

# Productive chain management around disruptive technologies. Engaging sustainability and materials research

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**Abstract.** Mining is always a controversial issue and mainly when the discussion is addressed to developing countries. In Colombia, the mining panorama was and continues to be ruled by a formal, modern, and large-scale mining mainly focused in coal, the exploitation of nickel, and some companies that exploit gold in different places. Also, a large part of the mining activity is done at minor scales, defined in many cases by informality and the subsistence character. Bearing sustainability in mind, it is worth asking about the balance implies by the exploitation without added value of local and strategic materials that are irreversibly scarcer every time, including metallic and non-metallic minerals. Opportunities around natural and non-renewable resources must focus on enhancing the quality of life, the question addressed here is how to penetrate in the global markets of sophisticated products as well as how to be serious about the so-called “innovation”, but with accent on sustainability and disruptive technologies.

## 1. Introduction

In order for a society to reach the capacity to be sustainable, certain economic, social, environmental, and energetic conditions must guarantee sufficiency of the available resources. This becomes a global and shared challenge in the context of different supply chains that consume and transform resources characterized by their scarcity. The development is sustainable if it involves a non-decreasing average life quality. Sustainability is a requirement of current generation to manage the resource base such that the average quality of life that societies ensure for themselves can potentially be shared by all future generations. In this context, sustainable development, the rational use of the resources, in particular non-renewable resources, and the evolution of technologies must be consistent with each other [1], especially in the current framework of history where the disruptive technologies (DTs) acquire an increasing relevance. DTs are technologies that broadly show the power of innovation to improve lives, transform industries and safeguard the planet. These technologies are generally new but include older technologies that are still controversial, relatively undeveloped in potential and do not have exclusively one application field. DTs include, but are not limited to artificial intelligence (AI), cloud computing, robotics, 3D printing (also known as additive manufacturing) and nanotechnology (NT), among others.

The general question addressed in this article is how to penetrate in the global markets of sophisticated products as well as how to be serious about the so-called “innovation”, but with accent on sustainability. As a first consideration, the different types of materials in 3DP processes as well as different kind of nanomaterials are really forms of matter as metallic minerals and non-metallic



minerals or industrial-minerals, which match two of the categories of the mining exploitation in Colombia. These categories are the first materials-type that could easily support the development of nano-intermediates, as long as 3DP technologies for processing a variety of polymers, metals, ceramics and composites [2]. The metallic and industrial minerals become of interest for different sectors and applications, besides having higher facilities for industrial appropriation in a changing and diverse market. This is why the appropriation of nanotechnology and 3DP makes sense in the context of a country with a traditional, artisan and large-scale mining like Colombia.

The true is that despite the higher level of foreign investment in recent years, the country continues to distinguish itself for its capacity for export raw materials. Conversely, the country mainly imports manufactured goods with more technology and added value. In other words, Colombian foreign trade continues to be tied to the dynamics of oil and mining activities. According to the Foundation for Higher Education and Development (Fedesarrollo), in the last 20 years the country has entered in a process of “re-primarization” of exports, sales of primary goods rose from 45% of the total in 1992 to nearly 70% to date, affecting industry growth and the creation of quality jobs. This process of deindustrialization could enter deceleration if, among other actions, agriculture and industry in general were further developed. Half of the Colombian GDP, estimated in 770 trillion in 2014, corresponds to the performance of four key sectors that besides financial establishments and commerce involve agriculture and industry. How to ensure that companies and these sectors – in the third world – move to the first world? In particular, Colombia is still far from achieving a real change in the composition of exports, where most products have added value. In a wider context, the first key is the generation, appropriation and dissemination of knowledge as a base for social and economic development, and also to close to exceed the gap for investment in R&D, which has reached less than 0,19% in proportion to the GDP [3]. In a study about economic growth in the six largest developing countries in Latin American, in which Colombia was included, Astorga [4] mentioned that despite significant advances in life expectancy and basic education, renewed efforts to strengthen the government's role in fostering secondary education and research activity remains a priority. Astorga also remarks that there is a need to secure macroeconomic stability to set the basis for high and sustained economic growth. This includes, among others, reinforcing and diversifying the export sector to minimize exposure to terms of trade fluctuations. The second key is diversification, which represents the element that correlates with scientific and technological competitiveness according to Cimini et al [5], who also mentioned that technological leading nations, beyond having the largest production of scientific papers and the largest number of citations, do not specialize in a few scientific domains [citar a F. Di trochio “las metiras de la ciencia” la ciencia no debe sesgarse: science must not be biased]. Rather, they diversify as much as possible their research system. On the other hand, less developed nations are competitive only in scientific domains where also many other nations are present.

