Measuring the contribution of the bioeconomy: the case of Colombia and Antioquia

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Abstract

The bioeconomy has gained attention in policy and academia scenarios as well as the need for strategies to foster the transition toward a more sustainable economic model. This paper provides evidence of the contribution of the bioeconomy to the value added and employment in Colombia and Antioquia, one of its regions. Since knowledge and scientific research are determinant factors for the bioeconomy strategies, relevant indicators of human capital and bioeconomy-related research capacities are studied for the case of Antioquia. The results show that bioeconomy in Colombia represents around 11% of the total value added and 21% of the national employment, which provides a baseline to building a monitoring strategy of the bioeconomy in Colombia and its regions.

Keywords: knowledge-based bioeconomy, sustainable development, bio-based industries, local strategies, Colombia

JEL codes: Q01, Q57, R58.

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Introduction

The global challenges that society is facing require urgent solutions that guarantee the long-term sustainability of the humankind. Besides the current economic and social crisis raised by the outbreak of Covid-19, the rapid population growth, the incidence of poverty and inequality, the need to ensure basic goods and services such as food and health, climate change, over-exploitation of natural resources, among other situations, obligate to rethink the production model based on fossil-fuel resources [1,2]. This makes imperative to seek for productive models that efficiently exploit and preserve natural resources using scientific knowledge and technological progress. In the last decades, it has been boosted an international common agenda consolidated in the Sustainable Development Goals. Different strategies, such as green growth, circular economy and regenerative capitalism have emerged as alternatives to pursuit sustainable, resilient, and inclusive economic growth. In this context, both policy and research debate coincide that in order to transit towards green economy incorporating the sustainable use of biodiversity and developing and strengthening knowledge-based value chains, a bioeconomic framework should be implemented.

From its origins, the term bioeconomy has evolved in the view of the policy makers and academic research, both recognizing the remarkable role of biotechnology as an enabling factor [3]. Birner [4] documents the origin of the term and argues that during 1960's and 1970's, authors as Zeman and Roegen use the term bioeconomics to refers to the discussion about the incompatibility between the unlimited economic growth and the availability of natural resources not only the depletable ones but also the renewables, while the concept of bioeconomy was developed in late 1990's by Juan Enriquez Cabot and Rodrigo Martinez in their work entitled "Genomics and the World's Economy". They describe the relationship between biology, broadly speaking, and the economy in the sense that the advance and progress of the genetic science would transform the industry. Although the concept of bioeconomy has been used in the policy agenda and in the scientific arena from the seventies, it became more important in the last years [2,5]. Especially when the European Commission launched the Bioeconomy Strategy in 2012 motivating the national actions to stablish priorities and policies to scale the bio-based sectors and deploy local economies [6,7].

Nowadays, there is a broad consensus about what bioeconomy is, and in fact, the definition provided by Global Bioeconomy Summit in 2018 has been adopted in many scenarios. According to this definition, bioeconomy refers to "the production, use and conservation of biological resources, including knowledge, science, technology and related innovation, for the provision of information, products and services through all economic sectors towards a more sustainable economic system" [8]. This definition makes clear the role of science, technology and innovation to move from a production factor-oriented economy towards a more knowledge-oriented economy [2,9]. This is reflected in the label "knowledge-based bioeconomy", which was aligned at first with the EU innovation policy and resulting in a vision of advancement towards economic growth by means of high-technology industries, fostering national and regional innovation systems and also demanding higher expenditures in R&D and specialized labor. In this manner, the bioeconomy implies a transformative change under three visions: biotechnology, bioecology and bioresources [1]. For developing countries, and especially for tropical countries like Colombia, the second richest country in biodiversity in the world, after Brazil, the bioeconomy appears as an area that allows generating value, developing markets and promoting economic and social growth at national and local level. Indeed, regional economies are an important element in the bioeconomy strategies as biodiversity is usually located in remote rural areas, and so, developing local innovation ecosystems, infrastructure and facilities as well as local markets connected to the whole supply chain are factors to successfully implement a bioeconomy [10–12].

It is useful to elaborate a little bit on the concepts related to bioeconomy before trying to map the correspondent economic activities. Concepts such as green economy, bio-based economy and circular economy are quite close but have some particularities worth to mention. In fact, the green economy is about ecosystems functioning, low carbon type of economic activities and even social inclusion. This green economy concept refers to environmental risks and the scarcity signals from the ecological systems. On the other hand, the bio-based economy concept is the closest term to bioeconomy since the former defines the production of goods and services from biological material or resources. Examples of typical bio-based products are biopolymers and bioplastics. At the same time, the bioeconomy is seen as part of the global economic growth and in that sense closer to the innovation and development perspective. Finally, circular economy refers to a way of producing goods and services that recycling and reducing original row materials including the biological resources [13].

One of the main challenges to design a bioeconomy strategy is the lack of comprehensive information allowing to map the economic activities with potential to develop sustainable bioeconomy models. European Commission has been also leading this regard through the project Biomonitor that aims to reduce the measurement gaps, disseminate thematic information, enhance modelling tools and foster research to inform policy makers in order to support long term programs [14]. One of the main concerns in this line consists of estimating the contribution of the bio-based economy to the whole economy, however there is not a unique framework that standardize the measurement method, which is a desirable feature to monitor the bioeconomy and facilitate the international and inter-regional comparisons [15,16].

There is a branch of literature devoted to link the scope of the definition of bioeconomy with the available data on economic activities. To do so, two approaches that measure the bio-share content of products and industries have been considered. The first, propose by JRC in collaboration with the Nova-Institute [17–19], is based on expert views who are interview about the biomass content of bio-based products at a high disaggregation level. This method provided detailed information to country and industry level. The second method is also an input-oriented approach that exploits available information in the Input-Output (IO) matrices from the Systems of National Account to infer how the different sectors use biological resources from the primary sector (agriculture, forestry, fishery and aquaculture) as a proxy of the biomass flows under the assumptions that that bio-based share of outputs is the same as that of inputs and constant return to scale production technology [20]. Accordingly, the bio-shares at industry level (e.g., using the Nomenclature statistique des activités économiques dans la Communauté européenne -NACE- or the International Standard Industrial Classification -ISIC-) are estimated, which enable to measure the contribution of bioeconomy to the gross value added. The main advantage of this approach is that It can be implemented across countries and regions where IO matrices are available and self-adjusts to the idiosyncratic productive structure. In fact, it can be implemented for many countries, for instance, Efken et al. [15] for Germany, Bracco et al. [2] for Germany, Argentina, Malasya, Netherlands, South Africa and the US, Wen et al. [21] for Japan, Loizou et al. [22] for Poland, and Kuosmanen et al. [20] for EU-28, among others.

The results suggest that the contribution of the bioeconomy varies importantly across countries. For instance, in the case of EU-28, Kuosmanen et al. [20] found that could range from 5% to 15% of the value added. While estimation about the employment in bio-based economic activities is around 15%. We contribute to this literature by studying the contribution of the bioeconomy in Colombia in the valued added and the total employment, and extent the analysis too the case of the region of Antioquia in order to provide useful information on the size of bioeconomy and identify opportunities at local economies level. Antioquia which is an important region of Colombia not only for its biodiversity richness but also for its contribution to the national GDP. Colombia and Antioquia are interesting cases of study because of their rich natural capital and the pronounced regional disparities that make important to think the development from the potential of the local economies.

