of categories, inclusive of LPI and IHS Risk. LPI is scored on a scale of 1 to 5, where higher is better. In contrast, IHS Risk is scored from 1 to 10, where 0 to 1.5 is considered low risk, 1.6 to 3.0 medium risk, 3.1 to 6.4 high risk, and 6.4 or greater extreme risk.

Table 5. IHS Risk and Logistic Performance Index (LPI) Category Definitions

IHS Risk		LPI	
Category	Sub-categories and definitions	Category	Definition
Political	Sub-categories: Government Instability, Political instability, and State Failure Risk the government will change in the next year; may implement broad policy shifts that lead to challenging business environments and/or state is unable to ensure law and order	Customs	Efficiency of the clearance process (*i.e.*, speed, simplicity, and predictability of formalities) by border control agencies, including customs
Economic	Sub-categories: Recession, Inflation, Depreciation, Capital Transfer, Sovereign Default, and Under-Development Risk of reduced economic growth to well below its potential sustainable pace over the next 12 months, major currency rate depreciation, added restrictions to cross boarder capital transfers and government defaulting, and degree of under-development of the economy.	Infrastructure	Quality of trade and transport related infrastructure (*e.g.*, ports, railroads, roads, and information technology)
Legal	Sub-categories: Expropriation, Alteration, and Enforcement Risk that the state will deprive, expropriate, nationalize, or confiscate the assets of private businesses, alter the terms of contracts it has with private parties without due process and/or judicial system will not enforce contractual agreements between private-sector entities because of inefficiency, corruption, bias, or an inability to enforce rulings promptly and firmly	International shipments	Ease of arranging competitively-priced shipments
Tax	Sub-categories: Increase and Inconsistency Risk that the overall tax burden for private enterprises will increase and/or taxes are levied in an inconsistent, unpredictable, or opaque fashion	Logistics competence	Competence and quality of logistics services (*e.g.*, transport operators and customs brokers)
Operational	Sub-categories: Corruption, Regulatory Burden, Infrastructure Disruption, and Labor Strikes Risk that individuals/companies will face bribery or other corrupt practices to carry out business, normal business operations become more costly due to the regulatory environment, disruption to and/or inadequacy of infrastructure for transport and strikes, politically motivated shutdowns, natural disasters, strikes, and other forms of industrial action disrupt normal activity and business operations	Tracking and tracing	Ability to track and trace consignments
Security	Sub-categories: Protests and Riots, Terrorism, Interstate War, and Civil War Risk of protests and riots disrupting normal activity and business operations, activities of any non-state armed group/individual causing property damage and/or injury, interstate groups engage in targeted strikes, with the aim of changing the government and/or occupation and intra-state military conflict in which rebels attempt to overthrow the government, achieve independence, or at least heavily influence major government policies	Timeliness	Timeliness of shipments in reaching their destination within the scheduled or expected delivery date

IHS Connect and World Bank Group (2016)

Table 6. Logistic Performance Index and IHS Risk Scores for North and South American Countries (2014, 2016)

Country	Combined Index	World Bank Logistic Procurement Index							IHS Connect Country Risk Index						
		Avg	Cust	Infr	Ship	Log	Trk	Time	Avg	Pol	Econ	Leg	Tax	Op	Se.
United States	6.84	3.92	3.73	4.18	3.45	3.97	4.14	4.14	1	1.3	0.2	0.7	1.2	1.2	1.3
Canada	6.82	3.86	3.61	4.05	3.46	3.94	3.97	4.18	0.9	1	0.4	0.7	1.5	0.9	0.6
Chile	5.02	3.26	3.17	3.17	3.12	3.19	3.3	3.59	1.5	1.4	1.5	1.2	1.9	1.7	1.5
Mexico	4.26	3.13	2.69	3.04	3.19	3.12	3.14	3.57	2	2.2	1.1	1.5	1.9	2.6	2.4
Uruguay	4.06	2.68	2.39	2.51	2.64	2.58	2.89	3.06	1.3	1.1	1.2	1	1.6	2.1	0.8
Dominican Republic	3.72	2.86	2.58	2.61	2.93	2.91	2.91	3.18	2	2.1	1.2	2	2	2.9	1.5
El Salvador	3.72	2.96	2.93	2.63	3.2	3.16	3	2.75	2.2	2.6	1	2.1	3	3.1	1.6
Costa Rica	3.5	2.7	2.39	2.43	2.63	2.86	2.83	3.04	1.9	1.8	1.2	2.1	2.6	2.2	1.3
Argentina	3.48	2.99	2.55	2.83	2.96	2.93	3.15	3.49	2.5	2	3.7	2.4	2.4	3	1.4
Brazil	3.48	2.94	2.48	2.93	2.8	3.05	3.03	3.39	2.4	2.6	2.5	1.7	2.8	3	1.5
Peru	3.48	2.84	2.47	2.72	2.94	2.78	2.81	3.3	2.2	2.4	1.5	2.3	2	2.8	2.2
Paraguay	3.26	2.78	2.49	2.46	2.83	2.76	2.89	3.22	2.3	2.5	2.1	2.2	2.4	3.3	1.5
Colombia	3.08	2.64	2.59	2.44	2.72	2.64	2.55	2.87	2.2	2.2	1.8	1.5	2.2	2.5	2.7
Guatemala	3	2.8	2.75	2.54	2.87	2.68	2.68	3.24	2.6	3.4	1.3	2.4	3.4	3.2	2.1
Nicaragua	2.7	2.65	2.66	2.2	2.69	2.58	2.58	3.17	2.6	2.2	1.7	3.1	3.5	3.4	1.8
Guyana	2.42	2.46	2.46	2.4	2.43	2.27	2.47	2.74	2.5	2.6	3.1	2.4	2.4	3	1.7
Honduras	2.42	2.61	2.7	2.24	2.79	2.47	2.61	2.79	2.8	3.1	1.3	3.3	3.3	3.5	2.3
Ecuador	2.32	2.71	2.49	2.5	2.79	2.61	2.67	3.18	3.1	2.5	2.2	4.2	4	3.8	1.9
Bolivia	1.66	2.48	2.4	2.17	2.35	2.68	2.68	2.6	3.3	2.8	2.7	4.5	3.6	4	2.1
Venezuela	1.22	2.81	2.39	2.61	2.94	2.76	2.92	3.18	4.4	3.9	5.5	5.8	4.1	4.9	2.4
Suriname	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	2.5	2.9	1.6	2.9	3	3	1.6