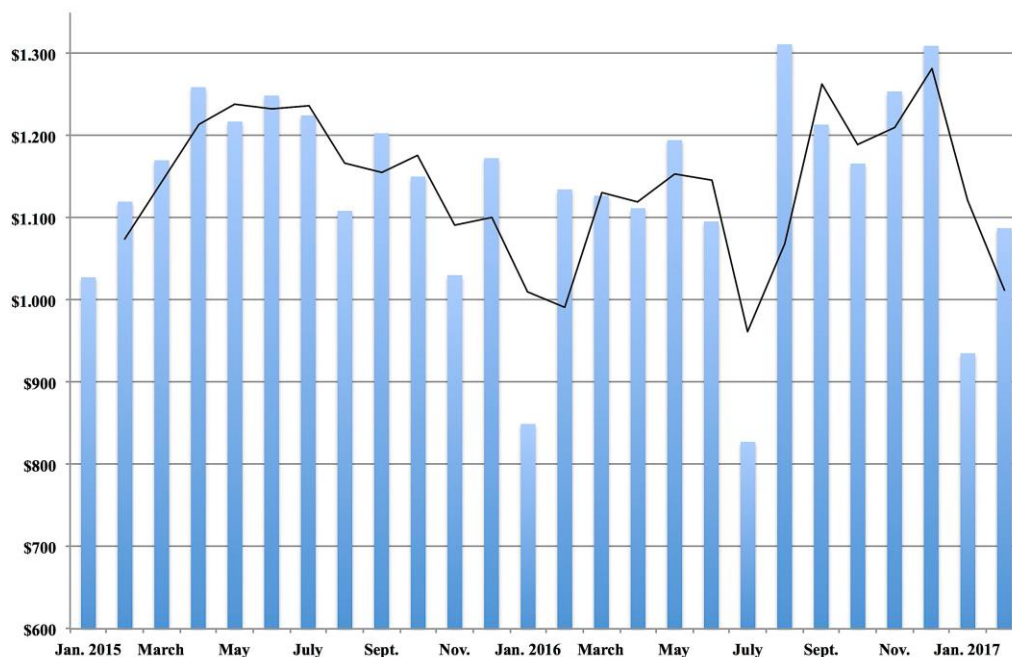
## **2. Dynamics of commodities facing sustainability in Colombia**

During the nineteenth century the comparative advantage of the products exported by Colombia resided in the abundance of some natural resources and unskilled labor, mainly in the agricultural sector and in mining. For example, hides, straw hats, platinum and tobacco, besides high concentration of exports in gold and coffee, this last one the only product that maintained the high export dynamism in this century. During the twentieth century, the share of exports other than coffee, crude oil, bananas and gold were remarkable just in a few periods. Currently, Colombia is recognized as a country with a high mining potential. In the world map of gross metallic ores extraction per country area, the country was ranked in more than 140 tons per km<sup>2</sup> in 2010 [6]. The mining sector has contributed historically close to 2,2% of the national GDP, and intends a participation 3,6% of the national GDP according to the Ministry of Mining and Energy. In 2012, the non- traditional exports of the mining sector were of USD 12,193 million, with an annual average of USD 13,765 million between 2015 and 2016, which show a record of historical growth (figure 1). Complementarily, the Direct Foreign Investment (DFI)

accumulated in mining, which between 2005 and 2014 was of USD 33,770 million, is projected to USD 51,776 million between 2015 and 2025. Excluding the mining-energy sector, for industrial and construction minerals as well as for metallic minerals, starting in of 52% in 2015, the projections of DFI for 2020 and 2025 will be respectively 62% and 79%. In this sense, the mining sector has invigorated the national economy, generating large incomes from exportations, attracting DFI and it is the great funder of social programs. In parallel, the royalties from the mining sector have supported largely the regional and national infrastructure.