Our results provide a baseline that make possible to scale the analysis of the contribution of the bioeconomy to other regions in Colombia and other countries in Latin American and the Caribbean. Given the importance of knowledge to foster the bioeconomy, we also measure human capita supply and research capacities. To do so, we consider study the enrollment in higher education in programs associated to biological knowledge and technology and innovation and the incidence of research groups developing projects related to bioeconomy. The former analysis uses information from the Education Ministry, while the latter is focused on the research groups in Antioquia and implemented text mining techniques on the information system of the Science and Technology Ministry.

Our preliminary results show that 11.03% of the gross value added in Colombia is due to activities associated to the bioeconomy, which also corresponds to the 21.10% of the total employment. For the Antioquia region, this percentages are 11.08% and 16.74% respectively. The contribution of bioeconomy too employment is significantly higher than the one observed in the European Community due to the larger share of the Colombian agricultural sector in the bioeconomy, however most of the employment is informal (79.28%). Analyzing the within industries contribution, we found that the primary sector represents 60 percent of the bioeconomy, the manufacturing sector 22 percent, and the services sector 16 percent. Results for the regions of Antioquia show important differences that remark the need of designing specific strategies by local policy makers.

Regarding education in areas related to bioeconomy, we found that there is a lack of students enrolled in academic programs associated with the bioeconomy activities. In the case of Colombia, less than 10% of total students enrolled in higher education are in programs related to bioeconomy such as biology, biotechnology, environmental engineering, agricultural sciences, livestock sciences, health sciences, natural sciences, among others. With respect to local capabilities to generate relevant research in bioeconomy we observe that, although Antioquia has improved in the last years in terms of scientific research, only 66 research scientific groups (8%) of the research groups in the region work on related fields to bioeconomy, biotechnology and sustainable development. Given the importance of bioeconomy as new engine of economic development, this result reveals the need of fostering the science and technology ecosystem addressed to take advantage of the local resources.

These results remark the importance of monitoring the bioeconomy for defining priorities of public policy. Colombia is one of the Latin-American countries where bioeconomy has called the attention of policy makers. Perhaps one of the key milestones in terms of the sustainable development perspective in Colombia has been the national Constitution in 1991 that established the basis to create the national environmental system in order to promote policies and strategies to use and protect our natural resources base in a sustainable way. From there, national biodiversity policy and the most recent green growth policy have laid the foundations of the, in construction, national bioeconomy strategy [23]. Our analysis might provide important insights on the elements that a regional bioeconomy strategy should have to complement this national strategy.

The rest of the paper if organized as follows. Section 2 presents the methodology to measure bioeconomy contribution based on IO matrices and discusses the main results for gross value added and employment for Colombia and Antioquia. In turn, Section 3 contains the measures on education and research capabilities at local level in Antioquia, and Section 4 presents concluding remarks.

Contribution of the bioeconomy in Colombia and Antioquia

There has been a global effort to build information systems to measure and to monitor the bioeconomy through indicators such as the participation of bioeconomy in the total GDP and value added as well as the contribution to total employment. The key ingredient for the estimation of these indicators is determining the bio-based content of either products or economic activities. To this end, the use of IO matrices has been proven as a suitable approach to measure the flows of biomass. This method considers that the primary sector (agriculture, forestry, fishery and aquaculture) is completely a bio-based sector because the outputs are biological resources, which are used as inputs for downstream sectors (see [20], for further details). This approach allows for an international comparison since the SNAs are standardized across countries. In order to provide some intuition about the estimation procedure, we consider the simplified versions of the IO matrices for two and three sectors in Table 1. The top part of the IO reports the flow of inputs between sectors, e.g., Sector I produces using inputs with equivalent value A their own production and B from Sector II. D and E have similar interpretation for Sector II, where E corresponds to self-consumed inputs. Each sector is composed by economic activities. In the bottom part, the matrix contains the value added and the total output. In the two sector IO, Sector I and II might represent primary sector (agriculture, forestry, fisheries, and aquaculture) and the rest of the economy (manufacturing and services). In turn, the three sectors matrix separates manufacturing and services.

Table 1. Structure of Input-Output matrices

a. Two sector IO matrix

	Sector I	**Sector II**
Sector I	A	D
Sector II	B	E
Total inputs	I_1=A+B	I_2=D+E
Value Added	V_1	V_2
Output	$O_1 = I_1 + V_1$	$O_2 = I_2 + V_2$

b. Three sector IO matrix

	Sector I	**Sector II**	**Sector III**
Sector I	A	D	G
Sector II	B	E	H
Sector III	C	F	I
Total inputs	I_1=A+B+C	I_2=D+E+F	I_3=G+H+I
Value Added	V_1	V_2	V_3
Output	$O_1 = I_1 + V_1$	$O_2 = I_2 + V_2$	$O_3 = I_3 + V_3$

Source: Own elaboration.

Following Heijman [24] and Kuosmanen et. al. [20], the contribution of the bioeconomy can be computed at sectoral basis such that the primary sector is full biobased and Sector II is treated as a mixed sector, where the bioshare is equivalent to proportion of inputs from the primary sector. Accordingly, the value added associated to the bioeconomy is the sum of the value added of the primary sector and the proportion of the value added of the Sector II equivalent to the intensity of the primary goods used. We compute the contribution of the bioeconomy of the non-primary sectors under three different scenarios. Under the two sector IO, we first consider that the rest of the activities have the same average productivity, and therefore, the bioshare is constant across activities and equivalent to the proportion of inputs from primary sector. Second, we compute bioshares at economic activity level. And finally, for the three sectors IO structure, it is assumed that the bioshares structure differ between Sector II (manufacturing) and Sector III assuming that the bio-content of inputs of the latter include a proportion inputs from Sector II.

In the first case, we compute a proportionality factor α between inputs and output in Sector II such that $O_2 = \alpha I_2$. That is, α is the output achieve by each unit of input used[5]. Assuming that the average productivity is the same by the origin of the inputs, the share of bioeconomy in the output O_{2b} and value added V_{2b} in Sector II is given by:

$$O_{2b} = \alpha D \qquad V_{2b} = O_{2b} - D = (\alpha - 1)D$$

which implies that the contribution of the bioeconomy in Sector II is the output achieved by the bio-inputs D. Therefore, the value added of the bioeconomy is $V_b = V_1 + V_{2b}$. Noticeable, the Sector II bioshare, i.e., the part of the total value added that is due to bioeconomy, can be compute as $\beta_2 = \frac{D}{I_2}$ that satisfies $V_{2b} = \beta_2(O_2 - I_2)$.

The second approach take advantages of the heterogeneity of economic activities belonging to Sector II by estimating individual industry bioshares β_{2i} given by $\beta_{2i} = \frac{d_i}{I_{2i}}$ where i is the index of the economic activity, d_i is the input that economic activity i in Sector II uses from primary sector and I_{2i} is the total input required by economic activity i. If Sector II has m industries, we have:

$$\sum_{i=1}^{m} d_i = D \qquad \sum_{i=1}^{m} I_{2i} = I_2.$$

In the third approach we use the extended version of the IO with three sectors and consider that the contribution of the bioeconomy to the value generation is Sector III is not only through the use of inputs from primary sector but also through the bio-content of inputs from manufacturing. Consequently, bioshares of the industries of Sector II remain unaltered with respect to the previous case, while we estimate bioshare of the economic activity j in Sector III as:

$$\gamma_{3j} = \frac{g_j + \sum_{i=1}^{m} \beta_{2i} h_j^i}{I_{3j}}$$

where t_r^s denotes is a general notation indicating the inputs from economic activity s used by r and t_r if the total input demand by economic activity j such that $\sum_{s=1}^{m} t_r^s = t_r$. That is, g_j is the total input used by economic activity j from the primary sector. Therefore, the total value of bioeconomy is $V_b = V_1 + V_{2b} + V_{3b}$ where:

$$V_{2b} = \sum_{i=1}^{m} \beta_{2i}(O_{2i} - I_{2i}) \qquad V_{3b} = \sum_{j=1}^{n} \gamma_{3j}\left(O_{3j} - I_{3j}\right)$$

with n the number of industries in Sector III. These estimated of bioshares β_{2i} and $\gamma_{3j}$are crucial to compute the contribution of bioeconomy to employment and the bioeconomy in Antioquia as it is assumed that this share also hold for these variables.