Abbreviations: Avg = Average, Cust = Customs, Infr = Infrastructure, Ship = Shipments, Log = Logistics, Trk = Tracking, Pol = Political, Econ = Economic, Leg = Legal, Op = Operations, and Se = Security

Categories with LPI and IHS Risk were scored and averaged together to arrive at an overall score. Because the supply chain and country risk factors were not directly correlated, a separate index was created to more effectively rank the countries. This index combined the overall scores of the LPI and IHS Risk as follows,

$$\text{Combined Index Score} = (LPI_i \times 2) - \text{IHS Risk}_i \quad (1)$$

where the LPI_i is the average LPI score for country *i* and the IHS $Risk_i$ is the average IHS Risk score for country *I* (Table 6). A higher Combined Index Score reflected better investment climates. The US, Canada, and Chile ranked the highest based on low risk and developed supply chain factors, whereas Venezuela and Bolivia ranked the lowest.

The abundance of wood and positive investment climates in the US and Canada may explain why wood pellet production is highest in these countries. While Brazil has significant wood resources, its modest investment ranking provides international investors reason to consider Chile, Mexico, or Uruguay instead. More research is required to better understand the financial trade-offs of building and operating a pellet mill in each country in order to predict future investments. This article provides a solid foundation for researchers and investors that are interested in finding locations to build a pellet mill in North and South American countries.

CONCLUSIONS

1. Environmental policies, including credit programs and feed-in-tariffs, in the E.U. have led to a significant increase in the amount of wood pellets produced in the southeast US. The largest importer is the UK, followed by Denmark and Italy. The UK views wood pellets as a medium terms solution, and will eventually move to more solar and wind sources.
2. Wood resource supply and cost, supply chain infrastructure and cost, and investment climate and risk are important determinants in international forestry investments.
3. There are sufficient wood resources to meet future bioenergy demands and forest plantations will likely play an increasingly important role as they reduce pressure on natural forests and achieve faster growth rates.
4. FAOSTAT is the most robust database for forestry trade and production data as it includes the widest variety of products (including wood pellets) and number of countries. ITTO's Annual Review Statistics Database has the advantage of disaggregating non-coniferous from non-coniferous tropical species for sawn wood, veneer and plywood products.
5. Feedstock delivery price is the most important cost-component in producing wood pellets, followed by labor, energy, consumables, depreciation, and taxes (in addition to port and shipping expenses when exporting).
6. Country performance indices range in their goals, from evaluating social, economic and political risk to supply chain factors, and provide an effective way of evaluating investment climates.

7. Results from the case study suggest that the US, Canada, and Chile may be best situated to receive investments in wood pellet mills given their abundant wood resources and attractive investment climates. Uruguay is also a feasible option; however, it may be limited by a lack of natural forest area. Argentina, Brazil, Colombia, Mexico, Paraguay, and Peru may be suitable for investors willing to accept greater risk. Given the higher growth rates of South American countries, this risk would likely be compensated with greater rates of return. The remaining countries would likely not see interest from investors given their low wood resources, poor investment climate, or combination thereof.

DISCUSSION

Environmental policy drivers in the European Union have led to a significant increase in the amount of wood pellets produced in the southeastern US. To identify where pellet mills should be located in North and South America to satisfy this demand, a critical review of literature, economic models, and data, as well as supply chain and country risk factors related to wood pellet production, were considered. The present analysis indicates that the feedstock supply and cost, the supply chain infrastructure and cost, and the investment climate of countries are important determinants in international forestry investment decisions. This is supported by the findings of Young *et al*. (2011) that bioenergy plants in the southern US are more likely to be built in areas with greater resources (availability of thinnings, unused residues, and wood-using mills), as well as infrastructure (amount of high density railways).

