*Revised Manuscript with No Changes Marked

Development of a technology roadmap for bioenergy exploitation including biofuels, waste-to-energy and power generation & CHP

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Abstract

This paper describes the process of developing a technology roadmap for deploying bioenergy technologies at a country level. A method for energy technology roadmapping adapted to the conditions of developing countries is proposed. This method combines an acknowledged roadmapping framework from prior art, a new strategy to build consensus based on the Delphi method and a strong focus on analytical modeling for supporting expert judgment. This method aims to be simple, transparent and affordable. The proposed method is applied to Colombia for creating a plan to deploy sustainable bioenergy technologies in Colombia until 2030. This plan consists of a set of long-term goals, milestones, barriers and action items identified by over 30 experts for key bioenergy technology areas (viz. bioethanol, biodiesel, renewable diesel, biomethane, biogas, waste-to-energy and power generation and combined heat and power). Finally, the relevance of the process of developing a technology roadmap for bioenergy exploitation in Colombia in other developing countries is discussed.

Keywords: roadmap, biomass, biofuels, bioethanol, biodiesel, renewable diesel, biomethane, biogas, power generation, CHP, waste-to-energy, Delphi method, Colombia

Nomenclature

Acronyms

Asocaña	Association of Sugar Cane Growers of Colombia
BID	Inter-American Development Bank
BOD	biochemical oxygen demand
CHP	combined heat and power
DOE	U.S. Department of Energy
Ecopetrol	Colombian Petroleum Co.
ESCO	Energy Service Company
FAO	Food and Agriculture Organization of the United Nations
FFV	flex-fuel vehicles
GBEP	Global Bioenergy Partnership
GDP	gross domestic product
GHG	greenhouse gas
IEA	International Energy Agency
ILUC	indirect land-use change
MME	Ministry of Mines and Energy, Colombia
NGO	non-governmental organization
NIZ	non-interconnected zones
NOx	nitrogen oxides
NREL	U.S. National Renewable Energy Laboratory
OECD	Organisation for Economic Co-operation and Development
OEM	original equipment manufacturer
R&D	research and development
SME	small and medium-sized enterprises
UPME	Mining and Energy Planning Unit, Colombia

1. Introduction

Nations face the critical challenge of designing energy systems able to ensure an adequate energy supply and a sustainable development, while protecting the environment and avoiding conflicts with other nations. Thus, it has become apparent that long-term and strategic planning of energy resources, energy supply and demand is pressingly required (Mizanur Rahman, Paatero, Lahdelma, & Wahid, 2016; Bale, Varga, & Foxon, 2015; Pfenninger & Keirstead, 2015; Igos, et al., 2015; Park, Kim, & Kim, 2014; Cheng, Chang, & Lu, 2015). Long-term and strategic planning offers multiple benefits: a) it enables a nation to prepare for the future in an orderly and systematic way, b) it provides a basis for building consensus on needs and for measuring progress and impact and c) it turns consensus and analytical work into systematic actions. While long-term and strategic planning is very advantageous, it is also demanding. It involves many uncertainties in a rapidly changing external environment that demands significantly more time and resources than short-term planning.

Technology roadmapping is a tool used in strategic planning, which offers the key advantage of providing information to organizations or nations to make better technology investment decisions (Garcia & Bray, 1997; Phaal, Farrukh, & Probert, 2001). Technology roadmapping does this by: a) engaging diverse stakeholders in finding consensus on common goals (e.g. needs, solutions, etc.), b) identify critical needs that drive technology selection and decisions, c) identify technologies that satisfy critical needs and d) develop and implement a plan to deploy selected technology alternatives. Technology roadmapping is particularly important when the investment decision is not straight forward, because of uncertainty in which alternative to pursue, or because a need to a coordinated deployment of multiple technologies exists (Garcia & Bray, 1997). While technology roadmapping is a powerful tool, it is also very resource intensive. It requires substantial amount of information, it requires skilled participants, and since it is a collaborative and iterative process, it requires significant planning and coordination (Garcia & Bray, 1997; Phaal, Farrukh, & Probert, 2001; IEA, 2010). So far, technology roadmapping has mostly been applied in industrialized nations and large emerging economies, where the requirements described above for carrying out technology roadmapping have been fulfilled and where more R&D activities have taken place (Amer & Daim, 2010). In contrast, technology roadmapping has been rarely employed in developing countries, where available data, skilled labor and resources may be limited.
Technology roadmapping has been extensively used at product, technology, company, sector and national levels by companies, NGO's, universities and international organizations to address a wide variety of topics (Amer & Daim, 2010). Across topics, energy is the single topic with the highest number of public domain roadmaps (Amer & Daim, 2010). Across energy roadmaps, Amer & Daim report that sustainable energy is the most addressed topic.

Among the different sustainable energy resources, one of particular interest as much to industrialized countries (for producing heat and power) as to emerging and developing countries (for cooking and heating) is biomass. Biomass is today the largest renewable resource and global interest on its sustainable use and potential to reduce dependency on fossil fuels and decrease greenhouse gas emissions continues to grow (IEA, 2012a). In recent years, various industrialized countries and emerging economies have developed roadmaps for exploiting biomass resources and deploying bioenergy technologies. Examples include global technology roadmaps on biofuels for transport (IEA, 2011b) and bioenergy for heat and power (IEA, 2012a), European Union roadmaps on biomass technology (RHC, 2014), biofuels for transport (E4tech, 2013) and biogas (AEBIOM, 2009), United States roadmaps on bioenergy and biobased products (Biomass Technical Advisory Committee, 2007) and algal biofuels technology (DOE, 2010a), a roadmap for sustainable aviation biofuels for Brazil (Boeing-Embraer-FAPESP-UNICAMP, 2014), China roadmaps on biomass energy technologies (ERI-NDRC, 2010) and rural biomass energy (Zhang, et al., 2010), a roadmap for biorefineries in Germany (Bundesregierung, 2012), among others. However, despite a vast potential and the significant demand for bioenergy, the deployment of technology roadmaps for exploiting bioenergy in developing countries has been scarce.

In summary, in developing countries the use of technology roadmapping has been scarce in general and particularly rare in the context of bioenergy, despite having a vast potential. This paper aims to fill this gap. The paper has two main goals. The first goal is to propose a method for energy technology roadmapping, which adapts IEA guidelines to the conditions of developing countries. The method aims to be simple, affordable and supported by analytical modeling. The second goal is to apply the proposed method to create a plan for deploying sustainable bioenergy technologies in Colombia for the period 2015-2030. This plan consists of a set of long-term goals, milestones, barriers and action items identified by experts for different bioenergy technology areas. It is important to note that the modeling framework used to evaluate the impacts of implementing this plan on the energy system, the GHG emissions and land use of the country are not presented here, but in a separate publication by the same authors (Gonzalez-Salazar, et al., 2016).

The paper is structured as follows: Section 2 presents the proposed method for energy technology roadmapping, Section 3 describes the application of this method to Colombia, Section 4 presents the main outcomes of the roadmapping process applied to Colombia, Section 5 presents lessons and recommendations to other developing countries and finally Section 6 draw some conclusions.

2 Method

2.1. State-of-the-art

A technology roadmap is a strategic plan that describes the steps required to achieve stated outcomes and goals (IEA, 2010). Roadmapping is the process of developing, implementing, monitoring and updating a technology roadmap (IEA, 2010). The process of developing a technology roadmap is as important as the roadmap itself, because of the associated communication and consensus generated between stakeholders (Phaal & Muller, 2009). An effective roadmap must address three key questions: Where are we now? Where do we want to go? How can we get there? (Phaal & Muller, 2009).

There are many of methods and approaches in the literature for creating technology roadmaps, as documented by (Amer & Daim, 2010). An analysis of 80 different roadmapping approaches concluded that while it is not possible to declare a single best and definitive method, there are a number of good practices (de Laat, 2004; Kostoff, Boylan, & Simons, 2004). Good practices include, identifying key stakeholders, organizing workshops, encouraging a multi-perspective approach, among others (de Laat, 2004; Kostoff, Boylan, & Simons, 2004; Amer & Daim, 2010).

Amer & Daim analyze the different techniques used in technology roadmapping at a national level in the particular context of renewable energy. Techniques very frequently used in most of the roadmaps include scenario based planning and expert panels, while a technique used in approximately 50% of the roadmaps is SWOT analysis. On the other hand, techniques rarely used in roadmaps include Delphi method, risk assessments, PEST analysis, patent analysis, citation work analysis and quality function deployment (QFD) (Amer & Daim, 2010).

Amer & Daim further recommend standardizing these renewable energy roadmaps by proposing a generic framework (Amer & Daim, 2010). The guide to develop and implement energy technology roadmaps by the International Energy Agency (IEA, 2010) is a step in this direction. This guide aims at providing countries and companies with a framework to design, manage and implement an effective energy roadmap process. The guide proposes a roadmap structure composed of five elements (IEA, 2010): 1) goals: set of targets that will result in the desired outcome; 2) milestones: interim performance targets for achieving the goals; 3) gaps and barriers: list of gaps in knowledge and barriers to achieve goals and milestones; 4) action items: actions to be taken to overcome gaps in knowledge or barriers for achieving the goals; 5) priorities and timelines: list of most important actions needed to achieve the goals and time frames. Regarding the roadmapping process itself, the guide proposes a process consisting of two types of activities (expert judgment and consensus and data and analysis) and four phases (planning and preparation, visioning, roadmap development and roadmap implementation and revision). Expert judgment and consensus activities are proposed to build consensus on goal and targets, verify assumptions, identify barriers and strategies. Data and analysis are proposed to support and facilitate expert judgment with sound facts. These two activities are carried out in four phases. In the planning and preparation phase, the scope, boundaries and implementation approach are defined. In the visioning phase, workshops are conducted to identify long-term goals. In the development phase, further workshops are conducted to setup priorities and the actual document is created, reviewed and refined. Finally, in the implementation phase, the roadmap is implemented and monitored and further workshops are conducted to re-assess priorities as time progress. The IEA recommends involving 40-100 stakeholders in the development of a roadmap and estimates 6-14 months to develop it. Advantages of this guide include: a) a very robust and systematic structure that allows its application to any sector and country, b) use of data and analysis to support expert judgment, c) detailed definition of activities, goals and responsibilities by the different stakeholders and d) recommendation of effective mechanisms to implement roadmaps. Disadvantages of this guide include: a) it can be challenging to implement the method in developing countries, as its structure might be too complex and the process too lengthy, b) while analytical modeling is considered, it is only optional, c) there is a lack methods to address the challenge of not building consensus among experts (the IEA recommends to choose one position, to present the opposing views if one of those is the minority, or to attempt to create consensus between the two sides).

In summary, while the guide proposed by IEA is a very detailed and robust method that can be applied to any country, its structure is best adapted to OECD countries. For developing countries, it can be challenging to implement the full method, which requires various detailed and lengthy processes and involve multiple working groups. In developing countries, resources and experts often lack or should focus on fulfilling needs that are more urgent.

2.2. Proposed method

A method for energy technology roadmapping adapted to the conditions of developing countries is proposed. The method consists of three components: 1) a simplified version of the IEA's guide structure, 2) a new strategy to build consensus and 3) a strong focus on analytical modeling for supporting expert judgment. This method recognizes the advantages of the guide to develop and implement energy technology roadmaps by the IEA and proposes various modifications to reduce its disadvantages when applied to developing countries.

Firstly, it is proposed to maintain the robust IEA's structure consisting of two types of activities (expert judgment and consensus and data and analysis) and four phases (planning and preparation, visioning, roadmap development and roadmap implementation and revision) but in a simplified version. The proposed method is shown in Figure 1, where feedback loops are avoided and workshops are reduced to a minimum. However, expert judgment as well as communication and consensus between stakeholders are needed for developing effective roadmaps. Hence, a new strategy to build consensus is proposed. This strategy combines surveys and a workshop following the Delphi method (see Figure 2). Rather than conducting three workshops at the visioning phase as in the IEA's guide, it is suggested to conduct two sequential surveys and a single workshop, following the Delphi method.