### 2.1. Non-traditional and high technology exports

Nevertheless, it must be highlighted that the Colombian mining panorama was and continues to be dominated by a formal, modern, and large-scale mining, but focused in the large coal projects located in the Caribbean coast and in the exploitation of nickel in Córdoba region. In contrast, a large part of the mining activity is done at minor scales, defined in many cases by informality and the subsistence character. Colombian mining employs around 350,000 people. 315,000 are dedicated to small and medium mining, with 76% of unqualified manpower, generating 59% of indirect employments and 41% of direct employments. On the contrary, large mining generates only about 35,000 employments, of which 56% are direct and 44% are indirect. Towards this unbalance there is a big question in terms of profitability and competitiveness, but mainly in terms of sustainability, much more when the inclusion of the named “mining machine” in the view of the Colombian State was broadly qualified as one of the main resources for the development of the country and its regions.



**Figure 1.** Not traditional exports of Colombia between 2015 and February-2017 (million USD) according to Mining analysis Bulletin from Colombian Ministry of Mines and Energy

As examples, in case of gold (Au), the region of Antioquia is the largest bulk gold producer in the country. This industry, together with the exploitation of other mineral resources such as coal, limestone, and construction materials, represent a significant source of royalties for this region since pre-Colombian times. Nevertheless, the gold activity settled in the culture and in the economy of many places in Antioquia contrasts with the technological gold products and productive chains established in developed countries, such as colloidal gold nanoparticles with unique optoelectronic properties useful in organic photovoltaics [7], sensory probes [8], therapeutic anticancer agents [9], drug delivery in biological [10] and medical applications [11] and catalysis [12], among others. As a second example,

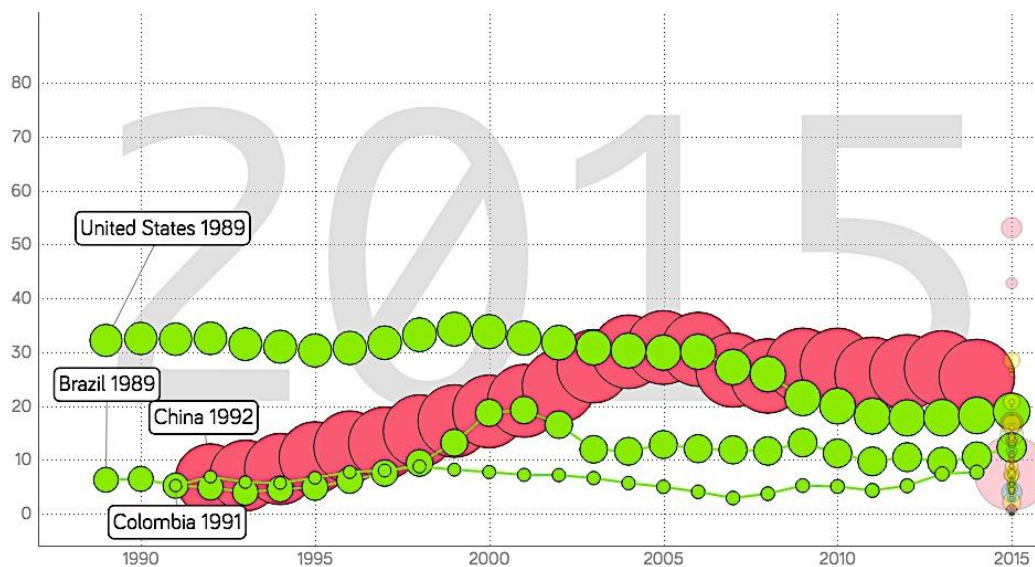
different metals such as cobalt, antimony, beryllium, fluorite, gallium, germanium, indium, magnesium, niobium, rare earth elements, tantalum, tungsten, including platinum (Pt) and the platinum group elements (PGEs), are also considered worldwide as critical main sources. In particular, because its physical and chemical properties, Pt is everyday more a “critical and environmental metal” than a precious metal, estimating that 20% of the products made in the world have Pt, mainly in the automobile industry, as the main component in screens for catalytic converters since the 80s decade, and used to transform toxic pollutants, such as carbon monoxide and nitrous oxide, into carbon dioxide, nitrogen, and water vapour. The use of Pt is therefore closely related to the demand for automobiles, and currently is very valuable, even more than Au, and the most important among the group of the nine most rare metals (that include Ru, Pd, Rh, Os, Ir, Pt; plus Au, Re, and Te) [13]. In Colombia, the region of Chocó currently produces the mainly bulk platinum in the country. Nonetheless, the Pt mining activity is informal in many cases [14]. Again, this situation is opposed to the technological products and productive chains established in developed countries around Pt and the PGEs, which are vital to fuel cells [15], as well as in the glass, petroleum, electric, and electronic industries, and the manufacture of jewelry. Besides, PGEs are exploited in medicine for cancer treatment and the preparation of dental fillings [16].