Our analysis found a significant lack of research looking at the comparative advantages of different countries to produce wood pellets. Smith and Junginger (2011) conducted a global analysis using a MCDM model that incorporated four types of variables, including feedstock, production costs, investment climate, and market potential and logistics. While their analysis suggests investors are likely to target North American and European regions, it is limited in several ways. First, only Brazil and Chile are considered for South America. As shown above, other countries such as Argentina, Mexico, Peru, Colombia, and Uruguay may be competitive given their significant resource capacity and fair to strong investment climates. Next, it does not distinguish between total forest area, forest area under protection, and planted forest area. This overestimates the feedstock availability of Brazil, which protects most of its amazon region. Finally, the present analysis uses capital costs (derived from interviews with industry professionals) and total river, sea, and rail networks available as measures of country risk and supply chain capacity. While these are important, indices such as IHS Risk and LPI provide more information and insight into the investment climate of countries. In addition, they are updated regularly and based either on extensive industry surveys or in-depth research by trained analysts. Other work that could be used to compare the benefits of building a pellet mill among different countries are limited in scope. Nunes *et al.* (2014a) focus on Portugal, Germany, and Sweden, whereas Ehrig *et al*. (2014) look at Canada, Australia, and Russia. The objective of each is to provide market analyses and cost comparisons; however, they do not consider country risk beyond the cost of capital (a single rate is applied uniformly to each country in both papers).

This paper attempts to bring together resources of interest to an investor looking to build an export oriented wood pellet plant. It examines European policy drivers and their likely future directions, existing economic trade models and databases and tools to evaluate supply chain and country risk factors. In addition, it builds on existing literature by using North and South American regions as a case study. While the present conclusions provide significant insight into the trade-offs of different countries, additional work is needed to better understand their associated labor, energy, tax, shipping, and feedstock costs. An initial assessment of these cost components shows that they vary significantly. Combining a techno-economic model, such as one of those reviewed under the Wood Pellet Supply Chain section, with the results of this case study would provide a more complete view of the trade-offs of investing in North or South America.

REFERENCES CITED

Abt, K. L., Abt, R. C., and Galik, C. (2012). "Effect of bioenergy demands and supply response on markets, carbon, and land use," *Forest Science* 58(5), 523-539. DOI: 10.5849/forsci.11-055

Argus Media. (2016). *Weekly Biomass Markets News and Analysis*, Argus Biomass Markets, (http://www.argusmedia.com/~/media/files/pdfs/samples/argus-biomass.pdf/?la=en) (accessed May 14, 2016).

Badri, M. (2007). "Dimensions of industrial location factors: Review and exploration," *Journal of Business and Public Affairs* 1(2), 1-26.

Balaman, Ş. Y., and Selim, H. (2015). "Biomass to energy supply chain network design: An overview of models, solution approaches and applications," in: *Handbook of Bioenergy*, S. D. Eksioglu, S. Rebennack, and P. M. Pardalos (eds.), Springer International, Cham, Switzerland, pp. 1-35. DOI: 10.1007/978-3-319-20092-7_1

Bandura, R. (2008). "A survey of composite indices measuring country performance: 2008 update," *New York: United Nations Development Programme*, Office of Development Studies (UNDP/ODS Working Papers).

Bimbo, R. (2013). *All Prices in the Market for Green Certificates*, (http://www.dailyenmoveme.com/en/market/all-prices-market-green-certificates) (accessed May 14, 2016).

Black, M. J., Sadhukhan, J., Day, K., Drage, G., and Murphy, R. J. (2015). "Developing database criteria for the assessment of biomass supply chains for biorefinery development," *Chemical Engineering Research & Design* 107, 253-262. DOI: 10.1016/j.cherd.2015.10.046

Bull, G., Mabee, W., and Sharpenberg, R. (1998). *FAO Global Fiber Supply Model*, Food and Agriculture Organization of the United Nations, Italy, Rome, (http://www.fao.org/docrep/006/x0105e/x0105e00.HTM) (accessed May 14, 2016).

Buongiorno, J., Zhu, S., Zhang, D., Turner, J., and Tomberlin, D. (2003). "Chapter 1 – Background and objectives," in: *The Global Forest Products Model: Structure, Estimation, and Applications*, Academic Press, Burlington, pp. 3-14, DOI: 10.1016/B978-012141362-0/50004-2

Carle, J., and Holmgren, P. (2008). "Wood from planted forests: A global outlook 2005-2030," *Forest Products Journal* 58(12), 6-18.

Carle, J., Vuorinen, P., and Del Lungo, A. (2002). "Status and trends in global forest plantation development," *Forest Products Journal* 52(7/8), 12-23.