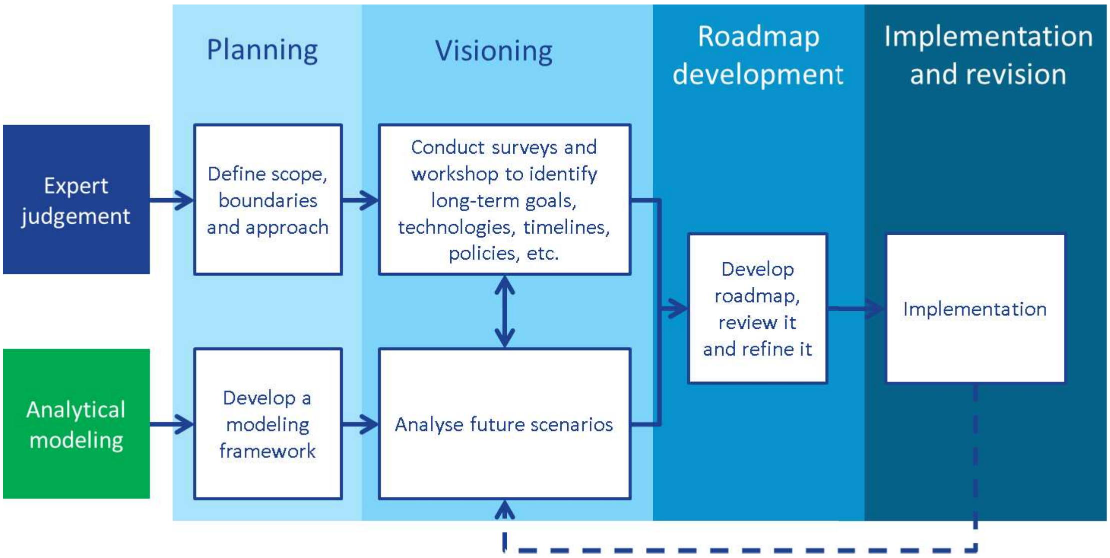

Figure 1. *Proposed method for energy technology roadmapping, adapted from (IEA, 2010).*

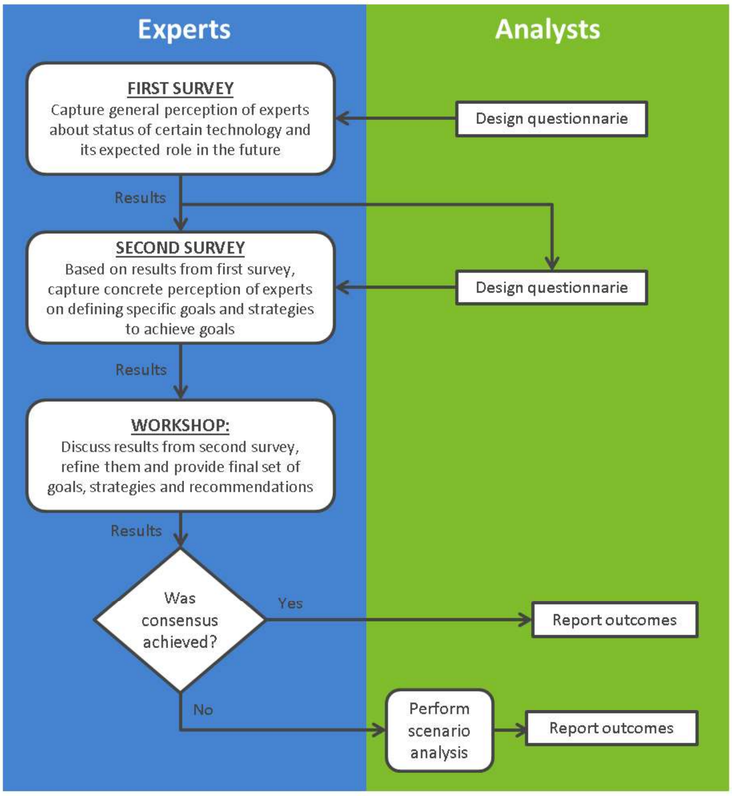

Figure 2. *Proposed strategy to build consensus*

In the first survey, analysts design a questionnaire whose goal is to capture the general perception of experts about the status of certain technology and what is its expected role in the future. Results from the first survey (maintaining anonymity of the participants) are summarized and based upon the results a new questionnaire is designed by analysts. This second survey aims to capture more concretely the perception of experts on the technology of study, and encourage them to define specific goals and strategies to achieve these goals. Results of the second survey (again maintaining anonymity of the participants) are summarized and presented in the workshop. In the workshop, experts discuss these results, refine them and define a final set of goals, strategies and recommendations. This sequential process follows the Delphi method, in which the opinion of individual experts at various stages is influenced by the opinion of the group. Opinion of experts tends to converge after various rounds, which encourages consensus building (Hsu & Sandford, 2007). If consensus was achieved during the process, analysts report outcomes. In case consensus is not achieved, it is proposed to perform scenario analysis, i.e. consider various possible storylines.

The third component of the proposed method is giving a stronger focus to analytical modeling for supporting expert judgment. The IEA's guide considers that analytical modeling adds value to the roadmapping process, but is not required. Moreover, the IEA's guide suggests that the extent to which analytical modeling should be applied depends on the amount and quality of available data, skilled labor and resources, which are limited in developing countries. Authors agree with these statements, but believe that start applying analytical modeling, although challenging, is essential for assessing complex challenges like energy, economy, emissions and land use and their linkages. Hence, it is proposed to use analytical modeling for supporting expert judgment and for adding value to technology roadmapping.

3. Application of the method to Colombia

3.1. Motivation

Colombia is contemplating peace agreements after a 50-year armed conflict, which would open up the possibility of modernizing agriculture, improving living standards in rural areas and exploiting the vast bioenergy potential (i.e. Colombia is one of the seven countries in the world where more than half of the potentially available global arable land is concentrated (FAO, 2011)). However, Colombia does not yet seem prepared for such ambitious reforms. While today bioenergy is the second largest renewable energy resource (3.8 million tons of oil equivalent –Mtoe–) after hydropower (4.2 Mtoe) (UPME, 2011), only a limited number of studies have previously explored its further deployment (MRI-UNC-NUMARK, 2010; Mora Alvarez, 2012) and the magnitude of its impact has not been investigated in detail. More importantly, no official plans exist today for exploiting it in the long-term at a national level. Recognizing the importance of biomass and the lack of long-term strategic planning to exploit it, a roadmap to support the deployment of bioenergy technologies until 2030 is proposed for Colombia, full details can be found in (Gonzalez-Salazar, et al., 2014c). The mentioned roadmap was developed in the framework of a long-term effort of the authors, as documented in (Gonzalez-Salazar, et al., 2014a; Gonzalez-Salazar, et al., 2014b).

3.2. Context

The current energy sector in Colombia is synthetically described in the following. Between 1975 and 2009, primary energy demand[1] doubled (from 17 to 37 Mtoe), increasing at a compound annual growth rate –CAGR– of 2.3% (UPME, 2011). While this rate of increase was similar to other countries in the region (Sheinbaum, Ruíz, & Ozawa, 2011), Colombia only accounted for 4% of the primary energy demand in Latin America in 2009 (EIA, 2016). Compared to primary energy demand, GDP grew at a CAGR of 3.7%. This promoted an annual reduction of 1.4% in energy intensity (from 0.16 to 0.09 toe/US$2005), which was significantly higher than other countries in the region (Sheinbaum, Ruíz, & Ozawa, 2011). The share of fossil fuels in the primary energy demand increased from 69% to 77%, while the share of renewables reduced from 31% to 23%. While this was actually contrary to the trend experienced by other countries in the region (Sheinbaum, Ruíz, & Ozawa, 2011), it is expected to continue in the future (Gonzalez-Salazar, et al., 2014c; Calderón, et al., 2015). Oil was and continues to be the source with the highest shares (45%) in the energy mix, followed by natural gas, which grew from 10 to 22%. In contrast, bioenergy (i.e. woodfuel, cane bagasse[2] and biomass residues[3]) reduced from 26 to 10%.

Final energy use also doubled between 1975 and 2009. Demand for modern energy services, such as electricity and natural gas increased at CAGR of 4.5% and 5.4% respectively. Furthermore, demand for crude oil increased at a CAGR of 1.6% and traditional biomass reduced at a CAGR of 0.5%. The substantial increase in demand for electricity and natural gas is partly explained by a higher level of access to these services. Between 1975 and 2009, access to electricity increased from 63 to 97%, while access to natural gas increased from 0 to 48% (Fresneda, Gonzalez, Cárdenas, & Sarmiento, 2009; Parra Torrado, 2011). Despite these improvements, Colombia is still below the average of Latin America (Fresneda, Gonzalez, Cárdenas, & Sarmiento, 2009; Parra Torrado, 2011). Today, 1 million people living in remote areas still lack access to electricity (Silva & Nakata, 2009). Hydro dominates power generation with an

[1] Defined as the sum of final energy use by sector and losses in energy transformation.
[2] Includes bagasse from sugarcane but excludes bagasse from jaggery cane.
[3] Mostly palm oil residues.

average contribution of 72%, followed by gas (16%), coal (9%) and to a lesser extent, oil, bioenergy and wind (UPME, 2011). Over-dependence on a hydro-dominated system has proven vulnerable to droughts caused by El Niño-Southern Oscillation (ENSO). For instance, in 1992 and 1997, severe droughts caused reductions in the water inflow of reservoirs by more than 30% and were also responsible for blackouts (Arango & Larsen, 2010). To reduce the over-dependence on uncertain weather conditions, new gas- and coal-fired power plants were built (Quijano, Botero, & Domínguez, 2012). This increased the reliability of the system, but raised emissions and concerns regarding energy security (Arango & Larsen, 2010). In the transport sector, vehicle ownership grew exponentially from 0.5 to 6 million vehicles between 1975 and 2009 (Echeverry, et al., 2008; MinTransporte-CEPAL, 2010; UPME, 2010) and their demand for energy increased three-fold at a CAGR of 2.8%. The bulk of this demand was mostly covered by fossil fuels (e.g. gasoline, diesel and compressed natural gas –CNG–), while biofuels (e.g. bioethanol and biodiesel) contributed to about 4% (UPME, 2011).

Some studies in the literature have addressed the future energy demand and supply, for example (Gonzalez-Salazar, et al., 2016; Calderón, et al., 2015; ECLAC, 2013). While Gonzalez-Salazar et al. employed LEAP to analyze the future energy demand and supply until 2030, Calderón et al. analyze it until 2050 using three models (viz. GCAM, TIAM-ECN and PHOENIX). Gonzalez-Salazar et al. estimate a significant growth in primary energy demand (from 41 to 94 Mtoe), road transport demand (from 8 to 27 Mtoe), electricity generation (from 5 to 11 Mtoe) and natural gas supply (from 4 to 14 Mtoe) between 2010 and 2030. These numbers agree with results of Calderón et al. and ECLAC, in which primary energy demand in 2030 ranges between 83 and 119 Mtoe. In Gonzalez-Salazar et al., the share of fossil fuels in the primary energy demand increases from 75% to 85%, while in power generation it increases from 29% to 50%. In contrast, the share of bioenergy during the same period reduces from 15% to 8% in the primary energy demand and from 3% to 1.6% in power generation. According to Gonzalez-Salazar et al., this result is a consequence of a combination of factors including increasing urbanization, greater access to electricity and natural gas services, rapid growth of road vehicle ownership and increased deployment of gas- and coal-fired power plants. The decline of biomass and hydro as well as the increase in demand for fossil fuels in the baseline also agrees with estimates published by ECLAC and by Calderón et al. for the three models mentioned earlier.

3.3. Scope

The proposed method is applied to create a plan (roadmap) to deploy sustainable biofuel and biomass technologies in Colombia for the period 2015-2030. Concretely, the roadmap aims to:

1. Define long-term goals, strategies, plans and policies to continue deploying first generation biofuels (sugar cane-based bioethanol and palm-oil based biodiesel) and to start deploying second-generation biofuels (i.e. solid, liquid and gas biofuels produced from feedstocks not used for human consumption (IEA, 2008)) and biomass-based heat and power generation technologies (using non-food feedstock, e.g. wood, agricultural residues, biogas, landfill gas, etc.) in Colombia for the period 2015-2030
2. Identify gaps in knowledge and barriers to accomplish the proposed goals.
3. Define actions that should be taken by stakeholders to overcome barriers and accomplish the proposed goals.

It is important to mention that the modeling framework used to evaluate the impacts of implementing this plan on the energy system, the GHG emissions and land use of the country are not presented here, but in a separate paper by the same authors (Gonzalez-Salazar, et al., 2016).