Actually, the economic growth in the last decade was possible in an exceptional manner in Colombia due to the increase of prices of certain mineral resources - mainly mining-energy resources-, which are highly sensible to the variation of the dollar price, the demand from developed countries, and clearly, to their general availability in the world [6]. In other words, Latin America is affected positively with a high price of the dollar, but only because it is a region that is highly dependent on the exportation of main sources, i.e. raw materials, oil and metals. But, with the arrival of the circular economy [17] and new supplies to world markets, the popularity of these main sources starts to finish and the prices of iron, copper, and especially oil, can dropped to low levels. According to the OECD, the end of the long period of popularity of the international prices of main sources would have concerns of high impact. Therefore, towards the need of a sustainable development for mining together with the global demand for more sophisticated products, the economic growth without productivity will have no sense. Even so, Colombia has not been able to penetrate in the world markets of sophisticated products (figure 2), and its natural non-renewable resources, such as minerals, are becoming increasingly depleted against a backdrop of extraction for export and low national consumption rates and intense industrialisation [18]. The previous reasons explain why it is necessary to be serious about innovation but with accent on sustainability. According to the World Trade Organization, between 1980 and 2010 the export of manufactures in the world grew an average of 8% yearly, more than the growth indexes of the exportations of main products (agricultural 5% and mining 6%).

## *2.2. Does mining sustainability exist?*

By definition, the extraction of non-renewable natural resources denies the possibility of sustainable mining. In reality, there are diverse types of mining, some with high social and environmental impact and others with low impact. In contrast to the environmental impact of the extraction process, there is what is being done with the economic results that come from the mining activity, and how these are related or not to sustainable human development. It happens that countries with similar mining wealth generate completely different development processes, that depend on how the mining income is used, building, or not, the possibility to leverage the sustainable development with resources from extraction activities. In like manner, countries that export assets that are relatively sophisticated for their own development level grow faster than those which simply export more of the same traditional products, such as most of South American countries.

In Colombia there is attention to the mining royalties in social terms, related to covering the basic needs of the population in the health, education, drinking water, and basic sewerage sectors, among others. Nevertheless, the question remains what to do with informal mining, low scale mining, and even worse, with illegal mining that obviously does not pay any royalties? The effect of mining depends on how the activity is done and how it is framed in a long-term economic proposal and social policies. Consequently, besides the development of complex and sustainable productive capacities, the promotion policies for mining in the country must enable to add value to the mineral resources, increasing the operational efficiency and contributing to the mitigation of the environmental impact that would lead to a reduction in social conflict [20]. Also, it is imperative that Colombian exporters of non-renewable minerals and energy resources (coal and oil) integrate themselves to the world race for productive and sustainable innovation, as well as establishing highly efficient value-added chains. Otherwise, the current state will continue increasing the damage and scarcity of the available resources, without other guarantee different to the compensation through royalties and therefore, against the concept of sustainability.



**Figure 2.** Comparative of High Technology Exports (HTE) for the beginning of the XXI century. (% of exportations of manufactured products). Data simulated in Gapminder™. The size of the circles corresponds to the approximate size of the population according to the country. Colombia appears in the smaller circles and is compared to the U.S.A., China, and Brazil. HTEs refers to products with high intensity of innovation and development [19].