Climate Scope. (2015). *Climate Scope Report*, (http://global-climatescope.org/en/download/) (accessed May 14, 2016).

Cubbage, F., Koesbandana, S., Mac Donagh, P., Rubilar, R., Balmelli, G., Olmos, V. M., De La Torre, R., Murara, M., Hoeflich, V.A., Kotze, H., *et al*. (2010). "Global timber investments, wood costs, regulation, and risk," *Biomass & Bioenergy* 34(12), 1667-1678. DOI: 10.1016/j.biombioe.2010.05.008

Cubbage, F., Mac Donagh, P., Balmelli, G., Morales Olmos, V., Bussoni, A., Rubilar, R., De La Torre, R., Lord, R., Huang, J., Afonso Hoeflich, V., *et al*. (2014). "Global timber investments and trends, 2005-2011," *New Zealand Journal of Forestry Science* 44(1), S7. DOI: 10.1186/1179-5395-44-S1-S7

Dewitt, D. (2015). "The wood pellet industry in NC: Economic boom or climate disaster," North Carolina Public Radio, (http://wunc.org/post/wood-pellet-industry-nc-economic-boon-or-climate-disaster#stream/0) (accessed May 14, 2016).

DECC (2015). "Appendix 5: The renewables obligation," in: *2010 to 2015 Government Policy: Low Carbon Technologies*, Department of Energy and Climate Change, Policy Paper. (https://www.gov.uk/government/publications/2010-to-2015-government-policy-low-carbon-technologies/2010-to-2015-government-policy-low-carbon-technologies) (accessed May 16, 2016).

Dornburg, V., van Vuuren, D., van de Ven, G., Langeveld, H., Meeusen, M., Banse, M., van Oorschot, M., Ros, J., van den Born, G. J., Aiking, H., *et al*. (2010). "Bioenergy revisited: Key factors in global potentials of bioenergy," *Energy & Environmental Science* 3(3), 258-267. DOI: 10.1039/B922422J

Drouin, R. (2015). "Wood pellets: Green energy or new source of CO_2 emissions?" Yale Environment 360, (http://e360.yale.edu/feature/wood_pellets_green_energy_or_new_source_of_co2_emissions/2840/) (accessed May 16, 2016).

EC (2016). 2020 climate & energy package, European Commission, (http://ec.europa.eu/clima/policies/strategies/2020/index_en.htm) (accessed May 16, 2016).

Ehrig, R., Behrendt, F., Wörgetter, M., and Strasser, C. (2014). "Pellet Supply Costs Along Three Case Studies," in: *Economics and Price Risks in International Pellet Supply Chains* (pp. 15-26). Springer International Publishing. DOI: 10.1007/978-3-319-07016-2_3

EIA (2016). *Average price of electricity to ultimate customers by end-use sector, by state, February 2016 and 2015 (Cents per Kilowatthour)*, Independent Statistics & Analysis, U.S. Energy Information Administration, (https://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_5_6_a) (accessed May 16, 2016).

ELIA (2016). *Minimum Price and Legal Frame*, European Language Industry Association, Belfium's Electricity Transmission System Operator, Products and Services, Green certificates, (http://www.elia.be/en/products-and-services/green-certificates/Minimumprice-legalframe) (accessed May 16, 2016).

EPRS (2015). *Biomass for Electricity and Heating; Opportunities and Challenges*, European Parliamentary Research Service, September 2015, (http://www.europarl.europa.eu/RegData/etudes/BRIE/2015/568329/EPRS_BRI(2015)568329_EN.pdf) (accessed May 16, 2016).

EU (2016). *Energy*, Energy by Topic, European Union, (http://europa.eu/pol/ener/index_en.htm) (accessed May 16, 2016).

FAO (1998). *The Global Forest Products Model (GFPM): User's Manual and Guide to Installation*, Food and Agriculture Organization of the United Nations, Corporate Document Repository, Forestry Department, (http://www.fao.org/docrep/003/x1674e/x1674e00.htm) (accessed May 16, 2016).

FAO (2005). *Global Forest Products Outlook Study*, Food and Agriculture Organization of the United Nations, Global Outlook Studies, (http://www.fao.org/forestry/outlook/gfpos/en/) (accessed May 16, 2016).

FAO (2014). *State of the World's Forests 2014: Enhancing the Socioeconomic Benefits from Forests*, Food and Agriculture Organization of the United Nations, Forestry, (http://www.fao.org/forestry/sofo/en/) (accessed May 16, 2016).

FAO (2015). *Global Forest Resources Assessments*, Food and Agriculture Organization of the United Nations, (http://www.fao.org/forest-resources-assessment/current-assessment/en/) (accessed May 16, 2016).

FAO (2015). *Resurgence in Global Wood Production*, Food and Agriculture Organization of the United Nations, News Articles, (http://www.fao.org/news/story/en/item/359583/icode/) (accessed May 16, 2016).