Using the 2017 IO for the Colombia economy, we computed the contribution of the economy to GDP and gross value added. Colombian System of National Accounts group 68 economic activities using the International Standard Industrial Classification (ISIC). Primary sector consists of 5 activities, while

[5] Note that this factor is given by =1+V2I2

manufacturing and services group 34 and 29 activities, respectively. Implementing the three alternative estimators of the bioshares, we obtained the results presented in Table 2.

Table 2. Results of the bioeconomy size in Colombia, three methods

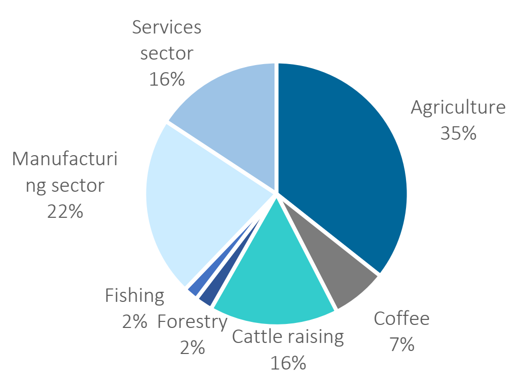
	Method 1	Method 2	Method 3
Sector I	100.00%	100.00%	100.00%
Sector II	7.01%	7.68%	13.33%
Sector III			2.11%
% VA	13.30%	9.39%	11.03%
% GDP	7.22%	5.07%	5.59%

Source: Own calculations.

Since the third methodological approach is the one that captures in a more global way the participation of biological inputs in the three large sectors of the economy, the bioshare found by the third method denoted by β_{2i} and γ_{3j} is selected to measure the added value of the bioeconomy and employment in Colombia and Antioquia. The importance of the inclusion of the third sector lies in the transition and the complexity of the productive apparatus and the decisions of the agents, where the tertiary sector has an increasing participation. For example, the decrease in household food consumption and the increase in consumption in restaurants.

As results, the primary sector has a higher share in the bioeconomy of Colombia, around 60%, while manufacturing sector represents 22% and the services sector approximately 16% (see Figure 1). Decomposing the contribution of economic activities of the primary sector, it is observed that agriculture account by 35% of total bioeconomy, following that the castle raising that it is account by 16% and coffee a tradition Colombia commodity is the 7%. This result suggests that these particular subsectors represent potential activities for rural development and for the introduction of knowledge of good practices and sustainable management of resources, which would not only improve the working conditions of farmers, but could also generate a higher added value.

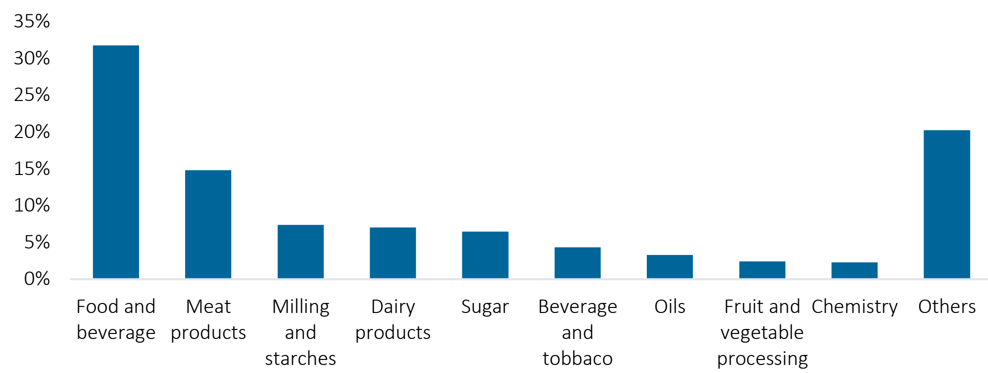
Figure 1. Participation of economic sectors in the bioeconomy



Source: Own calculations.

Analyzing the composition of the bioeconomy in the total of manufacturing and services, estimates show that services related to food and beverages (32% of the bioeconomy excluding primary sector) and the production foodstuff represent a high proportion of the added value of the bioeconomy activities (see Figure 2). Interestingly, these activities are closely related to agroindustry which is a naturally linked between primary sector and serve as a center for promoting integrated biomass use in circular models. With respect to the bioshares in manufacturing and services sectors, economic activities such as coffee products, meat products and sugar are highly bio-based, up to 80%. Other activities with high bioshares, higher that 50%, are dairy products, millings and starches and oils. These results show that industries with relevant economic and social impact, from the perspective of employment, are highly related to the bioeconomy, which constitutes and important starting point for the implementation of the nation strategy.

Figure 2. Main activities in the manufacturing and services sectors

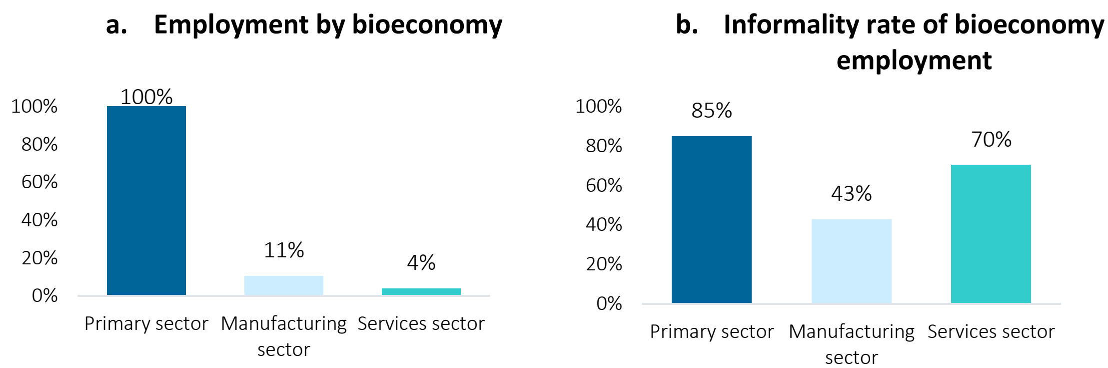


Source: Own calculations.