3.4. Position towards residual biomass

The roadmap supports the ongoing deployment of first-generation biofuels, but strongly encourages an accelerated and sustainable exploitation of residual biomass and other non-food feedstocks for energy production. The main reason for encouraging the use of non-food biomass feedstocks over sugars and vegetable oils for energy production is to reduce the potential upward pressure on agricultural and forestry land, commodity prices and ultimately food security. Recent studies have shown that while the current use of bioenergy production in Colombia has not triggered significant impacts on supply and prices, this might change if more biofuel targets are put in place (FAO-GBEP, 2014; Gonzalez-Salazar, et al., 2014b). Increasing blend mandates of bioethanol and biodiesel might lead to an associated decrease in forestry land and land for cultivating other agricultural products (Gonzalez-Salazar, et al., 2014b), as well as negative repercussions on environmental and social sustainability (FAO-GBEP, 2014; FAO, 2014).

In particular, this paper considers two main paths for exploiting residual biomass: 1) use of biomass residues and biogas to produce biomethane and 2) use of biomass residues and biogas to generate power and CHP. Instead, it should be noted that energy production from urban solid wastes is not considered in this study, as it is not fully from organic origin. A discussion about the opportunities offered by the solid waste sector in Colombia is reported by (Larochelle, Turner, & LaGiglia, 2012). Moreover, this paper does not consider either micro-algae. As discussed later, they are not expected to become commercially feasible in Colombia before 2030, even though biofuel production from algae has been recently claimed as feasible and sustainable (Gnansounou & Raman, 2016; Lehahn, Ingle, & Golberg, 2016).

3.5. Application of the process

The method proposed in Section 2 for technology roadmapping was used to build consensus among a group of 30 experts from the government, academia, industry and NGO's upon long-term goals and strategies. Firstly, the opinions of experts on the future deployment of bioenergy in Colombia were gathered through two surveys. The first survey captured the general perception of experts about the status of bioenergy in Colombia, the expected role of bioenergy in future energy goals and the key barriers to further deploying bioenergy in the country. The questions included in first survey and the responses received from experts are reported in Supplementary Information 1.

The second survey collected the advice of experts about concrete long-term goals to deploy bioenergy and specific pathways to achieve these goals (questions are reported in Supplementary Information 2 while expert feedback is quantitatively assessed in Supplementary Information 3). Experts met in a workshop to discuss the results of the surveys and to provide recommendations and advice. Finally, Independent researchers from academia reviewed the goals and milestones of the two long-term visions and provided complementary remarks and suggestions. It is hoped for that the long-term goals, milestones and action items identified here will be revised and adjusted by policy makers and local authorities and lead to an implementation program. Results of the roadmapping process for Colombia are presented in next section.

4. Results of the roadmapping process for Colombia

4.1. Overview of the vision

In order of importance, roadmap experts consider the three following reasons critical to supporting the deployment of bioenergy technologies in Colombia: 1) to promote rural development, 2) to enhance energy security (particularly in the road transport sector) and 3) to reduce greenhouse gas emissions. In addition, experts consider that further deployment of bioenergy should be one of the top three national energy targets to be implemented by 2030, the other two targets being increased energy efficiency nationwide and increased power coverage in non-interconnected zones (NIZ). Five bioenergy technology areas are considered fundamental for future deployment in Colombia: a) bioethanol, b) biodiesel, c) renewable diesel, d) biomethane and e) biomass-based power generation and combined heat and power (CHP). Some of them have already been deployed to a certain extent in the country (e.g. bioethanol, biodiesel, biomass-based power generation and CHP), while others have not been commercially explored yet (e.g.

renewable diesel[4] and biomethane). Experts unanimously agreed on the long-term vision of some bioenergy technology areas but disagreed on others. While there was consensus among experts on the long-term vision for biomethane and biomass-based power generation and CHP, there were opposing views with regard to the long-term vision of liquid transport biofuels (i.e. bioethanol, biodiesel and renewable diesel). Experts consider that advanced liquid biofuels (e.g. cellulosic ethanol, biodiesel from microalgae and other advanced routes) are not expected to become commercially available in Colombia before 2030 and that first generation liquid biofuels (biofuels produced from feedstocks that are used for human consumption, e.g. cane-based bioethanol, palm-based biodiesel, palm-based renewable diesel, etc.) will continue being produced in the future. The opinions of experts particularly differed on the levels of blend mandates to be implemented in the future. On one hand, some experts advocate a significant growth in the production of first generation liquid transport biofuels by increasing blend mandates. On the other hand, other experts consider that any further increase in the production of first generation biofuels might worsen the conflicts of land use and food vs. biofuels and are in favor of fixing the current blend mandates. Because of this dilemma, two different visions are considered:

- Vision focusing on new technologies: this targets the deployment of new technologies for the production of biomethane, electricity and CHP and fixes the current blend mandate of first generation liquid biofuels.
- Vision combining new and traditional technologies: this targets a combination of new technologies for production of biomethane, electricity and CHP with further growth of first generation biofuels (i.e. bioethanol and biodiesel and renewable diesel).

A detailed set of long-term goals, milestones, technologies, policies and barriers are defined for each of the two visions and are described as follows.

4.2. Long-term goals of the bioenergy technology roadmap

Long-term goals are quantifiable targets classified by bioenergy technology area for the two visions (see Figure 3 and Table 1). Goals for the vision focusing on new technologies cover biomethane and power generation and CHP, while goals for the vision combining new and traditional technologies cover all bioenergy technology areas. Long-term goals for bioethanol, biodiesel and renewable diesel aim at significantly increasing the quota mandates relative to fossil fuels in the transport sector. A second goal for bioethanol is the launch of a new E85 fuel program by 2030. The E85 blend was considered instead of E100 blend for various reasons according to current vehicle technology: i) cold start

[4] The Colombian national oil company, Ecopetrol, has already started analyzing the production of renewable diesel in dedicated or co-processing plants in the country (Ecopetrol, 2013).

emissions are lower, ii) vehicle performance (e.g. drivability in cold season) is improved, iii) water content can be increased without any separation, so avoiding problems during driving and iv) as required by the regulation framework of many Countries (e.g. US, Colombia, Brazil, Ecuador), the gas odorization process for ethanol by using hydrocarbons can be performed.

These goals reflect an interest in decreasing fossil fuel dependency and reducing carbon emissions in the transport sector through the use of first generation biofuels already deployed in Colombia (with the exception of renewable diesel, which has not been commercially deployed yet). On the other hand, the goals for biomethane, power generation and CHP are considered novel in the Colombian context. These goals aim at multiple directions, including: a) implementing advanced biofuels such as biomethane, b) implementing a renewable power target and deploying modern technologies such as biomass-based power plants, co-firing and gasification plants, which have not been widely deployed in the country and c) increasing the exploitation of residual biomass (e.g. biogas from animal waste and water treatment plants, landfill gas, etc.) for energy purposes. These novel goals show not only an interest in decreasing oil dependency and carbon emissions but also in using advance biofuels and biomass technologies that offer lower life cycle GHG emissions and land use than first generation commercial biofuels.

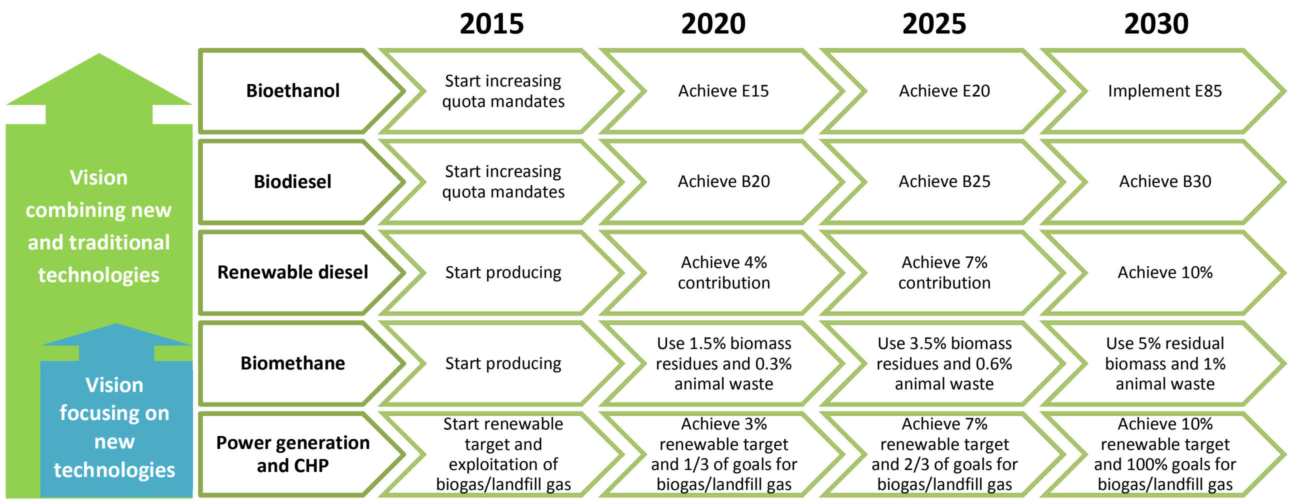

Figure 3. *Timeline of goals*

Table 1. *Set of long-term goals and milestones*

Vision	Bioenergy area	Long-term goals	Milestones
Vision combining new and traditional technologies	**Bioethanol**	• Increase the quota mandate from E10 to E20 (20% anhydrous ethanol in gasohol by volume) for gasoline-fuelled vehicles and motorcycles in 2025 • Implement an E85 (85% anhydrous ethanol in gasohol by volume) fuel program in 2030	• Gradually increase the bioethanol quota mandate. Start in 2015 and reach E20 in 2025 • Ensure that all new gasoline-fuelled vehicles and motorcycles commercially available in Colombia are flex-fuel vehicles (FFV) as of 2017 • Ensure satisfactory operation of non-flex-fuel aging vehicles with mid-level ethanol blends (>E10) by 2017-2020
Vision combining new and traditional technologies	**Biodiesel**	• Increase the quota mandate from B10 to B20 in 2020 and to B30 (30% biodiesel in blend by volume) in 2030 for all diesel-fuelled vehicles	• Gradually increase the biodiesel quota mandate. Start in 2015 and reach B20 in 2020 and B30 in 2030 • Ensure that all new diesel-fuelled vehicles commercially available in Colombia can operate with blends higher than B10 by 2017 • Ensure satisfactory operation of aging diesel-fuelled vehicles with blends higher than B10 by 2017-2020
Vision combining new and traditional technologies	**Renewable diesel**	• Achieve a 10% contribution (on an energy basis) of renewable diesel in the total diesel fuel production in 2030	• Gradually increase the contribution of renewable diesel in the total diesel fuel production. Start in 2015 and reach 10% in 2030
Vision combining new and traditional technologies; Vision focusing on new technologies	**Biomethane**	• Use 5% of biomass residues and 1% of biogas from animal waste nationwide to produce biomethane to be injected into the natural gas network by 2030	• Gradually increase the exploitation of residues and animal waste for biomethane production. Start in 2015 and reach goals in 2030
Vision combining new and traditional technologies; Vision focusing on new technologies	**Power generation and CHP**	• Supply 10% of the national electricity demand from renewable energy sources (excluding hydro > 10 MWe) by 2025. This target includes the following sub-targets: ○ Use 5% of the biogas from animal waste and municipal water treatment plants nationwide for energy purposes (electricity, heat or CHP) by 2030 ○ Use 100% of the biogas produced in the water treatment process of biodiesel production plants for energy purposes by 2030 ○ Use 10% of the municipal landfill gas produced nationwide for energy purposes by 2030	• Increase the renewable target from 0% in 2015 to 10% in 2025 ○ Gradually increase the exploitation of biogas from animal waste and municipal water treatment plants. Start in 2015 and reach 5% in 2030 ○ Gradually increase the exploitation of biogas in biodiesel production plants. Start in 2015 and reach 100% in 2030 ○ Gradually increase the exploitation of landfill gas. Start in 2015 and reach 10% in 2030

4.3. Milestones of the bioenergy technology roadmap

Milestones are intermediate steps required to accomplish the long-term goals. Details of the milestones classified by bioenergy area for the two visions are also shown in Table 1 and Figure 3. Most of the identified milestones are quantifiable measures. Examples include: gradual increases in the biofuels quota mandate (i.e. achieve B20 in 2020 and B30 in 2030), in the renewable target in power generation (i.e. reach 10% renewables in 2025), in the contribution of renewable diesel to total diesel production (i.e. reach a 10% contribution in energy in 2030) and in the exploitation of residual biomass (i.e. exploit 5% of the biomass residues and 1% of biogas from animal waste in 2030).