To have mineral resources and to use them is not by itself a negative activity. On the contrary, it can be a source of wealth and support for the sustainable well being of humans. Countries such as Sweden and Finland have done it; they have based their economic and social development partially on the finding and measured exploitation of mining resources. Other countries instead have exploited their mining resources to increase their consumption and very little to invest in the formation of human talent, without giving priority on the long term economic and social planning [21]. In Latin America, Chile has a fiscal rule that enables it to save lots of resources during the mining booms in order to spend them in bad times. This is why the mining countries, with high or low mineral sources require permanent and more R&D initiatives, in order to safely board a path towards development, adding the possibility to benefit “in a thoughtful and sustainable manner” from certain natural resources broad interest for diverse technological drivers in the world. One approach could consist in developing

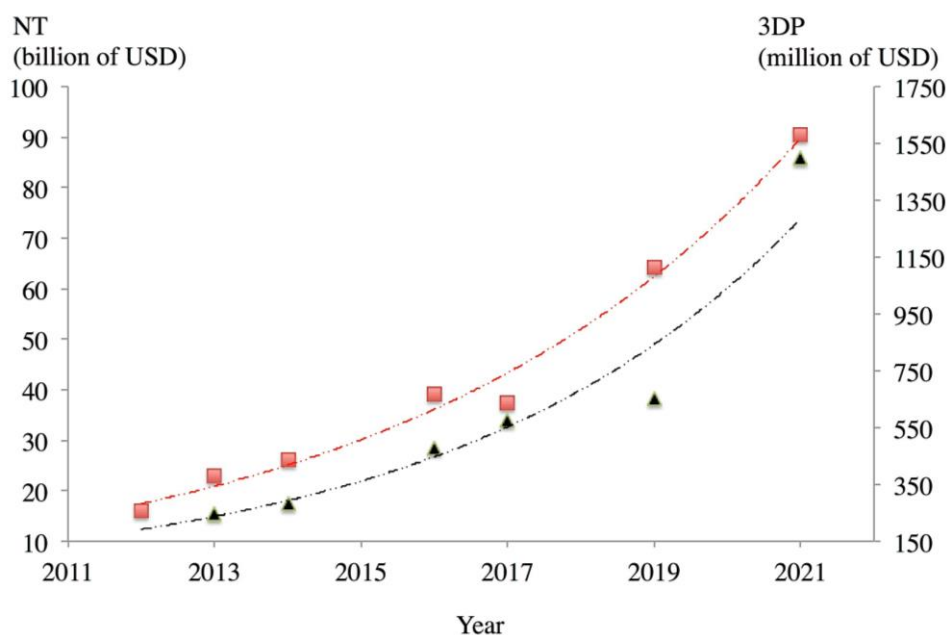


methods that provide maximum use of the elements composing the ore and/or minimize the amount of residues.

### 3. Alternatives with added value

The worldwide productive structure is being oriented towards a society and an economy based on knowledge (that in other terms is the concept of modern societies), then the complementary problem for Colombia is to guarantee that the international competitiveness of the mining and industrial sectors will be based, not only on the exploitation, exportation of main sources and in the geological knowledge of the country, but also on the sustainable exportation with added value. The capacity of sustainably optimizing the exploitation and benefit of local resources can be increased, for example, through disruptive sciences in order to generate complex productive supply chains, minimizing the consumption of minerals, and offering innovative and mainly value-added products that progressively transferring the qualification of exporter of commodities and main sources, to the status of producer of intermediate assets, and even final assets, for diverse applications of higher economic recovery. Second, appropriating circular economies as links in productive chains for the reuse of resources, materials and products, will increase not only the efficiency, but also the sustainability in the framework of the scarce resources available. The globalization, Free Trade Agreements (FTA) and the open regionalism increase the need for strategic actions, but planned according to the sustainability criteria. A key aspect is the question of which applied–research initiatives will consolidate a model more centered on technology while combining disruptive sciences.