To have a broad picture of the contribution of the bioeconomy to the Colombian economy, we estimate the employment of the bio-based economic activities using microdata from the Colombian household surveys for 2017, Gran Encuesta Integrada de Hogares (GEIH) in Spanish. Therefore, we estimate the share of jobs that can be associated to bioeconomy through the interaction between the bioshares and the distribution of workers across activities. Our results reveal that the contribution of bioeconomy to employment is 4.5 million jobs, which is 21% of total. Decomposing the participation of the three sectors, we observed that primary sector accounts by 79%, higher than the participation in value added. This result might be related to a well know challenge that productivity of agriculture is one of the main bottlenecks of the development of the rural areas in Colombia. In turn, participation of manufacturing and services are 9% and 12%, respectively. In this context, when comparing the number of jobs generated in each sector and the number of jobs that are related to the bioeconomy, it is evident that the jobs in the primary sector are 100% bio (following the assumption that the bioshare of the sector is 100% as well), while in the manufacturing sector this figure is approximately 11% and in the services sector it is 4% (see left Figure 3 panel a).

On the other hand, the informality rate that is an indicator that reflects job quality, which places them in a vulnerable situation when it comes to enforcing basic labor guarantees, shows that primary sector has near to 85% of informality in employments related to bioeconomy and manufacturing and services sectors informality rates are 43% and 70% respectively. These results, in addition to making it clear that the jobs generated by the bioeconomy in the country, in particular jobs belonging to the primary sector, are in an unfavorable condition, they show the needs that Colombia has to introduce policies that consider current trends, where it starts the recognition of the problem is to determine which new jobs must be generated and under what conditions to achieve the transition to sustainable production [25].

Figure 3. Contribution of bioeconomy to employment by sector and informality rate



Source: Own calculations.

Regarding the transition to a new and sustainable form of production, the concept of green jobs arises, which refers to occupations with an identifiable environmental focus [26]. The International Labour Organization (ILO) defines this type of occupations as jobs that promote the preservation of the environment in all sectors of the economy, whether in traditional sectors such as manufacturing or construction, or in green sectors such as renewable energy [27]. In the country's green policy, strategies have been implemented for the categorization and development of these new occupations and activities. Additionally, the term green markets has been coined, which comprises the following categories: Sustainable use and exploitation of natural resources , Eco - products, Environmental Services and Clean Development Mechanism [28], all of these strategies with the purpose to create the new occupations and jobs that bioeconomy need to generate value added in a sustainable way.

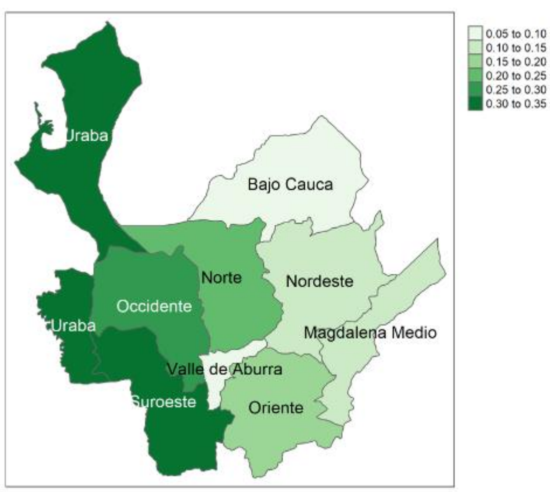
Overall, the contribution of the bioeconomy in Colombia is similar to the average for EU-28 found by Kuosmanen et. al. [20]. However, the composition of the value added differs as primary sector in Colombia accounts for most of the bioeconomy value added, while in EU-28 this sector exhibits the lower participation. In the case of employment, the results are qualitatively similar. Estimates for Romania are more seems to be similar to the case of Colombia. Therefore, defining priorities associated to the structure of the national economies is crucial for the success of the bioeconomy strategies. In the case of Colombia, the relevance of primary sector makes important to solve the puzzle of low agriculture productivity by promoting technology and bio-based knowledge, but also, encourage the transformation of manufacturing and services, which might complement the high potential given by the endowment of natural resources.

Regarding that the bioeconomy provides important opportunities to local economies to foster sustainable development from the social, economic, and environmental perspective taking advantages of the idiosyncratic factors of the regions, we compute the target indicators for the region of Antioquia, which is the second regional economy in Colombia. Antioquia is an interesting case as agriculture is an important economic activity, but this region has also a developed manufacturing sector with a remarkable participation of agroindustry in food and beverages and the production of another foodstuff. Antioquia is also endowed with an important stock of biodiversity. Indeed, if this region were a country, it would be the fifth worldwide in biological resources. Antioquia, which is equivalent to a state in term of political administration, is located in the northwest of the country and is divided 125 municipalities, organized in nine subregions. According to the most recent population census, Antioquia has 6.6 million of inhabitants (13.5% of the Colombia population), and 4 million living in the metropolitan area that group 10 municipalities including Medellín, the capital city. The Antioquia's economy accounts for 14.5% of the Colombian GDP, at the same time the contribution to the manufacturing sector is higher and equivalent to 19%. Mining and financial services are also important economic activities for the regional economy.

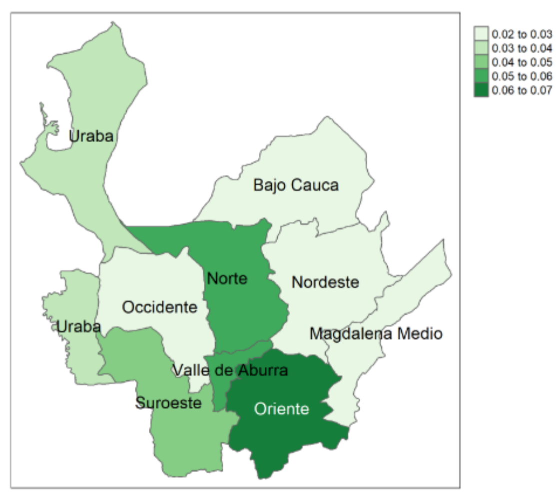
Although economic account systems are scare at the regional level, Antioquia is the only region in Colombia with available information at the municipality level. Following a similar approach than in the indicator to measure the employment contribution to bioeconomy, we exploited the heterogeneity of the value added at 12 economic activities aggregation for the municipalities of Antioquia and the estimates of bioshares for Colombia. Although we are assuming that the bioshare is invariant across municipalities, our estimates are considering idiosyncratic economic structure of the municipalities. In this manner, municipalities specialized in the agricultural production would report high participation of the bioeconomy, and so those with an agroindustry or services that intensively use bio inputs. Figure 4 presents the size of the bioeconomy aggregated at the 9 regions of Antioquia. Remarkably, there are regions where bioeconomy contributes up to a half of the total value added. For instance, this is the case of Suroeste and Urabá regions, whose economies are based on agriculture (coffee and banana, mainly) and tourism.

Figure 4. Contribution of bioeconomy in Antioquia at subregion level

a. All sectors



b. Excluding agriculture



Source: Own calculations.

Regarding the results at municipality level, our results show that bioeconomy account for more than 40% in 14 municipalities. An important number of these municipalities are in the southwest, which is a region traditionally linked to agriculture and coffee and the north where dairy industry is one of the main economic activities. We also estimate how municipalities participate in the total value added of the bioeconomy in Antioquia. The estimates show that the metropolitan area (36.2%), that concentrate the manufacturing activities, and Urabá (19.6%) are the regions with higher participation. Urabá is a zone specialized in the production of bananas, one of the main export products in Colombia. These results state an important challenge from the policy perspective as long as municipalities with higher potential of developing bioeconomy are based on traditional agriculture. This challenge has been also identified in the Colombian National Strategy of Green Growth [29], that asserts that two crucial issues to foster local economies sustainable development in Colombia are the low productivity of agriculture and the absence of public goods and infrastructure that facilitate the access to the markets.