It is worth mentioning, that targets and milestones for exploiting residual biomass (e.g. biomass residues, residual biogas and landfill gas) are conservative. There are two reasons for this decision. Firstly, recent studies have estimated that the current fraction of residual biomass available for energy production (but not yet exploited) ranges from 4% to 10% of the theoretical biomass potential (Gonzalez-Salazar, et al., 2014a). Secondly, experts consider that exploiting 4% to 10% of residual biomass would require a very ambitious growth in infrastructure. Thus, a more likely target would range between 1% and 5% of the theoretical biomass potential.

To realize the quantitative milestones different e.g. technical pre-conditions have to be achieved (s. also section 4.4), which has to be settled in qualitative milestones. For example to realize the quota mandates for bioethanol and biodiesel non-flex-fuel aging vehicles can operate with mid-level ethanol blends (>E10) or with diesel blends higher than B10, respectively.

4.4. Barriers to implement the bioenergy technology roadmap

Certainly, there are barriers and gaps in knowledge that might thwart achieving the long-term goals and milestones. The next sections discuss in detail the barriers and gaps in knowledge identified by experts, as well as the recommended action items necessary to overcome them and achieve the goals. Various regulatory, market, technological and public acceptance barriers are identified for accomplishing the long-term goals and milestones. The following discussion draws heavily on (Gonzalez-Salazar, et al., 2014c). Other barriers associated with renewable power systems in the country are available in (Rosso-Cerón & Kafarov, 2015; Caspary, 2009).

4.4.1. Regulatory barriers

For biofuels already deployed in the country (i.e. biodiesel and bioethanol), most of the regulatory barriers relate to the lack of a centralized and consolidated authority issuing regulations, defining non-political mechanisms and long-term policies that allow further growth. For the particular case of biodiesel, the lack of regulations and mechanisms for monitoring and controlling the quality of biodiesel at all stages of the supply chain represents another critical barrier. For power generation and CHP, the lack of an effective regulatory framework and pricing scheme that supports the deployment of renewable energy, distributed and small-scale power generation and CHP represents the largest barrier. To the date of writing this paper, a new legislation on power generation and CHP has been approved

(Law 1715 of 2014) but not regulated. The scope and potential impacts of it are not covered in this study. Hence, it is acknowledged that some of the barriers and actions identified in this study might be already addressed by Law 1715. For other biofuels such as renewable diesel and biomethane, there are currently no regulations or incentives to encourage deployment.

4.4.2. Market barriers

The principal market barrier for the two long-term visions is the economics of various biomass conversion processes, which are not currently competitive with fossil-based alternatives without subsidies (IEA, 2012). This barrier is more severe for advanced biofuels and technologies such as biomethane and renewable diesel than for mature technologies (e.g. first-generation biofuels, biogas, etc.). Other market barriers include: a) unfavorable pricing schemes and market conditions, b) dependency from international price of oil and commodities and c) market restrictions to deploy certain technologies. Small-scale power plants are for example unable to sell power surplus and benefit from incentives, which prevents them from competing with large-scale hydro power plants. Currently, the governmental regulation sees a linking of local biodiesel and bioethanol prices to the international price of oil, commodities (e.g. palm oil and sugar) and the exchange rate. By this, macroeconomic trends influences directly local prices without taking into account the local market conditions. Presently, for economic and technical reasons, car manufacturers are not willing to produce or import vehicles able to operate the proposed biofuel blends. Moreover, it should be also considered that oil companies and vehicle manufacturers may also represent a further barrier, since using biofuel blends implies the partial replacement of consolidated fossil fuels in the transport sector. This recently occurred in Colombia and is testified by a heated debate between biodiesel producers and car manufacturers and oil companies about the possibility of increasing from B10 to B15 in 2018 and finally to B20 in 2022. Two measures are under consideration in Colombia to guide this process: i) creation of a national agency which reviews the fuel quality actually available in gas stations and ii) performing and extensive experimental campaign on currently available vehicles to assess how blends impact on engine performance and useful life.

4.4.3. Public acceptance barriers

Public acceptance barriers can be divided into three categories: a) lack of acceptance of the current regulatory framework, b) overlooking benefits associated with bioenergy and c) lack of acceptance of new technologies. Various stakeholders including end-users, smallholders, farmers and sectors of academia consider the current regulatory framework and commercialization scheme of biofuels (viz. bioethanol and biodiesel) to be inappropriate. On the other hand, the benefits of distributed generation and CHP are not perceived by sectors of the government, utilities and investors mainly because large hydro is considered the best option. Regarding new technologies, such as biomethane and renewable diesel, there is a perception that there is lack of collaborative projects between OEMs, utilities, SMEs and universities.

4.4.4. Technological barriers

Various technological barriers were identified for the different bioenergy areas (c.f. (Gonzalez-Salazar, et al., 2014c)) and can be divided into four categories: a) barriers due to appropriate feedstocks, b) barriers due to incompatibility and operability problems of biofuels in aging engines, c) barriers due to limited technology transfer and d) barriers due to unsound technological practices.

Barriers due to appropriate feedstocks are principally expected for the production of liquid biofuels, e.g. bioethanol, biodiesel, renewable diesel. Firstly, a conflict of crops for food vs. biofuels exists because feedstocks currently used for producing such biofuels (i.e. sugar cane and palm oil) are also used for human consumption. In addition, alternative feedstocks are not expected to be cost-competitive before 2030 with traditional feedstocks. That is the case of jaggery cane, cassava, red beet and lignocellulosic feedstocks to produce ethanol as well as jatropha curcas, soy, sunflower and algae to produce biodiesel and renewable diesel.

Barriers due to incompatibility and operability problems of biofuels in aging engines are expected for bioethanol, biodiesel and renewable diesel. While mid-level ethanol blends (> 10 v%) have been tested in aging vehicles in Colombia, claimed positive results are not fully acknowledged by all stakeholders, particularly the car industry and some sectors of academia. One of the main reasons for this skepticism is that previous international experiences using or testing such blends in non-flex-fuel aging vehicles are not conclusive (Gonzalez-Salazar, et al., 2014c). Moreover, results from test programs in other countries are often contradictory and show that potential impacts of mid-level ethanol blends on an aging fleet are site-specific and strongly dependent on vehicle technologies. For the case of biodiesel, some issues associated with its production and use remain unsolved, e.g. oxidative degradation and crystallization as well as increased tailpipe NOx emissions, ultrafine particles and particulate matter in aging and new engines. Furthermore, the use of mid-level biodiesel blends (> 10 v%) have not yet been tested in Colombia and international experience on this topic is non-conclusive (Gonzalez-Salazar, et al., 2014c). For the case of renewable diesel, no operability issues are expected in aging engines. However, given that the final fuel delivered to end-users of diesel engines would contain diesel fuel, biodiesel and renewable diesel, operability might be affected and should be tested.

Barriers due to limited technology transfer occur in all bioenergy areas. For bioethanol and biodiesel, there is limited interest of car manufacturers to commercialize vehicles able to operate with blends containing more than 10 v%. For renewable diesel and biomethane, the technology transfer is today practically non-existing. This lack of technology transfer combined with a limited local development of technologies is actually the largest obstacle to accomplish the goals of power generation & CHP. Particularly, it will affect the ability to increase the installed capacity of renewable power, to ensure robust performance and to exploit resources such as biogas and landfill gas. Barriers due to unsound technological practices also exist in many bioenergy areas. For bioethanol, the harvesting of sugar cane occurs today after burning of fields, which prevents the possibility of burning this residual biomass for energy production. For biodiesel, fossil fuels are used in all the supply chain and methane is released from water treatment plants in production facilities, which negatively affect the life cycle emissions. Similarly, the use of oil-based hydrogen in the production of renewable diesel affects its environmental performance. On the other hand, there is a lack of studies addressing the challenge of estimating the energy potential associated with various resources nationwide, such as biomethane, biogas, landfill gas, etc.

4.5. Action items to implement the bioenergy technology roadmap

In order to overcome barriers and achieve the envisioned long-term goals and milestones for the two visions, various action items are required. The multiple action items are divided into: a) sustainability, b) regulatory, c) financing mechanisms and business development and d) technological. Sustainability is an overarching concept that requires consideration of regulatory, financing and technological items. Therefore, it cannot be considered at the same level of these items. For this reason, sustainability action items prevail over other action items.

4.5.1. Sustainability action items

Bioenergy is considered an alternative energy to reduce greenhouse gas emissions, decrease oil dependence, enhance rural development and diversify the energy matrix. However, significant concerns need to be addressed to make use of bioenergy. Hurdles include the presumed negative environmental impact, land use competition, crops for food vs. biofuels, direct and indirect land use change, deforestation, pressure on water resources, etc. In the Colombian context, additional concerns need to be considered. A 50-year armed conflict resulted in massive internal displacement of civilians, farmers and indigenous communities by illegal armed groups. Abandoned land was usurped, illegally traded and used for agriculture, mining and other purposes (UNDP, 2011). In addition, public policies ruling rural areas have historically privileged large landholders over small farmers and have supported low productivity activities (e.g. extensive cattle farms) with limited capacity to create jobs (UNDP, 2011). Therefore, a more balanced and democratic land distribution that allows a more productive and environmentally friendly use of rural land should be a priority. The inclusion of all stakeholders, particularly small- and medium-scale farmers, in the decision-making process of deploying bioenergy technologies is therefore essential. In this context, the victims and land restitution land law (Law 148) issued in 2011 in Colombia (MIJ, 2011) is certainly a step in the right direction.

There is scientific consensus that sustainability requirements and certification schemes are necessary to monitor environmental and social sustainability of bioenergy policies (GBEP, 2011a). Certification schemes also offer several advantages to biomass growers and bioenergy producers. On one hand, certification schemes ensure a credible standard to demonstrate benefits to tax payers and authorities. On the other hand, stakeholders can be recognized for the environmental, social and economic sustainable production of bioenergy. Strategic planning of land use should be emphasized to avoid deforestation, loss of biodiversity, displacement of communities, water and soil pollution, increasing gap between rich and poor and overall negative impacts. Various national and international initiatives and approaches for the sustainability certification of bioenergy have been recently proposed and developed worldwide (Scarlat & Dallemand, 2011). Although a dedicated effort to select and define bioenergy sustainability criteria for Colombia is certainly beyond the scope of this study, an exploratory scheme on the sustainability of bioenergy is suggested. This sustainability scheme also aims at mitigating the multiple public acceptance barriers identified in Section 4.4.3. It is strongly recommended, however, that a commission representing all stakeholders (environmental authorities, industry, academia, local communities, etc.) take a leading role in defining a more detailed framework for bioenergy certification schemes in Colombia and consider lessons learnt from pilot testing the GBEP indicators in the country. The deployment of bioenergy technologies and particularly the long-term goals defined in Section 4.2 should be bound to the bioenergy sustainability scheme to ensure not only environmental and economic benefits, but also rural and social development. The proposed scheme comprises four main categories of requirements explained as follows:

<u>Requirements related to climate policy</u>

Use of biofuels and conversion of biomass into energy should reach a minimum of GHG savings. Biofuels should reach a reduction in GHG of for example 40% relative to fossil fuels in 2015, 50% in 2020 and 60% in 2025. Biomass conversion to electricity, heating or cooling should reach a reduction in GHG of for example of 40% relative to fossil fuels in 2015, 50% in 2020 and 60% in 2025. Monitoring and reporting of GHG emissions is mandatory and should be rigorously supervised by environmental authorities. GHG savings should include emissions from cultivation, processing, transport, distribution and direct land use changes. Indirect land use changes (ILUC) must be included, but only after the scientific community reaches consensus on a sound accounting method. The method to calculate GHG savings should be widely recognized by the scientific community; examples include the Renewable Energy Directive 2009/28/EC of the European Union (EC, 2009a; EC, 2009b), the GBEP framework for GHG life cycle analysis of bioenergy (GBEP, 2011b), the Roundtable on Sustainable Biofuels GHG Calculation Methodology (RSB, 2011), among others. Well-accepted methodologies for estimating GHG emissions are also presented in (Jaramillo, Griffin, & Matthews, 2007; Jiang, et al., 2011; Burnham, et al., 2012).