FAO (2016). *FAOSTAT*, Food and Agriculture Organization of the United Nations, Statistics Division, (http://faostat3.fao.org/home/E) (accessed May 16, 2016).

FAO (2016). *Forest Resource Assessment: FLUDE*, Food and Agriculture Organization of the United Nations, Global Forest Resources Assessments, (http://www.fao.org/forest-resources-assessment/explore-data/flude/en/) (accessed May 16, 2016).

FMEAE (2014). *2014 Renewable Energy Sources Act: Plannable, Affordable, Efficient*, Topics: Energy and Renewable Energy, Federal Ministry for Economic Affairs and Energy, (http://www.bmwi.de/EN/Topics/Energy/Renewable-Energy/2014-renewable-energy-sources-act.html) (accessed May 16, 2016).

GSE (2012). *Green Certificates*, Qualifications and Certificates, Gestore Servizi Energetici [Energy Services Manager], (http://www.gse.it/en/qualificationandcertificates/GreenCertificates/Pages/default.aspx) (accessed May 16, 2016).

Goh, C. S., Junginger, M., Cocchi, M., Marchal, D., Thrän, D., Hennig, C., Heinimö, J., Nikolaisen, L., Schouwenberg, P. P., Bradley, D., *et al*. (2013). "Wood pellet market and trade: A global perspective," *Biofuels, Bioproducts and Biorefining* 7(1), 24-42. DOI: 10.1002/bbb.1366

Goetzl, A. (2015). "Developments in the global trade of wood pellets," *Working Paper-Office of Industries, US International Trade Commission*.

Gonzalez, R. W., Saloni, D., Dasmohapatra, S., and Cubbage, F. (2008). "South America: Industrial roundwood supply potential," *BioResources* 3(1), 255-269. DOI: 10.15376/biores.3.1.255-269

Gonzalez, R., Phillips, R., Saloni, D., Jameel, H., Abt, R., Pirraglia, A., and Wright, J. (2011). "Biomass to energy in the southern united states: Supply chain and delivered cost," *BioResources* 6(3), 2954-76. DOI: 10.15376/biores.6.3.2954-2976

Gronowska, M., Joshi, S., and MacLean, H. L. (2008). "A review of US and Canadian biomass supply studies," *BioResources* 4(1), 341-369. DOI: 10.15376/biores.4.1.341-369

Purdue University. (2016). "Global trade analysis project," Purdue University, (https://www.gtap.agecon.purdue.edu/about/project.asp) (accessed May 16, 2016).

Hartley, M. J. (2002). "Rationale and methods for conserving biodiversity in plantation forests," *Forest Ecology and Management*, *155*(1), 81-95. DOI: 10.1016/S0378-1127(01)00549-7

Hayter, R. (1997). "The location of factories," in: *The Dynamics of Industrial Location: the Factory, the Firm, and the Production System*, Wiley Publishing, Chichester, UK, pp. 79-110.

Hiegl, W., and Pichler, W. (2009). "Development and promotion of a transparent European pellets market: Creation of a European real-time pellets atlas," *Holzforshung Austria, Intelligent Energy, WIP Renewable Energies,* Munich, Germany.

Hoque, M., Sokhansanj, S., Bi, T., Mani, S., Jafari, L., Lim, J., Zaini, P., Melin, S., Sowlati, T. and Afzal, M. (2006). "Economics of pellet production for export market," in: *2006 ASAE Annual Meeting*, July 16-19, Edmonton, Alberta, Canada.

Hughes, N. M., Shahi, C., and Pulkki, R. (2014). "A review of the wood pellet value chain, modern value/supply chain management approaches, and value/supply chain models," *Journal of Renewable Energy* 2014, 654158. DOI: 10.1155/2014/654158

IHS Connect (2016). "Country risk," (http://connect.ihs.com.prox.lib.ncsu.edu/risks) (accessed May 16, 2016).

IEA (2015). *Bioenergy TASK 40*, International Energy Agency Publications, (http://www.bioenergytrade.org/publications.html) (accessed May 16, 2016).

IEA (2016). *Our work: Tasks*, International Energy Agency Bioenergy, (http://www.ieabioenergy.com/our-work-tasks/) (accessed May 16, 2016).

IEA (2016). *Stimulering duurzame energie* [Promotion of Sustainable Energy], International Energy Agency Policies and Measures, Netherlands, (http://www.iea.org/policiesandmeasures/pams/netherlands/name-24872-en.php) (accessed May 16, 2016).

ILO (2016). *ILOSTAT Database, Statistics and Database*, International Labor Organization, (http://www.ilo.org/ilostat/faces/oracle/webcenter/portalapp/pagehierarchy/Page137.jspx?_afrLoop=22352074411920&clean=true#%40%3F_afrLoop%3D22352074411920%26clean%3Dtrue%26_adf.ctrl-state%3Drphosa5zd_9) (accessed May 16, 2016).