Finally, we also estimate the contribution of bioeconomy to employment in Antioquia using microdata from household surveys, which allows to identify the geographical location of workers at the state level in Colombia. In Table 3, that reports the aggregated results for Colombia and Antioquia, it is observed that contribution of bioeconomy in the value added is similar, while contribution to employment is lower in Antioquia. This might be driven by the fact that manufacturing has a higher impact in bioeconomy in Antioquia compared with the average in Colombia, and this sector has higher labor productivity and lower informality rate than primary sector and services. Indeed, informality rate in Antioquia is lower.

Table 3. Contribution of bioeconomy to value added and employment and informality rate in Colombia and Antioquia

	Colombia	Antioquia
% VA	11.0%	11.1%
% Employment	21.1%	16.3%
% Informality	79.3%	61.6%

Source: Own calculations.

Human capital and research capabilities to develop a local bioeconomy in Antioquia

The term *Knowledge economy* is generally used to describe an economy where the accumulation of knowledge leads to a considerable share of production and is usually measured by classifying different productive activities in categories according to their technological intensity, generally in terms of R&D expenditures or high skilled labor [30]. In Colombia, the investment on R&D represented nearly 0.28% of the Gross Domestic Product (GDP) for 2019, whereas the average expenditure on R&D in the OECD countries corresponded to 2.4% [31]. This lack of investment has been outlined in several documents related to the Bioeconomy in Latin America [32,33] and Colombia [34] as one of the main reasons that hinders its development. However, despite the low R&D investment at national level, Antioquia is the region that has a larger share, corresponding to 31.6% of the national total for the 2017 – 2019 period [35].

Alternatively to the R&D expenditure, Jaffe et al. [36] proposed that the academic productivity (publications per capita) is more related to the GDP and the Human Development Index as measurement of a nation economic development and welfare than other commonly used variables employed to that end, and therefore, should be considered in the measurement of economic activities. Since knowledge, science, and technology are catalyst factors to develop the bioeconomy at local level, measuring and monitoring the capacity of generate knowledge in related fields to bioeconomy is important to formulate public policies aimed to foster the bieconomy. In South Africa for example, indicators such as full-time equivalent researchers, scientific publications, and bioeconomy-related publications are included within of the bioeconomy strategy, in order to approach the level of scientific development and the contributions of this area of knowledge to the science of the territories [2].

However, these approaches have been concerned with the process of knowledge generation, and the diffusion and use of knowledge are not usually addressed within the analysis of the bioeconomy. Urmetzer et al. [37] proposed to consider 3 categories of knowledge into the policy agenda of sustainable knowledge-based bioeconomy (SKBB), namely systems knowledge, normative knowledge, and transformative knowledge. The first refers to the understanding the complexity and interdependence of production, environmental, economic, social and political processes. The second refers to the desired system state and the evaluation of alternative system states, including not only the economic aspect, but also the social and ecological ones. Finally, transformative knowledge refers to the competences that must be acquired to affect a transgression from the *status quo* to the desired state, accordingly to the other two kinds of knowledge: systems and normative. The transformative knowledge, as its name suggest, could ultimately motivate structural changes to achieve sustainability goals embedded in the bioeconomy [9].

To study the level of bioeconomy-relevant transformative knowledge within the policy agenda in Colombia or Antioquia is a difficult task. The Colombian Green Growth National Strategy, which explicitly incorporates the concept of bioeconomy into the public policy in the country was launched in 2018 and it is unlikely that its implementation within the local development plans had already taken place. However, we consider that the academic environment and related research could be more aware of the advancement of bioeconomy. Therefore, we approximated to the knowledge relevant to the bioeconomy in Antioquia from the perspective of education of human capital and knowledge generation. To do so, we studied two indicators, first the total enrollment in higher education in academic programs that are directly related to the bioeconomy, and second a proxy of research capabilities which is computed analyzing the research fields and publications of research groups recognized by the Science Ministry. The intuition behind these indicators is that supply of human capital and academic research production allow to map the installed capacities in the region to undertake the transformation toward sustainable development. Nevertheless, these indicators also provide insights about the gaps that might be prioritized by local authorities.

With respect to enrollment in higher education, we use data from the National Higher Education Information System (SNIES, in Spanish) in 2018 which contains the number of students enrolled at academic programs including undergraduate and graduate levels. We defined the following four areas as bioeconomy related programs: Engineering and related (agricultural, forestry, agro-industrial, food and related, agronomic, environmental, sanitary, biomedical, chemical, and related engineering), Agronomy, veterinary medicine and related (agronomy, veterinary medicine and zootechnics), Mathematics and natural sciences (biology, microbiology and related and Chemistry and related) and Health Sciences (Bacteriology and Public Health). Estimating the share of students enrolled in bioeconomy related academic areas, we find that only 9.8% of total enrollment in Colombia, belong to these academic areas, while in Antioquia the percentage is 9.2% when considering technical and undergrad level. In the case of graduate programs, the participation is 9.3% in Colombia and 14.9% in Antioquia.

The selection of knowledge areas and related programs was made considering the definition of bioeconomy, where technological transformation, biological knowledge and the use of waste are pillars. Thus, one of the criteria to select the bioeconomy related academic programs is to see how these programs are problem solving oriented. In other words, programs oriented to transforming production processes in search of better practices and less environmental damage or the creation of new biological knowledge. In that sense, we consider academic areas which are associated with biotechnology. Regarding the programs related to bioeconomy, Table 4 show that environmental, sanitary, and related engineering represent 30.6% of the enrollments at the professional level for Colombia and 21% for Antioquia, followed by the veterinary medicine program and biomedical and related engineering at the regional level. At the national level the second area of enrollment is public health.

Table 4. Participation of bio-related higher education programs in total enrollment by field of knowledge

Programs	Bachelor level		Master and PhD programas	
	Colombia	Antioquia	Colombia	Antioquia
Environmental, sanitary and related engineering	30.6%	21.1%	13.7%	10.4%
Public Health	10.1%	1.8%	24.9%	22.1%
Agronomy	8.8%	2.3%	9.7%	6.9%
Veterinary Medicine	7.3%	14.4%	3.1%	4.9%
Biology, microbiology and related	7.2%	6.5%	20.3%	19.1%
Chemical and related engineering	6.5%	8.7%	5.6%	3.9%
Agro-industrial engineering, food and related	6.3%	4.1%	3.7%	7.2%
Chemistry and related	5.6%	8.3%	11.2%	7.9%
Zootechnics	4.8%	5.2%	1.3%	0.8%
Agronomic and related engineering	4.0%	5.3%	0.0%	0.0%
Agricultural, forestry and related engineering	3.4%	4.1%	0.6%	1.8%
Biomedical and related engineering	3.2%	14.1%	1.8%	1.8%
Bacteriology	2.2%	4.1%	4.0%	13.0%

Source: Own calculations.

On the other hand, it is worthy to mention that the geographical distribution of the enrollment in academic programs between larger cities and rural areas implies a challenge for public policies related to education and human capital improvement needed for the bioeconomy. In fact, in the case of Antioquia, 96% of the students enrolled in academic programs related to the bioeconomy is in Medellín and its metropolitan area. However, only 4% is located out of Medellín. This situation brings several questions about the higher education system in the sense that young people in rural areas, where the natural capital including biodiversity are located, have very few educational and training opportunities to be part of the bioeconomy activities.