Requirements related to environmental policy

Some land categories should be excluded of use for bioenergy production. These land categories include: a) natural parks and protected forests, b) tropical forests, native rain forest and wooded land, c) highly biodiverse ecosystems (wetlands, swamps, paramo, biodiverse savannah, etc.) and d) land with high carbon stock. Additionally, forests used to supply wood to energy projects (e.g. power generation, biofuels, biomethane, etc.) should comply with the certification of the Forest Stewardship Council (FSC), which is the best certification currently available (Leonard, 2010). Tropical forests or forests with indigenous vegetation must not be replaced by tree plantations. Tree plantations are monoculture fields of imported species, which provide relatively few jobs, increase the use of pesticides and negatively impact water cycles (Meadows, 1997). It might be advisable to use tree plantation only in eroded or degraded land. Regarding protection of water resources, biomass conversion and biofuels production must ensure that the quality of groundwater and surface water remains at high standards (a 5-day carbonaceous BOD below 2 mg/L) for human consumption, small-scale farming and fishing. Furthermore, it is advisable that these processes must regularly report their associated water footprint, which is the total volume of fresh water used.

Requirements related to rural development measures

The participation of local indigenous communities (natives, Afro-Colombians and members of other minorities) in the decision-making and the environmental planning process of projects affecting their land, resources and communities must be secured and protected. This in accordance with the United Nations Declaration on the Rights of Indigenous People adopted in 2007 (UN, 2007). Thus, permits to use land for bioenergy purposes fulfilling environmental requirements must be jointly evaluated by indigenous communities, and regulatory and environmental authorities.

Requirements related to incentives and financial mechanisms

Four main requirements related to incentives and financial mechanisms are recommended. Firstly, additional economic and tributary incentives should be given to conversion of waste, residues, non-food cellulosic and lignocellulosic biomass into energy. Secondly, as it is expected that biofuels and bioenergy will become more price-competitive over time, subsidies and economic incentives should not be indefinite and should start declining by 2015.

Thirdly, access to subsidies and tributary incentives should be subject to a verifiable increase in rural jobs, and rural development (e.g. increase in rural GDP, infrastructure, etc.) in areas producing bioenergy, reduction in life cycle GHG emissions, protection of water sources and biodiversity and non-use of land categories excluded from bioenergy production. In the particular case of CHP, access to incentives should be subject to an appropriate use of the heat released in power plants to supply industrial, commercial, agricultural or energy processes. Finally, it is advisable to jointly revise and re-design the current biofuel regulatory framework with representatives from consumers, smallholders, farmers and academia. Topics to address include: a) appropriateness of subsidies, b) pricing system, c) mechanisms to protect the end-users, d) responsibilities of local biofuel producers to ensure sustainable operation, reduce GHG emissions, increase rural jobs, etc.

4.5.2. Regulatory action items

Regulatory action items classified by bioenergy area for the two visions are summarized in Table 2. For bioethanol and biodiesel, it is firstly advisable to unify and centralize the definition of policies, regulations and long-term goals. It is also necessary to modify the existing policy framework (viz. to enable E20 in 2025, B30 and E85 in 2030, to implement a flex-fuel framework, to regulate the compliance of a sustainability scheme) to achieve the proposed long-term goals. For power generation and CHP, it is recommended to implement a renewable energy auction scheme, modify the existing policy framework to enable a renewable target of 10% in 2025 and stimulate the deployment of distributed generation, CHP, biogas, and landfill gas. For biomethane, it is appropriate to stimulate an efficient use of residues and encourage the substitution of highly pollutant coal in order to achieve the targets by 2030. For renewable diesel, a new policy is required to enable the implementation of a 10% energy contribution by 2030.

Table 2. *Regulatory action items*

Vision	Bioenergy area	Regulatory action items
Vision combining new and traditional technologies	**Biodiesel and bioethanol**	• It is advisable that various ministries jointly create policies and regulations for biofuels, or alternatively by a new institution, that centralizes actions and policies. This offers various benefits: a. It would unify the official position of the government towards biofuels. b. It would define a clear and unambiguous set of national long-term goals for biofuels, aiming at improving the sustainable development of the country. c. It would centralize the definition of standards and rules (e.g. the bioenergy sustainability scheme), aiming at reducing the political influence of third parties on biofuel policies. d. It would encourage a multidisciplinary discussion within the government to address biofuels from an energetic, agricultural and environmental perspective. • It is required to implement a regulatory framework enabling: a) a gradual increase in quota mandate to B20 in 2020, E20 in 2025 and B30 in 2030 and b) the implementation of an E85 fuel program in 2030. • It is required to implement a clear and definitive regulatory framework to force the introduction of flex-fuel vehicles (FFV) as of 2017. It would ensure that all new vehicles and motorcycles commercialized in the country are FFV and can satisfactorily operate with any blend of ethanol and gasoline. This regulatory framework should also force the introduction of diesel-fuelled vehicles able to operate blends higher than B10. Additionally, it would be advisable to design this framework in such a way that it does not block introduction of other vehicle alternatives, such as electric and hybrid vehicles. • It is advisable to implement a regulatory framework to supervise and verify that local biofuel producers comply with the requirements of the sustainability scheme. It is also necessary, particularly in the biodiesel case, to control the quality of the biofuel at all stages of the supply chain.
Vision combining new and traditional technologies	**Renewable diesel**	It is required to implement new regulations and legislation to enable the deployment of renewable diesel targets by 2030.
Vision combining new and traditional technologies; Vision focusing on new technologies	**Biomethane**	It is required to modify existing regulations and legislation to: a. Enable the implementation of biomethane targets by 2030. b. Stimulate the substitution of highly-pollutant coal by biogas/biomethane in various sectors either by penalizing emissions, by offering incentives (tariff exemption for importing/developing equipment, tax reduction, support for demonstration projects, etc.) or by combinations thereof. c. Create a mechanism to stimulate an efficient use of biomass residues and animal waste (urban and non-urban) for energy purposes. Potential solutions include price bonuses for effective waste management solutions, tariff exemption for developing equipment, tax reduction for imports, support for demos, etc. d. Control and monitor the disposal of organic waste in landfills.
Vision combining new and traditional technologies; Vision focusing on new technologies	**Power generation and CHP**	• The most appropriate framework to support a new power generation and CHP policy is the national renewable energy auction. It is considered the most appropriate because it respects the principle of equal opportunity and competitiveness among different technologies (a characteristic of the Colombian electricity framework), it limits the risk for investors and it increases the predictability of the renewable energy supply (IRENA, 2013). However, it should be carefully designed and acknowledge the experiences of other countries in order to avoid failures (e.g. favoring large players, discontinuous market development and risk of underbidding (IRENA, 2013)). • It is required to modify existing regulations and legislation to: a. Enable the implementation of a 10% renewable target by 2025, biogas and landfill gas targets by 2030. b. Allow “self-generators” to sell power surplus to the grid. Additionally, it is advisable to estimate the actual installed capacity to evaluate the real impact of “self-generators”. c. Allow cogeneration power plants to apply for the reliability charge incentive. d. Allow the implementation of clusters of hybrid power plants (combination of different technologies, e.g. wind, small-hydro and biomass) to increase availability, reliability and risk mitigation not by power plant but by cluster. e. Stimulate the capture and use of biogas produced from animal waste, municipal water treatment plants and biodiesel plants either by penalizing emissions or offering incentives. f. Stimulate the capture and use of municipal landfill gas either by penalizing emissions or offering incentives.

4.5.3. Action items on financing mechanisms and business development

Action items on financing mechanisms and business development are summarized in Table 3.

Table 3. *Action items on financing mechanisms and business development*

Vision	Bioenergy area	Action items on financing mechanisms and business development
Vision combining new and traditional technologies	**Biodiesel and bioethanol**	• Implement a program to reduce the cost of producing bioethanol and biodiesel by improving the efficiency in harvesting, collection and exploitation of residues (e.g. cane leaves and tops and palm oil rachis), wastewater treatment practices (e.g. methane capture) and conversion processes (e.g. boilers and CHP systems). This program might be accompanied by benefits for developing or importing appropriate machinery and equipment • Implement an incentive program primarily aimed at encouraging the local development or assembly of vehicles able to operate with high biofuel blends (e.g. flex-fuel vehicles for bioethanol) or secondly at reducing the import tariffs. Seek partnerships with OEMs willing to locally develop, assemble or import such vehicles • Implement an incentive program aimed at reducing import tariffs or the value added tax (VAT) for importing agricultural supplies used by local producers of biomass and biofuels
	Renewable diesel	• Implement a careful plan for managing palm oil production and distribution to biodiesel and renewable diesel processing plants in order to reduce the impacts of competition for feedstocks. Additionally, implement a mitigation plant to identify and manage alternative feedstocks
Vision focusing on new technologies	**Biomethane**	• Implement an incentive program aimed at encouraging the substitution of cheap fossil fuels (e.g. coal, diesel fuel, etc.) by biomethane (pure or blended with natural gas) either by penalizing the consumption of fossil fuels or by reducing taxes on biomethane
	Power generation and CHP	• Implement an incentive program aimed at encouraging the operation of small scale and distributed power plants and CHP (e.g. (Gonzalez-Salazar & Willinger, 2007)) through tax benefits and technical support. Additionally, encourage the local development or assembly of distributed and renewable energy technologies. It is crucial to seek partnerships with OEMs, utilities, SMEs and universities to build demonstration and pilot projects, etc. • New initiatives for providing services and energy solutions are required to support the incipient industry of distributed power generation and CHP. It would be advantageous to promote the creation of Energy Service Companies (ESCOs), able to provide energy savings projects, energy efficiency solutions, implementation of renewable energy sources, risk management, etc. However, a program for the promotion of ESCOs should be carefully designed in order to avoid the most common failures, e.g. lack of trust among investors, perceived high technical and business risk, lack of policy mechanisms to support ESCOs, high transaction costs, etc. (Bertoldi, Boza-Kiss, & Rezessy, 2007; Kostka & Shin, 2011)

It is recommended to implement incentive programs to encourage the use of bioenergy through tax incentives and the local development of technologies. These incentive programs aim to reduce the production costs of bioenergy technologies, improving the efficiency of supply chains and conversion processes, improving the national competitiveness and supporting the local development of machinery, equipment and R&D. It should be noted that these actions require a minimum case-by-case sensitive scale to be economically feasible and therefore require proper planning. For this purpose it is crucial to seek partnerships with OEMs, utilities, SMEs and universities to build demonstration and pilot projects. Additionally, new initiatives for providing services and energy solutions (e.g. Energy Service Companies –ESCOs–) are required to support the incipient industry of distributed power generation.

4.5.4. Technological action items

Technological action items by bioenergy technology area are described as follows. Technologies recommended for deployment by bioenergy technology area are summarized in Figure 4.

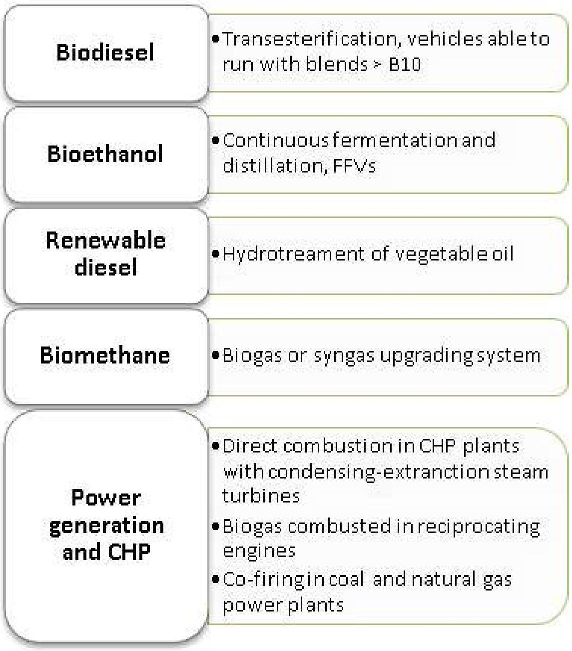

Figure 4. *Technologies to deploy by bioenergy technology area*

<u>Bioethanol</u>

It is recommended to further deploy cane-based bioethanol with continuous fermentation and vinasse recirculation, subject to compliance with the sustainability scheme. Continuous fermentation with vinasse recirculation is recommended, as it is a mature and commercially available technology, which has been already successfully implemented in the country. Besides, vinasse recirculation offers a significantly lower vinasse production (i.e. 0.8 to 3 l-vinasse/l-ethanol) than the ferti-irrigation approach currently used in Brazil (8-12 l-vinasse/l-ethanol) (BID-MME, Consorcio CUE, 2012). It is also recommended to continue deploying water treatment plants for effluents to ensure high quality standards for ground- and surface water. Additionally, a satisfactory operation of non-flex-fuel aging vehicles and motorcycles with mid-level ethanol blends (> E10) must be ensured. Thus, it is recommended to start a well-coordinated test campaign involving all stakeholders, covering a statistically representative sample of the existing vehicle fleet and following a methodology that might be verified by the scientific community. In order to improve the environmental performance of bioethanol, rigorous environmental studies subject to verification must be undertaken, including analyses of land use change, water demand and wastewater production, impact on biodiversity, impact of vinasse disposal on soil, groundwater and surface water, and life cycle emissions. Finally, various improvements are recommended to enhance productivity and environmental performance, such as avoid cane burning before harvesting and deploy mechanical harvesting and exploit residues in CHP systems.