ITA (2015). *Sector Snapshot: Biomass Wood Pellets*, Renewable Fuels Top Market Report, International Trade Administration, (http://trade.gov/topmarkets/pdf/Renewable_Fuels_Biomass_Wood_Pellets.pdf) (accessed May 16, 2016).

ITTO (2014). *Biennial Review and Assessment of the World Timber Situation*, International Tropical Timber Organization Publications, (http://www.itto.int/annual_review/) (accessed May 16, 2016).

ITTO (2015). *Tropical Forest Update*, International Tropical Timber Organization Publications, (http://www.itto.int/tfu/) (accessed May 16, 2016).

ITTO (2016). *Tropical Timber Market Report*, International Tropical Timber Organization Publications, Market Information Service, (http://www.itto.int/mis_detail/) (accessed May 16, 2016).

ITTO (2016). *Annual Review Statistics Database*, International Tropical Timber Organization, Work, Economic Information, and Market intelligence, (http://www.itto.int/annual_review_output/) (accessed May 16, 2016).

Kallio, M., Dykstra, D. P., and Binkley, C. S. (1987). "Forest resources and timber supply," in: *The Global Forest Sector: An Analytical Perspective*, John Wiley and Sons Inc., New York, NY.

Kallio, A. M. I., Moiseyev, A., and Solberg, B. (2004). "General structure of a partial equilibrium model," in: *The Global Forest Sector Model EFI-GTM: The Model Structure* (Internal Report No. 15), European Forest Institute, Joensuu, Finland.

Kallio, A. M. I., Moiseyev, A., and Solberg, B. (2006). "Economic impacts of increased forest conservation in Europe: A forest sector model analysis," *Environmental Science & Policy* 9(5), 457-465. DOI: 10.1016/j.envsci.2006.03.002

Katers, J. F., Snippen, A. J., and Puettmann, M. E. (2012). "Life-cycle inventory of wood pellet manufacturing and utilization in Wisconsin," *Forest Products Journal* 62(4), 289-295. DOI: http://dx.doi.org.prox.lib.ncsu.edu/10.13073/FPJ-D-12-00018.1

Ladanai, S., and Vinterbäck, J. (2009). "Global potential of sustainable biomass for energy," Technical Report, *(Institutionen för energi och teknik)* [Department of Energy and Technology].

Lamers, P., Marchal, D., Heinimö, J., and Steierer, F. (2014). "Global woody biomass trade for energy," in: *International Bioenergy Trade*, M. Junginger, C. S. Goh, and A. Faaij (eds.), Springer, Amsterdam, The Netherlands, pp. 41-63. DOI: 10.1007/978-94-007-6982-3_3

Lamers, P., Hoefnagels, R., Junginger, M., Hamelinck, C., and Faaij, A. (2015). "Global solid biomass trade for energy by 2020: An assessment of potential import streams and supply costs to North-West Europe under different sustainability constraints," *GCB Bioenergy* 7(4), 618-634. DOI: 10.1111/gcbb.12162

Lewandowski, I. (2015). "Securing a sustainable biomass supply in a growing bioeconomy," *Global Food Security* 6, 34-42. DOI: 10.1016/j.gfs.2015.10.001

Long, H., Li, X., Wang, H., and Jia, J. (2013). "Biomass resources and their bioenergy potential estimation: A review," *Renewable and Sustainable Energy Reviews* 26, 344-352. DOI: 10.1016/j.rser.2013.05.035

Lowenthal-Savy, D. (2015). "UK's renewable energy targets drive increases in U.S. wood pellet exports," US Energy Information Administration, (http://www.eia.gov/todayinenergy/detail.cfm?id=20912) (accessed May 16, 2016).

MacDicken, K. G. (2015). "Global forest resources assessment 2015: What, why and how?" *Forest Ecology and Management* 352, 3-8. DOI: 10.1016/j.foreco.2015.02.006

Magelli, F., Boucher, K., Bi, H. T., Melin, S., and Bonoli, A. (2009). "An environmental impact assessment of exported wood pellets from Canada to Europe," *Biomass and Bioenergy* 33(3), 434-441. DOI: 10.1016/j.biombioe.2008.08.016

NEA (2016). *Stimulation of Sustainable Energy Production (SDE+)*, Netherlands Enterprise Agency, Subsidies & Programmes, (http://english.rvo.nl/subsidies-programmes/sde) (accessed May 16, 2016).

Nielsen, S. (2011). "Suzano Invests $534 Million in Brazil Pellet Export Project," Bloomberg, (http://www.bloomberg.com/news/articles/2011-09-30/suzano-to-invest-534-million-in-brazil-wood-pellet-production) (accessed May 16, 2016).

Nilsson, S., and Bull, G. (2005). "Global wood supply analysis," in: *Proceeding from the 46th Session of the FAO Advisory Committee*, Vancouver, BC, Canada.

Nunes, L. J. R., Matias, J. C. O., and Catalão, J. P. S. (2014a). "Economic and sustainability comparative study of wood pellets production in Portugal, Germany and Sweden," in: *Proceedings of the International Conference on Renewable Energies and Power Quality*, Cordoba, Spain.