At the same time, according to Table 5, which shows the proportion of the programs related to the bioeconomy over the total enrollment in higher education by gender and location for Antioquia, if we consider this 4% of students enrolled out of Medellín in programs related to the bioeconomy, it is important to mention the two main areas of knowledge: agronomy and engineering representing 45% for both areas. Regarding the gender distribution of the enrollment rate, one could say that there is a quasi-equilibrium between men and women attending the academic programs related to bioeconomy. The field of health sciences shows the predominance of women enrolled in this type of programs, 12% versus 6% for men. Summarizing, Colombia must improve the opportunities for young people to be enrolled in higher education programs related to the bioeconomy. The current enrollment rate is low comparing to the potential of natural capital and biological resources to develop the bioeconomy activities, particularly, in rural areas. It is precisely in rural areas where the lack of higher education programs is more severe.

Table 5. Participation of bio-related higher education programs in total enrollment by gender and region in Antioquia

Knowledge areas	Men	Women	AMVA*	Outside AMVA*	Total
Agronomy, veterinary and related	21%	21%	20%	45%	21%
Engineering and related	59%	51%	55%	45%	55%
Mathematics and natural sciences	14%	16%	15%	8%	15%
Health Sciences	6%	12%	10%	2%	9%

*Note: AMVA: Metropolitan area of Aburrá Valley
Source: Own calculations.

By increasing the human capital, there is a positive effect on innovation, competitiveness, economic development and economic growth [37]. In order to identify the research capabilities in bioeconomy-related fields in the region of Antioquia, we used R statistical software [38] and several R packages to implement web scrapping and text mining techniques along with automated language detection [39–42] over the information for all the Research Groups (RG) in Antioquia registered on the *Scienti*[6] portal of the Ministry of Science, Technology and Innovation [43]. *Scienti* encompasses different information repositories, e.g., GrupLAC and CvLAC containing detailed information on RG and researchers, respectively.

We focus our analysis on information extracted from the GrupLAC that include RG identifiers, RG name and vision, research fields, list of publications and location. RG are classified among 11 National Programs of Science and Technology (NPST), named: *Environment, Biodiversity and Habitat, Biotechnology, Basic Science, Agricultural Science, Social Science, Humanities and Education, Energy and Mining, Engineering, Water Resources, Health Science, Information and Communication Technology (ICT),* and *Uncategorized*. After selecting all RG from the region of Antioquia (830 out of 5770), we conducted three systematic searches to identify the bioeconomy-related research groups (BRG). First, we identified those RG that included explicitly the word "bioeconomy" in their research fields. Second, we searched for RG that included words beginning with the prefix "bio" (ˆbio*), "sustainable development" or "sustainability" to have a broader scope of groups working in bio-based knowledge. And third, we searched for a list of specific terms related to bioeconomy and biotechnology which might be a proxy of the potential to generate research and innovation to boost the bioeconomy regional strategy (Table 6). The results of the BRG search are listed on Table 7.

Interestingly, the first search resulted in only two BRG (0.24% of RG in Antioquia), both from Medellín (1% of the region's municipalities) and corresponding to *Environment, Biodiversity and Habitat* and *Social Science and Education* NPST's and not to the *Biotechnology or Agricultural Science* NPST. The second search identifies 66 RG (8% of the total) that can be considered bioeconomy-related. Most of the RG (64, 97.7%) are in Medellín, and only two in other municipalities, one in Envigado and other Rionegro. The NPST distribution was: 12 RG related to *Environment, Biodiversity and Habitat* (18%);

[6] Scienti is a web platform created by the Colombian Ministry of Science and Technology to facilitate the management of information of the National System of Science and Technology. https://minciencias.gov.co/scienti. Last accessed November 2020.

7 RG related to *Biotechnology* (11%); 2 RG related to *Agricultural Sciences* (3%); 6 RG related to *Basic Science* (9%); 9 RG related to *Social Science, Humanities and Education* (14%); 2 RG related to *Energy and Mining* (3%); 9 RG related to *Engineering* (14%); 2 RG related with *Uncategorized NPST* (3%); and 17 RG related *Health Sciences* (26%).

Table 6. Terms related to bioeconomy and biotechnology used as search criteria for RG

Search criteria			
^bio*	bioenergy	ecology	GMO
agricultural	biofuel	ecosystem	microorganisms
agriculture	biomass	ecosystem service	plant
agroindustrial residues	biophysics	ecosystem services	rhizosphere
algae	biorefineries	ecosystems	second generation biofuels
animal	biorefinery	first generation biofuels	sustainability
biocatalysis	biotechnology	fungi	sustainable development
biodiesel	botanic	forest	third generation biofuels
biodiversity	cell culture	genetic	vegetal
bioeconomy	crops	genetically modified organisms	zoology
		genomics	

Source: own elaboration.

Table 7. Number of Bioeconomy-related Research Groups (BRG) in Antioquia.

Region	Search I (TOTAL BRG = 2)			Search II (TOTAL BRG = 66)			Search III (TOTAL BRG = 220)		
	Number of BRG	% over RG*	% over BRG	Number of BRG	% over RG*	% over BRG	Number of BRG	% over RG*	% over BRG
Medellín	2	0.24%	100%	64	7.71%	97.0%	198	24%	90%
Metropolitan area (w/o Medellín)	0	0%	0%	1	0.1%	1.5%	7	1%	3%
Rest of Antioquia	0	0%	0%	1	0.1%	1.5%	15	2%	7%
TOTAL	2	0.24%	100%	66	8%	1	220	27%	100%

*Note: Total RG in Antioquia = 830
Source: Own calculations.

The third search found 220 RG (26.5% of the region) distributed among 12 municipalities of Antioquia (2% of the region's municipalities). The NPST distribution was: 30 RG related to *Environment, Biodiversity and Habitat* (13.6%); 23 RG related to *Biotechnology* (10.5%); 27 RG related to *Agricultural Sciences* (12.3%); 37 RG related to *Basic Science* (16.8%); 9 RG related to *Social Science, Humanities and Education* (4.1%); 5 RG related to *Energy and Mining* (2.3%); 26 RG related to *Engineering* (11.8%); 9 RG related with *Uncategorized NPST* (4.1%); 2 RG related to *Water Resources* (0.9%); 51 RG related *Health Sciences* (23.2%); and 1 RG related to *ICT* (0.5%).

We characterized the research topics of the NPST by studying whether there are any R&D tendencies in the publication titles. To do so, we counted the occurrence of words related with bioeconomy in the publication titles. This exercises allow us to relate the research capabilities in Antioquia with the Productive Pathways of Bioeconomy for Latin America and the Caribbean identified in the ALCUE-KBBE Project (America Latina y el Caribe – Unión Europea – Knowledge Based Bioeconomy) [45]: (i) Biodiversity resources utilization; (ii) Eco-intensification; (iii) Biotechnology; (iv) Biorefineries and bio-products; (v) Value chain improvements; and (vi) Ecosystem services [45]. These paths seem to fit well within the Colombian National Programs of Technology of Science and Technology (NPST). Particularly, in the case of the BRG in Antioquia, the research in the Environment, Biodiversity and Habitat NPST is focused mainly with tropical resources, particularly water, forest and soil, related with biodiversity resources utilization, eco-intensification and ecosystem services productive paths (see Appendix, panel a in Figure 6).