Biodiesel

It is recommended to continue deploying palm-based biodiesel via transesterification equipped with water treatment plants and subject to compliance with the sustainability scheme. In addition, a satisfactory operation of legacy vehicles operating with blends > B10 must be ensured. Similarly, to the case of bioethanol, a well-coordinated test campaign involving all stakeholders and rigorous environmental studies are recommended. Further research is required to reduce the negative impacts associated with biodiesel blends. Topics include reduce tailpipe NOx, particulate matter and ozone, reduce the negative impacts of antioxidant additives, reduce the impact of biodiesel crystallization on engine operability, etc. Other recommended improvements to enhance productivity and environmental performance include: a) minimize the use of fossil fuels and encourage their substitution for palm oil residues and b) deploy technologies to capture methane from wastewater plants.

Renewable diesel

Long-term goals for renewable diesel can be reached using hydrocracking or hydrogenation of vegetable oil, which are in an early commercial phase and are expected to become available in Colombia in the short-term. Additionally, further research is required to find ways to produce cost-effective hydrogen from renewable sources and to carefully blend diesel fuel, biodiesel and renewable diesel.

Biomethane

It is recommended to deploy two technologies, depending on the feedstock: a) the purification of landfill gas and biogas from animal waste and b) syngas via gasification followed by methanation to convert biomass residues. While landfill gas/biogas purification is a mature technology, gasification and methanation are in an early commercial stage. Additionally, further research is required to increase the ability to process different types of feedstocks, to improve syngas cleaning (e.g. tar removal) and upgrade, and to reduce operability issues (particularly for biomass gasification).

Power generation and CHP

To achieve the renewable target of 10% in 2025, it is recommended to deploy onshore wind, small-hydro and biomass power plants. Recommended biomass-based power generation technologies, include: a) direct combustion in CHP power plants using condensing-extraction steam turbines (feedstocks: wood residues, bagasse, cane and palm residues and rice husk), b) co-firing in coal power plants using biomass pellets and co-firing in natural gas power plants using syngas from gasified biomass, c) combustion of landfill gas and biogas in reciprocating engines. It is also

recommended that clusters of hybrid power plants (a combination of different technologies, e.g. wind, small-hydro and biomass) are implemented, thereby increasing availability and reliability not by power plant but by cluster. The best practices of the sugar cane and paper industry engaged in cogeneration should be replicated to other crops producing large amounts of residues and consuming energy, such as palm oil, jaggery cane, rice, coffee, coconut, etc.
In addition, further research is required to evaluate the impact of replacing hydropower by biomass-based power. For instance, a complementing effect might be expected in dry seasons when the availability of bagasse-fired CHP tends to increase, while the availability of hydropower tends to reduce. Potential advantages include a higher availability and grid reliability and a reduced consumption of fossil fuels to replace hydro. Therefore, more in general, the development of renewable sources is helpful for a Country energy security, especially during drought seasons. Finally, it is recommended to seek partnerships between OEMs, utilities, local companies and universities, to start demos and pilots in the short term that might lead to commercial projects in the medium term. It is necessary to encourage technology transfer combined with local manufacturing to ensure the continuity of projects and know-how creation.

5. Guidelines and recommendations

Considering the vast potential and the significant demand for bioenergy in developing countries, it is useful to ask how the process of developing a roadmap for deploying bioenergy technologies in Colombia can bring lessons and provide guidelines to other countries.

Firstly, it is fundamental to start a technology roadmapping process. In many countries, bioenergy resources have been used informally and inefficiently, which has led to severe environmental and health problems. Thus, initiating the process of technology roadmapping offers various benefits: a) it enables a nation to prepare for the future in an orderly and systematic way, b) it provides a basis for building consensus on needs and for measuring progress and impact and c) it turns consensus and analytical work into systematic actions. In this paper authors initiated this process in Colombia and governmental agencies can update it or continue it in the future. While technology roadmapping is very advantageous, it is also demanding. It involves many uncertainties in a rapidly changing external environment that demands significant more time and resources than short-term planning.

Secondly, it is fundamental to employ the right roadmapping method. In this paper, a new method for technology roadmapping is proposed. This method is largely based on the guide to development and implementation of energy technology roadmaps developed by IEA (IEA, 2010). While the IEA's guide is a very detailed and robust method that can be applied to any country, its structure is best adapted to OECD countries. For such countries, it can be challenging to implement the full method, which requires various detailed and lengthy processes and involve multiple working groups. In developing countries, resources and experts often lack or should focus on fulfilling needs that are more urgent. Thus, the original IEA method has been here simplified. The number of process steps and feedback loops has been reduced, a new strategy for building consensus has been proposed and a more prominent role to analytical modeling has been given (optional in the IEA's guide). In addition, authors stress the importance of using inexpensive and generic tools to perform analytical modeling, as discussed in detail in a separate paper (Gonzalez-Salazar, et al., 2016).

Thirdly, it is critical to involve decision-makers and a significant number of experts representing all stakeholders. Involvement of decision-makers from the government would certainly facilitate not only the access to data and analyses, but also the process of implementing the roadmap and updating or continuing the roadmapping process. Moreover, decision-makers should drive the roadmapping process. On the other hand, the involvement of experts representing all stakeholders encourages inclusiveness in the definition of long-term strategies and adds credibility to the roadmap and its implementation. However, an extensive number of participants can be counterproductive, as reaching consensus might be difficult.

Fourthly, it is important to understand that sometimes consensus cannot be built among experts. In this case, the IEA recommends choosing one position, to present the opposing views if one of those is the minority, or to attempt to create consensus between the two sides. In this study, experts strongly disagreed on the long-term goals for deploying transport biofuels (i.e. bioethanol, biodiesel and renewable diesel) and no consensus could be built. Authors decided to present both views in this paper and analyze them separately through a scenario analysis. While typically, technology roadmaps do not consider various storylines, in this study the scenario analysis helped to investigate the most effective policy measures, which might increase their chances of implementation.

Finally, it is crucial to define the right mechanism to put the roadmap into place. The present study, which is an academic initiative, does not have forcing mechanisms to put it into place. Conclusions and recommendations presented here can be interpreted as an attempt to initiate the technology roadmapping process and can be used as an input to policy-makers. However, the possibility to implement it is currently uncertain, even though various participants from governmental agencies were involved. Thus, to ensure the success of a technology roadmap, it is necessary that governmental agencies drive the process and ensure its implementation.

6. Conclusions

In this paper, the process of developing a roadmap for deploying bioenergy technologies at a country level is described. On one hand, a method for energy technology roadmapping adapted to the conditions of developing countries is proposed. The method consists of three components: 1) a simplified version of the structure proposed in the guide to develop and implement energy technology roadmaps by the IEA, 2) a new strategy to build consensus and 3) a strong focus on analytical modeling for supporting expert judgment. Advantages of the proposed method include: simplicity, adaptability to developing countries, a more systematic strategy to achieve consensus and to handle divergence and a stronger focus on analytical modeling compared to state-of-the-art approaches.

On the other hand, the proposed method is applied for creating a plan to deploy sustainable bioenergy technologies in Colombia for the period 2015-2030. The plan consists of a set of long-term goals, milestones, barriers and action items identified by 30 experts for different bioenergy technology areas. This group of experts considered five key bioenergy technology areas: a) bioethanol, b) biodiesel, c) renewable diesel, d) biomethane and e) biomass-based power generation and combined heat & power (CHP). Unanimous agreement was achieved on the long-term vision for biomethane and biomass-based power generation. However, there were opposing views on the long-term vision of liquid transport biofuels (i.e. bioethanol, biodiesel and renewable diesel) produced from feedstocks that are used for human consumption. Consequently, two different long-term visions are considered in the roadmap. The first vision targets the deployment of new technologies for the production of biomethane, electricity & CHP, while fixing the current blend mandate of first generation liquid biofuels. The second vision targets a combination of new technologies for the production of biomethane, electricity & CHP, while further growing first generation biofuels. Various actions are required to deploy the technologies defined in both visions. Firstly, it is necessary to define and implement a bioenergy sustainability scheme to be bound to the deployment of bioenergy technologies. Secondly, new regulations and policies are required to enable the implementation of long-term targets for the different bioenergy areas. Thirdly, incentive programs and financial mechanisms need to be implemented to encourage technology transfer combined with local development. Fourthly, technical risks must be mitigated by engaging all stakeholders and local communities, acknowledging past international experiences and following best practices.

Application of the proposed method to the study case of Colombia involved some limitations, which are here acknowledged as a guideline for possible implementations in other developing countries. Firstly, the number of experts that participated in the development of the roadmap is lower than the one recommended for similar initiatives at a country level (approximately 50-100 participants according to IEA), but the experts were representative of the whole Colombian energy scenario. Secondly, the proposed roadmap is the result of an academic initiative, which does not have forcing mechanisms to put it into place. Instead, conclusions and recommendations presented can be regarded as: a) an attempt to initiate a technology roadmapping process that governmental agencies can continue and effectively implement in the future and b) an input to policy-makers planning the deployment of bioenergy in a post-conflict scenario in the country. In summary, this paper provides various lessons and policy implications to other developing countries using technology roadmaps to exploit biomass resources and bioenergy technologies on the long-term.

Acknowledgments

Authors would like to express their gratitude to all roadmap experts and reviewers and to GE Global Research for its contributions.

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Supplementary Information 1: Questions formulated in the first survey and responses from experts

Questions		Possible answers	Response
1	Country of origin		Colombia (91%), Ecuador (4.5%), Portugal (4.5%)
2	Field of expertise	a) Biofuels, b) power generation, c) biofuels and power generation, d) other	Biofuels and/or power generation (82%), other (18%)
3	Affiliation	a) University or R&D, b) industry, c) government, d) international organization or non-governmental organization, e) other	University and R&D (62%), industry (24%), government (10%), IO/NGO (5%)
4	Would you like to participate on behalf of your institution or on your own behalf?	a) Institution, b) own behalf	Institution (40%), own behalf (60%)
5	Do you work or have worked on the design of energy policies?	a) Yes, b) no	Yes (59%), no (41%)
6	How would you describe the current market conditions to:	a) Very good/good, b) neither good nor poor, c) poor/very poor	
	a. Produce bioethanol?		Very good/good (68%), neither good nor poor (32%), poor/very poor (0%)
	b. Produce biodiesel?		Very good/good (68%), neither good nor poor (23%), poor/very poor (9%)
	c. Generate biomass-based power and combined heat and power (CHP)?		Very good/good (19%), neither good nor poor (32%), poor/very poor (50%)
7	How would you describe the current technologies used in Colombia to:	a) Very good/good, b) neither good nor poor, c) poor/very poor	
	a. Produce bioethanol?		Very good/good (64%), neither good nor poor (32%), poor/very poor (5%)
	b. Produce biodiesel?		Very good/good (64%), neither good nor poor (32%), poor/very poor (5%)
	c. Generate biomass-based power and CHP?		Very good/good (10%), neither good nor poor (41%), poor/very poor (50%)
8	How would you describe the effectiveness of the current policy framework to:	a) Very good/good, b) neither good nor poor, c) poor/very poor	
	a. Produce bioethanol?		Very good/good (55%), neither good nor poor (23%), poor/very poor (23%)
	b. Produce biodiesel?		Very good/good (54%), neither good nor poor (18%), poor/very poor (28%)
	c. Generate biomass-based power and CHP?		Very good/good (5%), neither good nor poor (23%), poor/very poor (73%)
9	Do you think bioenergy should be promoted in the future?	a) Yes, b) no	Yes (100%)
10	Please select the top-3 reasons why bioenergy should be supported	a) Reduce GHG emissions, b) enhance energy security, c) create jobs, d) promote rural development, e) other.	
	a. 1st reason		Promote rural development (30.3%)
	b. 2nd reason		Enhance energy security (25.8%)
	c. 3rd reason		Reduce GHG emissions (21.2%)
11	Please select the top-3 national energy targets that you expect will be implemented over 2014-2030 in Colombia.	a) Reduce GHG emissions below 1990 levels, b) increase share of renewable power generation (exc. Large hydro), c) increase share of biofuels of road transport fuel, d) reduce the volume of imported fossil fuels, e) increase energy efficiency, f) increase access to electricity in non-interconnected zones, g) other	
	a. 1st national energy target		Increase energy efficiency nationwide (22.8%)
	b. 2nd national energy target		Increase share of biofuels in road transport fuel (19.7%)
	c. 3rd national energy target		Increase share of renewable power generation, exc. large hydro (16.7%)