Nunes, L. J. R., Matias, J. C. O., and Catalão, J. P. S. (2014b). "A review on torrefied biomass pellets as a sustainable alternative to coal in power generation," *Renewable and Sustainable Energy Reviews* 40, 153-160. DOI: 10.1016/j.rser.2014.07.181

OFGEM (2015). *The Renewables Obligation (RO) Buy-Out Price (44.33) and Mutualisation Ceilings 2015-2016*, Office of Gas and Electricity Markets, Environmental Programs, (https://www.ofgem.gov.uk/publications-and-updates/renewables-obligation-ro-buy-out-price-44-33-and-mutualisation-ceilings-2015-16) (accessed May 16, 2016).

Pa, A., Craven, J. S., Bi, X. T., Melin, S., and Sokhansanj, S. (2012). "Environmental footprints of British Columbia wood pellets from a simplified life cycle analysis," *The International Journal of Life Cycle Assessment* 17(2), 220-231. DOI: 10.1007/s11367-011-0358-7

Payn, T., Carnus, J. M., Freer-Smith, P., Kimberley, M., Kollert, W., Liu, S., Orazio, C., Rodriguez, L., Silva, L. N., and Wingfield, M. J. (2015). "Changes in planted forests and future global implications," *Forest Ecology & Management* 352, 57-67. DOI: 10.1016/j.foreco.2015.06.021

Pirraglia, A., Gonzalez, R., and Saloni, D. (2010). "Techno-economical analysis of wood pellets production for U.S. manufacturers," *BioResources* 5(4), 2374-2390. DOI: 10.15376/biores.5.4.2374-2390

Pirraglia, A., Gonzalez, R., Denig, J., Saloni, D., and Wright, J. (2012). "Assessment of the most adequate pre-treatments and woody biomass sources intended for direct co-firing in the US," *BioResources* 7(4), 4817-4842. DOI: 10.15376/biores.7.4.4817-4842

Pirraglia, A., Gonzalez, R., Denig, J., and Saloni, D. (2013). "Technical and economic modeling for the production of torrefied lignocellulosic biomass for the US densified fuel industry," *Bioenergy Research* 6(1), 263-275. DOI: 10.1007/s12155-012-9255-6

Qian, Y., and McDow, W. (2013). "The wood pellet value chain: An economic analysis of the wood pellet supply chain from the Southeast United States to European Consumers," US Endowment for Forestry and Communities.

RFIT (2014). "Consultation on changes to grandfathering policy with respect to future biomass co-firing and conversion projects in the renewables obligation," Renewables Financial Incentives Team.

Seebaluck, V., and Leal, M. R. L. V. (2015). "Feedstock supply chains," in: *Bioenergy and Sustainability: Bridging the Gaps*, Scientific Committee on Problems of the Environment, 348-372.

Sedjo, R. A., and Lyon, K. S. (1996). "Timber supply model 96: A global timber supply model with a pulpwood component," Discussion Paper 96-15, Washington, DC: Resources for the Future (http://www.rff.org/research/publications/timber-supply-model-96-global-timber-supply-model-pulpwood-component) (accessed May 16, 2016).

Sedjo, R. A. (1999). "The potential of high-yield plantation forestry for meeting timber needs," in: *Planted Forests: Contributions to the Quest for Sustainable Societies*, J. R. Boyle, J. K. Winjum, K. Kavanagh, and E. C. Jensen (eds.), Springer, Amsterdam, The Netherlands, pp. 339-359. DOI: 10.1007/978-94-017-2689-4_21

Sikkema, R., Junginger, M., Pichler, W., Hayes, S., and Faaij, A. P. (2010). "The international logistics of wood pellets for heating and power production in Europe: Costs, energy-input and greenhouse gas balances of pellet consumption in Italy, Sweden and the Netherlands," *Biofuels, Bioproducts & Biorefining* 4(2), 132-153. DOI: 10.1002/bbb.208

Siry, J. P., Greene, W. D., Harris, T. G., Izlar, R. L., Hamsley, A. K., Eason, K., Tye, T., Baldwin, S. S., and Hyldahl, C. (2006). "Wood supply chain efficiency and fiber cost: What can we do better?" *Forest Products Journal* 56(10), 4.

Slade, R., Bauen, A., and Gross, R. (2014). "Global bioenergy resources," *Nature Climate Change* 4(2), 99-105. DOI: 10.1038/nclimate2097

Smith, T. P., and Junginger, H. M. (2011). "Analysis of the global production location dynamics in the industrial wood pellet market: An MCDA approach," *Biofuels, Bioproducts & Biorefining* 5(5), 533-547. DOI: 10.1002/bbb.292

SEA (2015). *The Norwegian-Swedish Electricity Certificate Market*, Annual Report 2013, Swedish Energy Agency, (http://www.energimyndigheten.se/en/sustainability/the-electricity-certificate-system/) (accessed May 16, 2016).