The academic production of BRG in the Biotechnology NPST in Antioquia is inserted, naturally, within the path of biotechnology. Moreover, the focus in this NPST over potato and other nightshades plants is articulated with the productive paths of eco-intensification and ecosystem services. However, despite the weight of agricultural activities in Antioquia and the implementation of GM crops such as maize and cotton in Colombia, the words "genetic transformation", "transformation" or any related term were not recurrent (see Appendix, panel b in Figure 6). The research in the Basic Science NPST, where the description and taxonomic classification of species, particularly of insects and their genetic pool, correspond with the productive paths of biodiversity resources utilization, potential biotechnological applications and ecosystems services.

The research of BRG in the Agricultural Science NPST is focused on dairy products, milk and cattle breeding, assisting the eco-intensification and ecological services paths. The BRG research within the Social Science NPST focuses on the potential development of eco-tourism initiatives, akin to the ecosystem services pathway. The Energy and Mining NPST relates with the biorefineries and bio-products through biofuels-related research potential application of bionanotechnological products in de cosmetic industry [46]. The Uncategorized NPST is framed within the eco-intensification path and ecosystem services, through research on bovine breeding and veterinary research. The Water Resources NPST contributes to ecosystem services through research related with rivers and the Caribbean, including mangrove ecosystems. It also focusses its research over the Urabá region, particularly its gulf, highlighting its potential for aquacultural industries within the primary sector of the economy.

The Health NPST fosters the advancement of biotechnology, focusing on tropical diseases such as malaria and paracoccidioidomycosis caused by the fungus *Paracoccidioides brasiliensis*, and genetic causes of HIV and cancer. Finally, the ICT's NPST, through research in Petri networks and its uses in computational biology and workflow in management systems, could contribute to the biotechnology path and the improvement to the value chain. Interestingly, there is no clear relationship between the Engineering NPST, and research terms associated with the bioeconomy productive paths, despite having the larger amount of enrollment in higher education academic programs. The reason might be that there are diverse engineering programs that may have distant research interests, and therefore the results in represent a general view rather than a specialized one (see Appendix, panel g in Figure 6).

Discussion

The introduction of bioeconomy is considered a strong approach to act against the current trends of unsustainability. Policy makers, academia and private organizations are shaping alternative models to tackle the impacts of climate change and boost a more sustainable world from social, economic, and environmental perspectives. Fostering bioeconomy has gained an important space in the debate and draws new work lines for the transition towards a greening economy. Cleaner productive process, but also developing bio-based products based on knowledge and technology are the basis of this transition process, where biodiversity is a crucial input, particularly for those countries having abundant biological resources such as the tropical ones.

This study underlines the lack of a unified framework to analyze the contribution of the bioeconomy across the countries, which does not allow any straightforward comparison of the relevance of bioeconomy in different economies. The measurement of the bioeconomy becomes a policy input understanding that it reveals the capacities of the territories to generate value added in different sectors of the economy with the use of natural renewable resources and goods provided by the primary sector. In this way, with the calculation of the size of the bioeconomy in Colombia and Antioquia in particular, efforts could be directed towards the comparative advantages of the municipalities and proposing the development of sustainable practices that improve the quality of life of populations and ecosystems. However, additional effort is needed to consider social and environmental dimensions, but our results are the baseline for the monitoring of the bioeconomy in the case of Colombia and Antioquia.

When measuring the bioeconomy in Colombia, the highest participation is attributed to the primary sector with approximately 62%, followed by the secondary or manufacturing sector (22%) and the tertiary sector (16%). On the other hand, when decomposing the primary sector, agriculture is the sector with the highest participation in the formation of value added with 35%, followed by livestock with 16% and coffee with 7%. Regarding the participation of the other subsectors assigned to the secondary and tertiary sectors, services related to food and beverages (32%) and the production of meat products (15%) and the production of other foods represents around 20% in the generation of value added. In this line, education and construction have a participation close to 2%. In this context, the potential of the Colombian economy for the sustainable exploitation of the biobased sectors is evident, with the aim of obtaining greater profitability, but above all sustainability of the resource in the territories, guaranteeing employment for its inhabitants and an important source of income, in one expression sustainable rural development.

Most bioeconomy policies around the world do not consider the diffusion and use of bioeconomy-related knowledge within the productive system, nor the different types of knowledges that intervene for a sustainable bioeconomy framework. The focus has traditionally been on R&D expenditures to create the knowledge necessary to generate economic value, and this not necessarily implies the achievement of sustainable goals [36]. Particularly, in the case of the Colombian National Strategy of Green Growth, technological transfer is mentioned, but a detailed description of the mechanisms to do so is not provided. Most bioeconomy policies around the world do not consider the diffusion and use of bioeconomy-related knowledge within the productive system, nor the different types of knowledges that intervene for a sustainable bioeconomy framework. The focus has traditionally been on R&D expenditures to create the knowledge necessary to generate economic value, and this not necessarily implies the achievement of sustainable goals [37]. Particularly, in the case of the Colombian National Strategy of Green Growth, technological transfer is mentioned, but a detailed description of the mechanisms to do so is not provided.

Regarding biobased knowledge and scientific research, there is room for improving the access to higher education programs particularly in rural areas where the enrollment rate is lower compared to the observed in urban areas in terms of academic areas related to bioeconomy and biotechnology. For Colombia and Antioquia there is a need to transform the higher education system making it much more flexible, perhaps motivating the children from the high school level to be part of the present and future development of the bioeconomy taking the comparative advantages that our abundant biodiversity gives to the rural territories.

When analyzing the number of research groups related with the bioeconomy in the Department of Antioquia, it is evident the centralization in the process of generating scientific knowledge mainly within the Metropolitan Area, consisting in the municipalities of Barbosa, Copacabana, Girardota, Bello, Medellín, Envigado, Itagüí, Sabaneta, La Estrella y Caldas. From these 10 municipalities, Medellín comprises 90% of the RG in the Department. This situation evidences the absence of higher education programs and research developed in rural areas of Antioquia, where most of the agricultural activities, the main component of the bioeconomy in the region, take place (Figure 1).

Our search on research capacities in Antioquia is limited to a set of words related to the bioeconomy over the publication titles reported in the GrupLAC, and not the words contained in research papers and publication per se. However, the results are sufficient to picture the relationship between the research conducted in Antioquia and the potential productive pathways of the bioeconomy, given the idiosyncratic and economic particularities in the region. In general terms, the productive pathways which had more research associated with, corresponded to eco-intensification and ecosystem services. This search addressed in a general way the “creation” of knowledge. However, given the cultural and biological diversity among the regions of Colombia, the diffusion and implementation of knowledge (systems, normative and transformative) should be analyzed at a regional or local level to describe how the knowledge impacts the bioeconomy in a more detailed fashion.