12	Please select the top-3 key barriers to further deploy bioethanol	a) Low price of bioethanol, b) lack of political support, c) potential market threat from imported duty-free ethanol, d) limitations in technology, e) limited production capacity, f) limited infrastructure for expansion, g) limited infrastructure for transporting ethanol, h) limited success of current policy framework, i) lack of clear targets and strategic planning, j) lack of public acceptance, k) other	
	a. 1st key barrier		Lack of clear targets and strategic planning (21.7%)
	b. 2nd key barrier		Limitations in technologies to produce bioethanol (11.7%)
	c. 3rd key barrier		Others (11.7%)
13	Please select the top-3 key barriers to further deploy biodiesel	a) Low price of biodiesel, b) lack of political support, c) potential market threat from imported duty-free biodiesel, d) limitations in technology, e) limited production capacity, f) limited infrastructure for expansion, g) limited infrastructure for transporting biodiesel, h) limited success of current policy framework, i) lack of clear targets and strategic planning, j) lack of public acceptance, k) other	
	a. 1st key barrier		Lack of clear targets and strategic planning (17%)
	b. 2nd key barrier		Limited production capacity that covers only domestic market (17%)
	c. 3rd key barrier		Others (15.2%)
14	Please select the top-3 key barriers to further deploy biomass-based power generation	a) Low price of electricity, b) lack of political support, c) competition with subsidized diesel-based generation in NIZ, d) limitations in technology, e) high cost of technologies, f) limited infrastructure for transporting biomass, g) perception that hydropower is the best solution, h) limited success of current policies, i) lack of clear targets and strategic planning, j) lack of public acceptance, k) other.	
	a. 1st key barrier		Lack of clear targets and strategic planning (19.3%)
	b. 2nd key barrier		High cost of power generation equipment (17.5%)
	c. 3rd key barrier		Competition with subsidized diesel-based generation in NIZ (15.8%)

Supplementary Information 2: Questions in second survey

Part 1: Information about the participant

This part intends to collect information about the expertise of the survey's participant

	Question	Possible answers
1	Please select your level of expertise on biomass-based power generation	a) excellent, b) above average, c) average, d) below average, e) poor
2	Please select your level of expertise on biofuels	a) excellent, b) above average, c) average, d) below average, e) poor
3	Please select your level of expertise on energy policy	a) excellent, b) above average, c) average, d) below average, e) poor

Part 2: Increase share of renewable power generation

This part intends to identify concrete goals and specific pathways for the target of increasing share of renewable power generation (excluding hydropower >10 MW)

	Question	Possible answers
4	Please select the percentage of total electricity that you think should be generated from renewable energy sources (excluding hydropower > 10 MW)	a) 2.5%, b) 5%, c) 7.5%, d) 10%, e) other
5	Please select the year at which you expect this target to be accomplished	a) 2015, b) 2020, c) 2025, d) 2030
6	Please select the top-3 technology scenarios to generate biomass-based power and CHP that you expect to be implemented to achieve this target	a) Biomass fired CHP plants using condensing-extraction steam turbines, b) Biomass fired organic Rankine cycle (ORC) power plants, c) Biomass gasification and syngas combustion in reciprocating gas engines, d) Biomass gasification and syngas combustion in gas turbines, e) Biomass co-firing (up to 10% by volume) in existing coal power plants, f) Combustion of landfill gas in reciprocating engines, g) Anaerobic digestion and biogas combustion in reciprocating engines, h) other
	a. 1st scenario	
	b. 2nd scenario	
	c. 3rd scenario	
7	Do you think a new policy framework is necessary to support renewable power generation (excluding hydropower > 10 MW)?	a) yes, b) no
8	If the answer to the previous question is positive, please select the option that you consider most appropriate for Colombia	a) feed-in-tariff, b) Renewable Energy Portfolio Standard, c) National Renewable Energy Auction, d) Net metering, e) Renewable Energy Certificates, f) Other, g) Do not know

Part 3: Increase share of biofuels in road transport fuel (bioethanol)

This part intends to identify concrete goals and specific pathways for the target of increasing share of bioethanol in the road transport fuel

	Question	Possible answers
9	Please select the percentage quota mandate of bioethanol in gasohol (volume basis)	a) E12, b) E15, c) E20, d) E25, e) hE15 (15% hydrous ethanol), f) he100 (pure hydrous ethanol), g) other
10	Please select the year at which you expect this target to be accomplished	a) 2015, b) 2020, c) 2025, d) 2030
11	Please select the top-3 technology scenarios to produce bioethanol that you expect to be implemented to achieve this target	a) cane-based bioethanol with standard fermentation and distillation, b) cane-based bioethanol with improved fermentation and distillation, c) small-scale cane-based bioethanol with batch fermentation and distillation, d) bioethanol from alternative feedstock (cassava, beet, etc.), e) lignocellulosic bioethanol, f) other
	a. 1st scenario	
	b. 2nd scenario	
	c. 3rd scenario	
12	Do you think the existing policy framework to support bioethanol production should be modified?	a) yes, b) no
13	If the answer to the previous question is positive, please describe the reasons for doing so	

Part 4: Increase share of biofuels in road transport fuel (biodiesel)

This part intends to identify concrete goals and specific pathways for the target of increasing share of biodiesel in the road transport fuel

	Question	Possible answers
14	Please select the percentage quota mandate of biodiesel in diesel fuel (volume basis)	a) B12, b) B15, c) B20, d) B25, e) other
15	Please select the year at which you expect this target to be accomplished	a) 2015, b) 2020, c) 2025, d) 2030
16	Please select the top-3 technology scenarios to produce biodiesel that you expect to be implemented to achieve this target	a) palm-oil biodiesel via transesterification, b) palm-oil biodiesel vial alternative methods, c) biodiesel from alternative feedstock (jatropha, soy, etc.), d) biodiesel via hydrotreated vegetable oil, e) biodiesel via gasification and Fischer-Tropsch, f) biodiesel via algae, g) other
	a. 1st scenario	
	b. 2nd scenario	
	c. 3rd scenario	
17	Do you think the existing policy framework to support biodiesel production should be modified?	a) yes, b) no
18	If the answer to the previous question is positive, please describe the reasons for doing so	

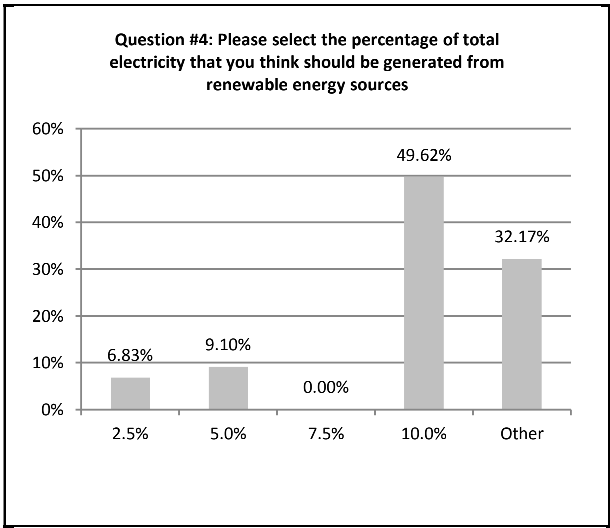
Part 5: Alternative biofuels and additives

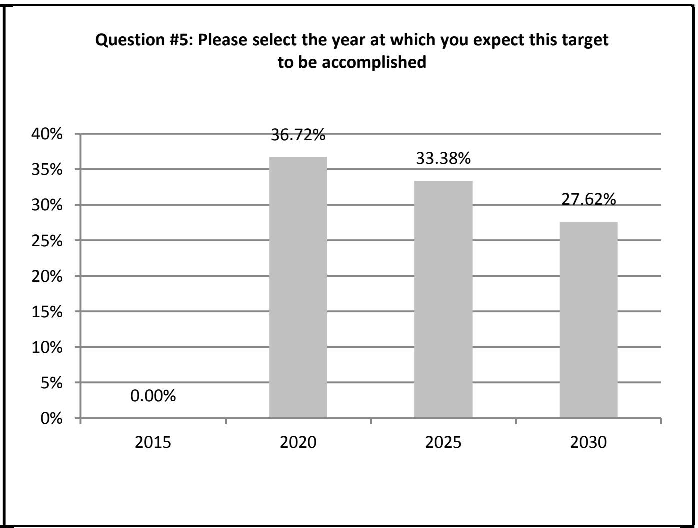
This part intends to capture the participant's perception of the use of alternative biofuels and additives

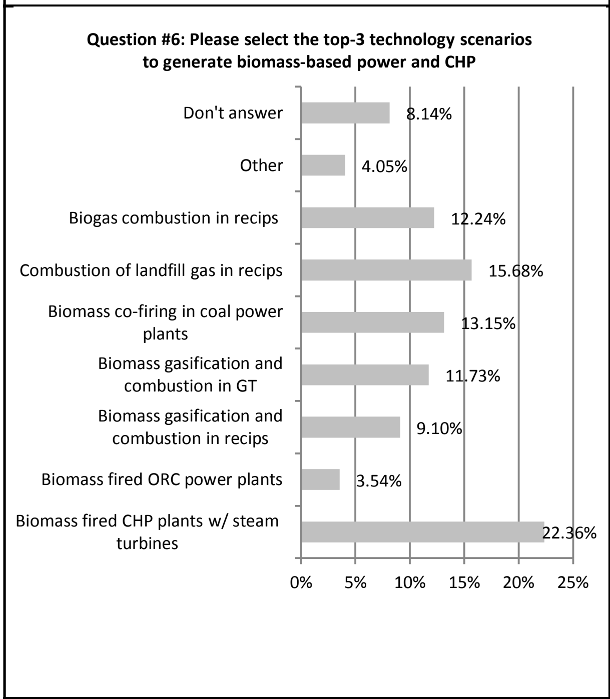
	Question	Possible answers
19	Do you think alternative biofuels and additives should be promoted?	a) yes, b) no
20	If the answer to the previous question is positive, please select the most appropriate option for Colombia	a) Bio-methane for injection into natural gas grid, b) pyrolysis-based fuels, c) Dimethyl ether (DME), d) methanol, e) hydrogen, f) other
21	Do you think there should be a target for your selected option? Please describe it.	a) yes, b) no

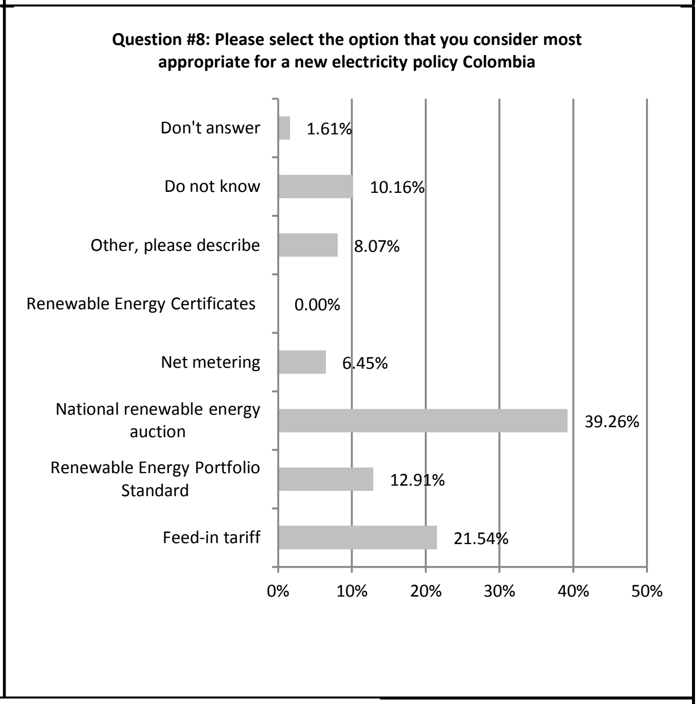
Supplementary Information 3: Responses from experts to questions of second survey