SELC (2015). *Wood Pellet Plants and European Export Map*, Southern Environmental Law Center, (https://www.southernenvironment.org/uploads/maps/Wood_Pellet_Exports_2015_1030_map+table.pdf) (accessed May 16, 2016).

Stelte, W., Sanadi, A. R., Shang, L., Holm, J. K., Ahrenfeldt, J., and Henriksen, U. B. (2012). "Recent developments in biomass pelletization: A review," *BioResources* 7(3), 4451-4490. DOI: 10.15376/biores.7.3.4451-4490

TANAC (2014). "TANAC S. A. announces plans to construct a US$60 million wood pellet mill in Brazil," (http://www.tanac.com.br/en/news/tanac-sa-announces-plans-construct-us60-million-wood-pellet-mill-brazil) (accessed May 16, 2016).

Thek, G., and Obernberger, I. (2004). "Wood pellet production costs under Austrian and in comparison to Swedish framework conditions," *Biomass and Bioenergy* 27(6), 671-693. DOI: 10.1016/j.biombioe.2003.07.007

Trømborg, E., Ranta, T., Schweinle, J., Solberg, B., Skjevrak, G., and Tiffany, D. G. (2013). "Economic sustainability for wood pellets production: A comparative study between Finland, Germany, Norway, Sweden and the US," *Biomass and Bioenergy* 57, 68-77. DOI: 10.1016/j.biombioe.2013.01.030

Turner, J. A., Buongiorno, J., and Zhu, S. (2006). "An economic model of international wood supply, forest stock and forest area change," *Scandinavian Journal of Forest Research* 21(1), 73-86. DOI: 10.1080/02827580500478506

Uasuf, A., and Becker, G. (2011). "Wood pellets production costs and energy consumption under different framework conditions in Northeast Argentina," *Biomass and Bioenergy* 35(3), 1357-1366. DOI: 10.1016/j.biombioe.2010.12.029

UNECE (2015). "Forest products annual market review, 2014-2015," *Forest Products Markets, Outputs, Annual Market Reviews*, United Nations Economic Commission for Europe, (http://www.unece.org/forests/fpm/annualmarketreviews.html) (accessed May 16, 2016).

UNDP (2016). *Human Development Index*, United Nations Development Programme, (http://hdr.undp.org/en/content/human-development-index-hdi) (accessed May 16, 2016).

USDA (2013). *The Market for Wood Pellets in the Benelux*, United States Department of Agriculture, USDA Gains Report, The Hague, Netherlands, (http://gain.fas.usda.gov/Recent%20GAIN%20Publications/The%20Market%20for%

20Wood%20Pellets%20in%20the%20Benelux_The%20Hague_Netherlands_1-4-2013.pdf) (accessed May 16, 2016).
USDA (2013). *The Market for Wood Pellets in Denmark*, United States Department of Agriculture, USDA Gains Report, The Hague, Netherlands, (http://gain.fas.usda.gov/Recent%20GAIN%20Publications/The%20Market%20for%20Wood%20Pellets%20in%20Denmark_The%20Hague_Denmark_11-5-2013.pdf) (accessed May 16, 2016).
Wang, W., Dwivedi, P., Abt, R., and Khanna, M. (2015). "Carbon savings with transatlantic trade in pellets: Accounting for market-driven effects," *Environmental Research Letters* 10(11), 114019. DOI: 10.1088/1748-9326/10/11/114019
Wear, D. N., and Parks, P. J. (1994). "The economics of timber supply: An analytical synthesis of modeling approaches," *Natural Resource Modeling* 8(3), 199-223.
Wear, D. N., and Pattanayak, S. K. (2003). "Aggregate timber supply," in: *Forests in a Market Economy*, E. O. Sills and K. L. Abt (eds.), Springer, Amsterdam, The Netherlands, pp. 117-132. DOI: 10.1007/978-94-017-0219-5_8
WBG (2016). *Logistics Performance Index*, International LPI Global Rankings, World Bank Group, (http://lpi.worldbank.org/international/global) (accessed May 16, 2016).
WBG (2016). "Economy rankings," in: *Doing Business: Measuring Business, Rankings*, World Bank Group, (http://www.doingbusiness.org/rankings) (accessed May 16, 2016).
WEF (2016). *The Global Competitiveness Report 2015-2016*, World Economic Forum, (http://reports.weforum.org/global-competitiveness-report-2015-2016/) (accessed May 16, 2016).
Young, T. M., Zaretski, R. L., Perdue, J. H., Guess, F. M., and Liu, X. (2011). "Logistic regression models of factors influencing the location of bioenergy and biofuels plants," *BioResources* 6(1), 329-343. DOI: 10.15376/biores.6.1.329-343

Article submitted: April 28, 2016; Peer review completed: June 17, 2016; Revisions accepted: July 8, 2016; Published: July 14, 2016.
DOI: 10.15376/biores.11.3.Singh