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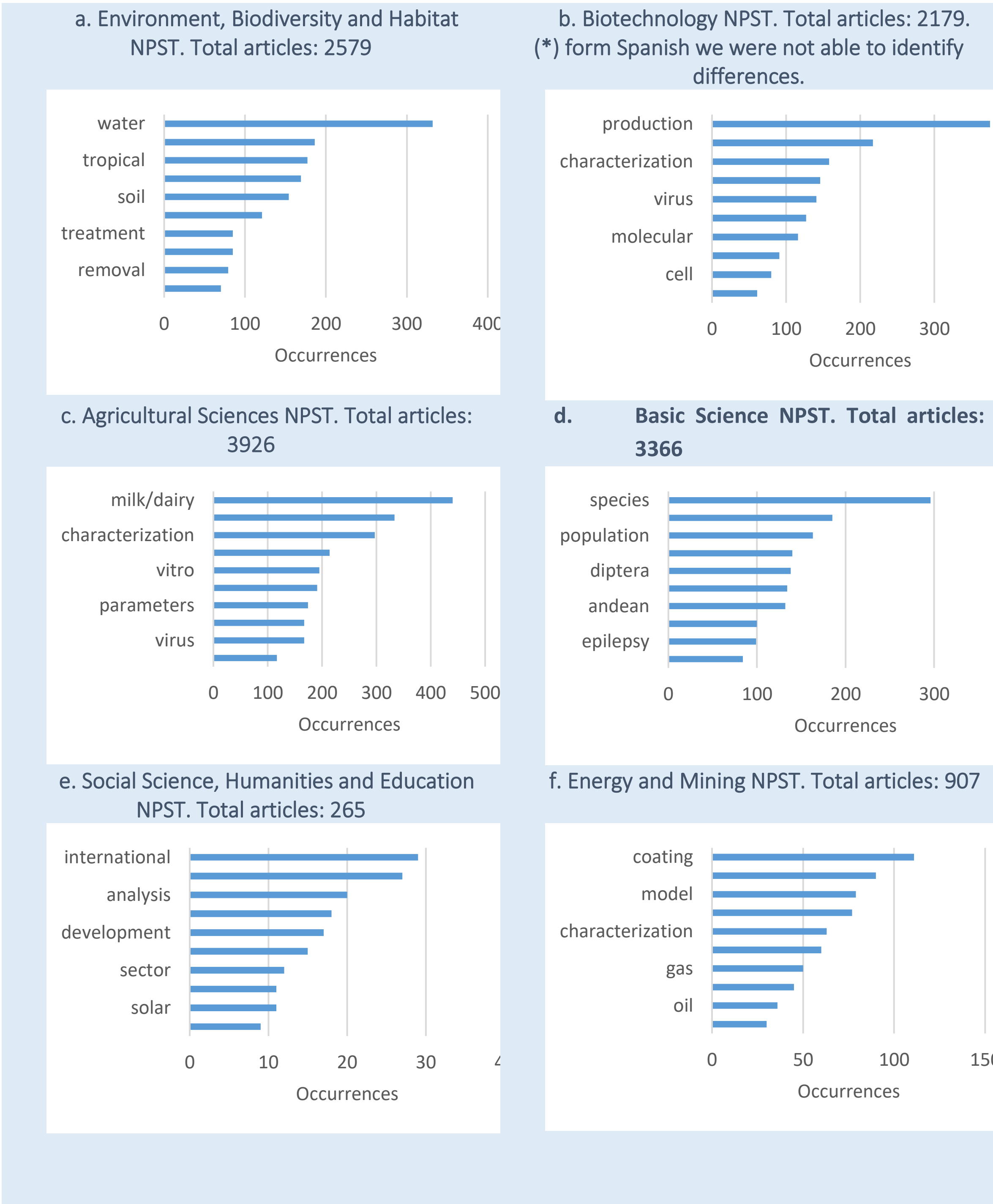
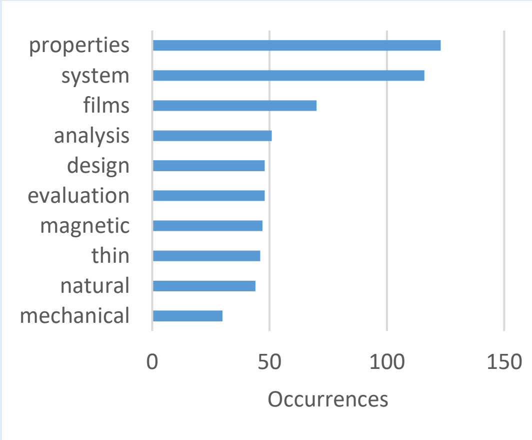
Appendix

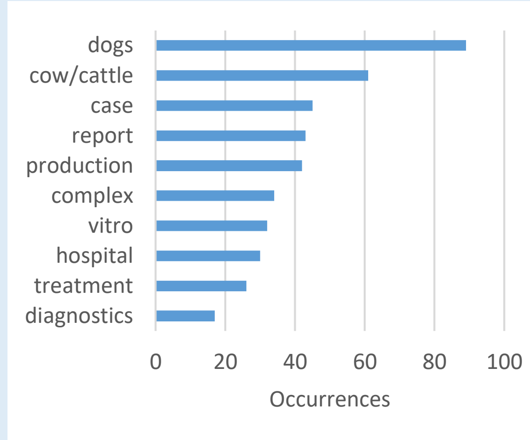
Figure 6. Top 10 word from academic production of Bioeconomy-related Research Groups (BRG) in Antioquia from the different National Programs of Science and Technology (NPST).



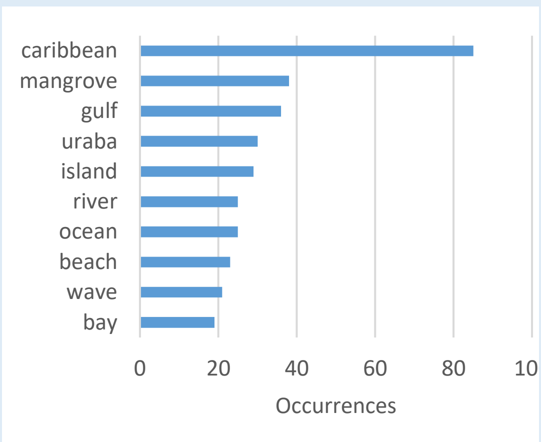
g. Engineering NPST. Total articles: 1698



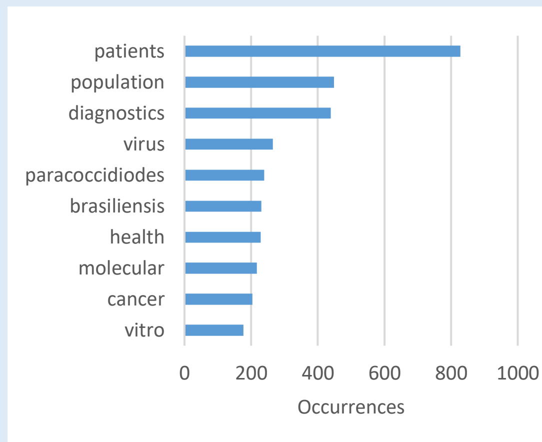
h. Uncategorized NPST. Total articles: 628



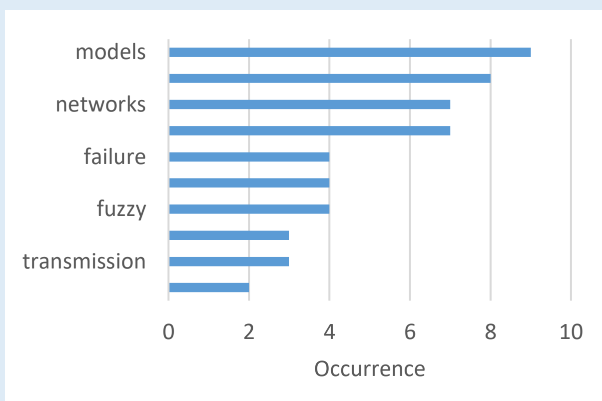
i. Water Resources NPST. Total articles: 253



j. Health Sciences NPST. Total articles: 7065



k. ICT NPST. Total articles: 26



Source: Own elaboration