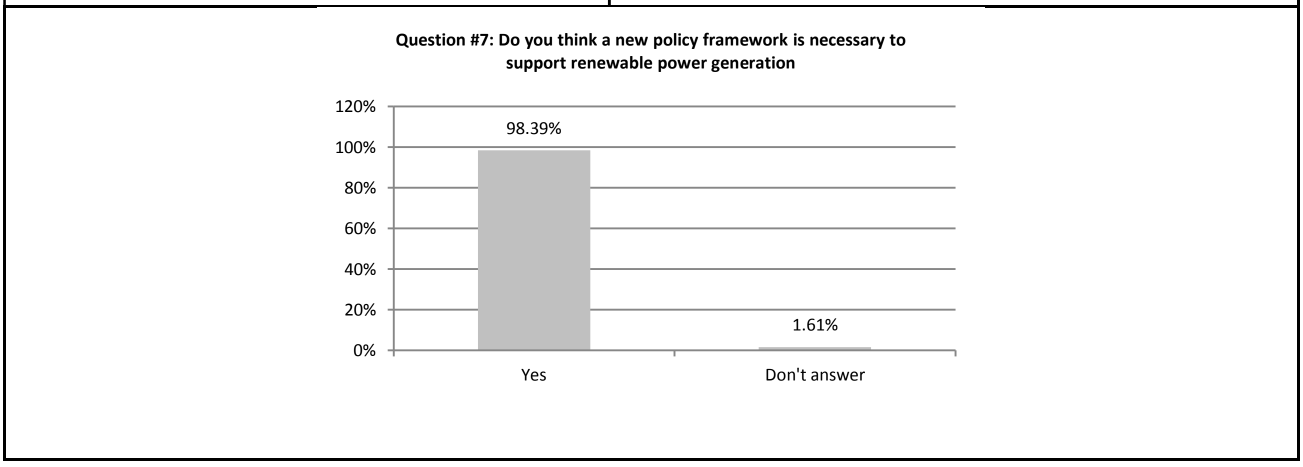
Answers from experts regarding Part 2 of the survey (Increase share of renewable power generation)



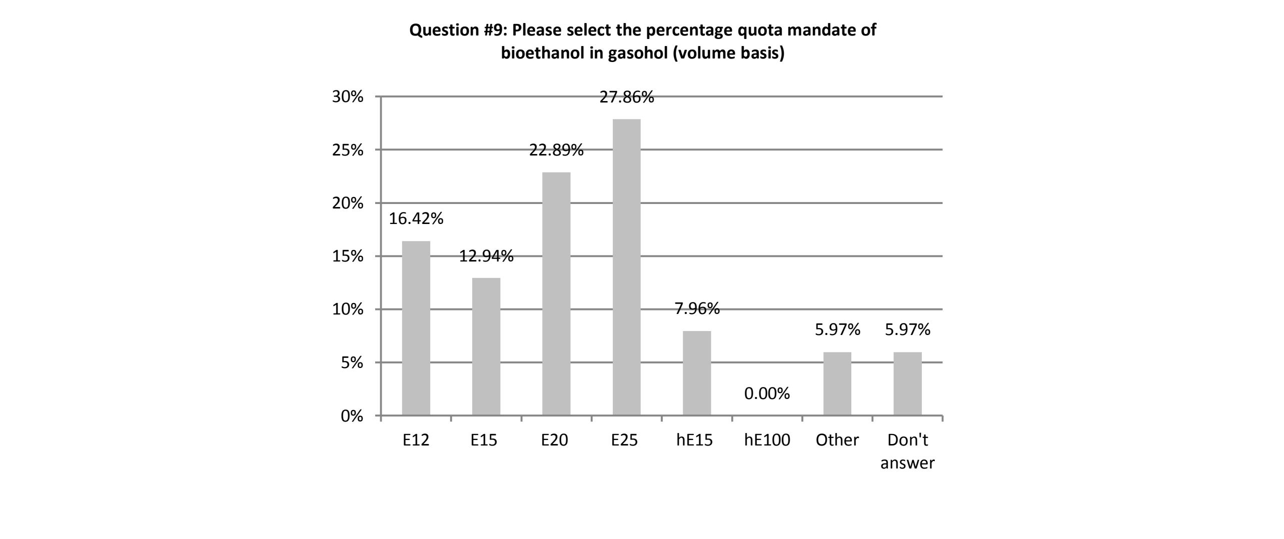


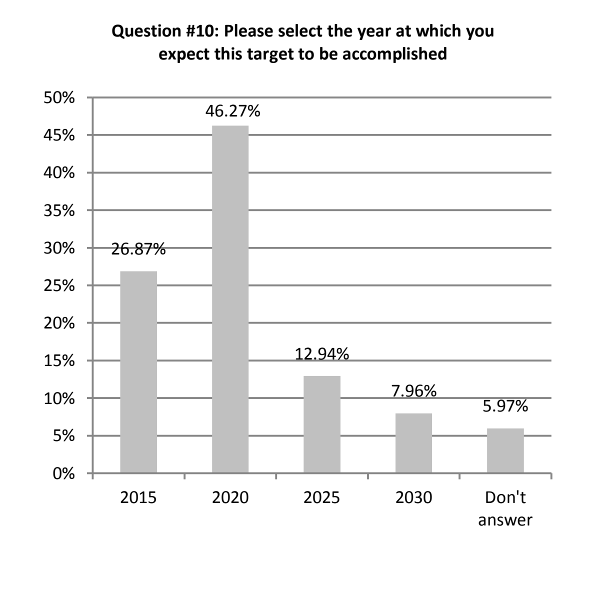


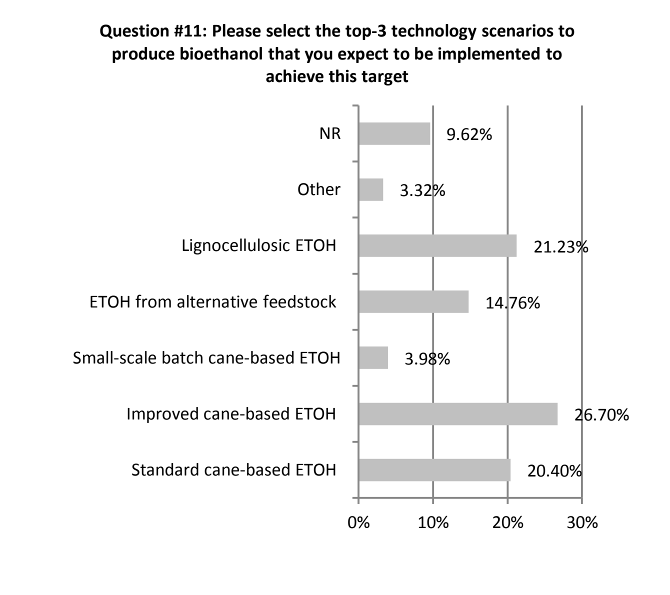




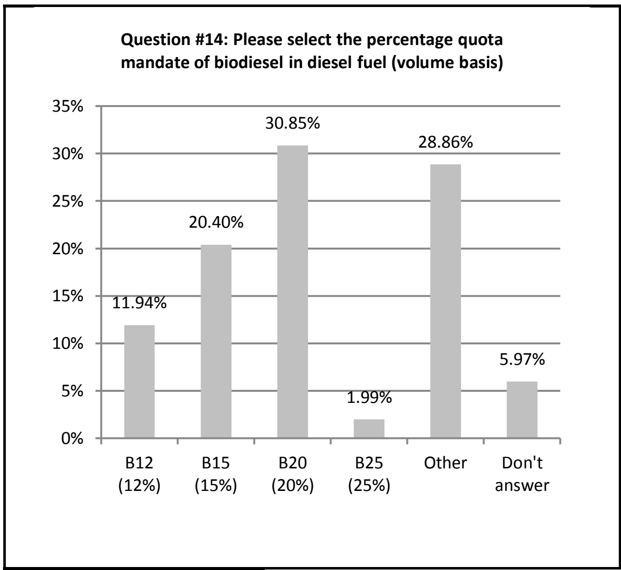
Answers from experts regarding Part 3 of the survey (Increase share of bioethanol in road transport fuel)

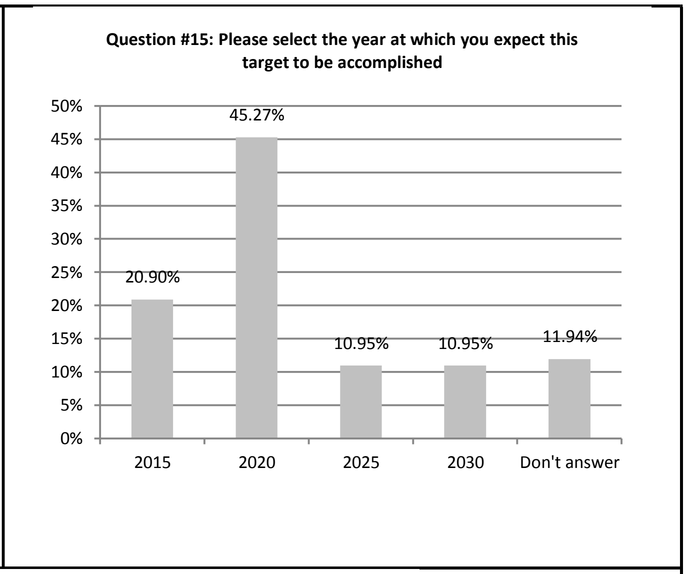


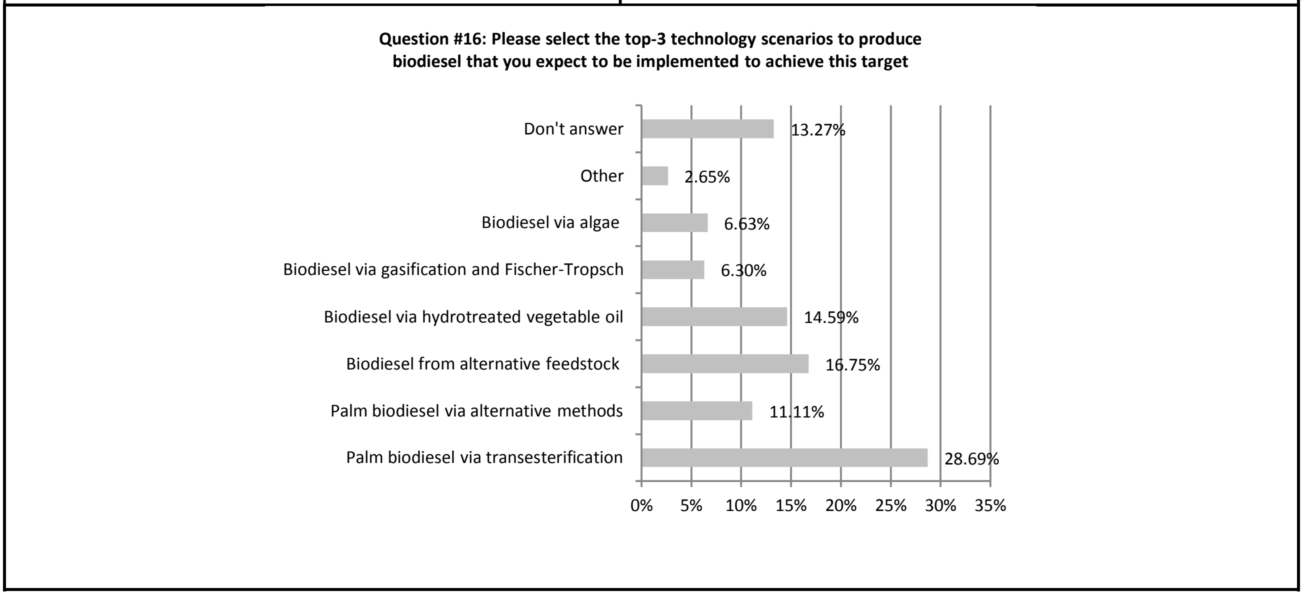




Answers from experts regarding Part 4 of the survey (Increase share of biodiesel in road transport fuel)







Answers from experts regarding Part 5 of the survey (Alternative biofuels and additives)