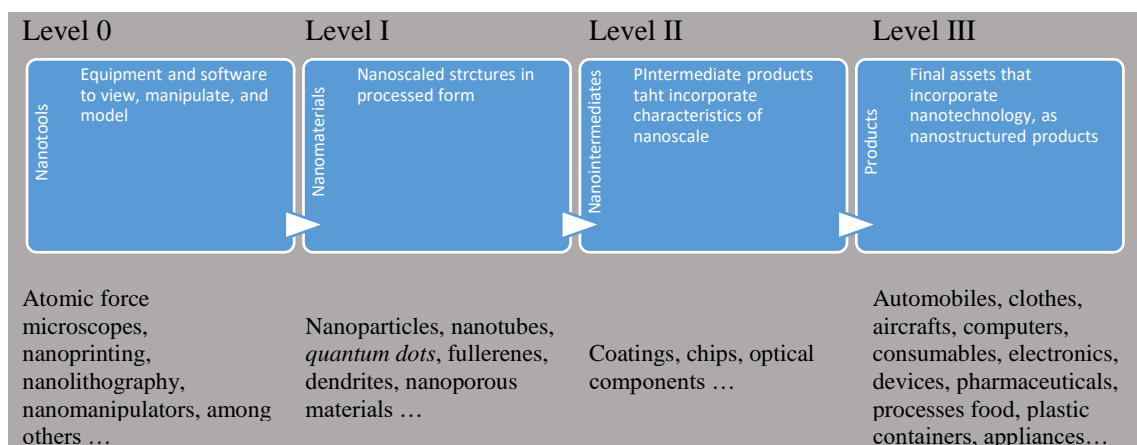
As far as disruptive sciences are concerned at least two examples can be mentioned here (See also figure 3): First, the NT global market has evolved and currently presents a greater opportunity to participate in the so-called nano–intermediate products, which are products that incorporate nanomaterials or nano–scale characteristics [53]. As a second example, 3DP will strongly influence manufacturing in aerospace, medical components, tooling and transport [22]. In particular, transport sector is and will be one of the biggest consumer for 3DP components, given the level of development required by different types of automotive–part suppliers and particularly for the companies that are part of the automotive supply chain in Colombia.



**Figure 3.** Global market forecast for NT (□) and advanced materials for 3DP, technologies and global markets (Δ). Data source: [23]–[25].

### 3.1. NT value chain

It is easier to sell something that is useful for different applications, with greater ease of appropriation in a changing and diverse market [54]. In relation to the sales of products that incorporate nanotechnology, it is convenient to distinguish three levels in the nanotechnology value chain (figure 4). The introduction of tools and instruments adapted to the work at the nanoscale level is an indispensable requirement to develop any application (Level 0). Therefore, the manufacturers of instruments for processing and characterization of nanomaterials, are the first segment of nanotechnology to reach the market. According to forecasts from the OECD, the growth in nanotools is expected to be around 30% annually. In 2005, nanotools market represented more than USD 266 million in the United States. The forecast is near to USD 10 billion in 2017. The next level is represented by the advancement of knowledge in nanomaterials (Level I), which industry develops to the large-scale supply of future applications [55]. The global market scale for nanomaterials is expected to double the numbers; with USD 15,9 billion in 2012, to 37,3 billion in 2017 [25] (figure 3). Level III is the entrance in the market of nanotechnology-derived applications, represented in products and processes, with the main target sectors being energy, health and electronics [13].



**Figure 4.** Nanotechnology value chain. Adapted from [26].

Indeed after the notable development of nanomaterials in the last 10–15 years, the challenge is currently to incorporate them into semi-finished products. Currently, the global nanotechnology market had evolved and presents a greater opportunity for the so-called nano-intermediate products (Level II). As a reference data, the relationship between applications for patents and publications increased from 0.23 in 1999 to 1.2 in 2008, thus indicating that besides discovery or basic research in nanotechnology, corporations have more interest toward commercial applications and benefits. In this context, not only in Colombia, but also in any emerging economy, the premises of applied research (pending and ongoing) directly related to nanotechnology and especially to nano-intermediate products should be the basis of projects, programs and activities that contribute to promoting national development. The appropriation of nanotechnology in combination with traditional, artisan, and large-scale mining has sense because some of the different types of nanomaterials are really forms of matter, such as oxides, nitrates, carbides, composites and metals. At the same time, they can be used in new developments and Colombian technological drivers, including structural and biological applications, photonics, medicine, and energy, among other topics that are having more commercial impact each time (table 1).

### 3.2. 3DP and transport

3DP allows objects to be fabricated layer by layer in a continuous or incremental manner, enabling three-dimensional objects to be ‘printed’ on demand [2], with significant advantages in design freedoms, mass customization, co-creation and innovative business models [41]. The global market for 3-D printing materials reached \$475.4 million in 2015 and is expected to reach \$576.6 million in 2016 and over \$1.5 billion in 2021 (figure 3) [23]. The key concept suggested here is that when a part or spare is printed, mainly by using cyclical materials flows [42], the object will last longer. This is possible because 3DP shifts towards more localized production besides re-shift production to consumer countries as the share of labour costs in the total production costs decreases [22]. Also, despite its early maturation phase, it should become aware that 3DP represents a technology which can greatly lower the input and output intensities of industrial manufacturing [43] (figure 5).

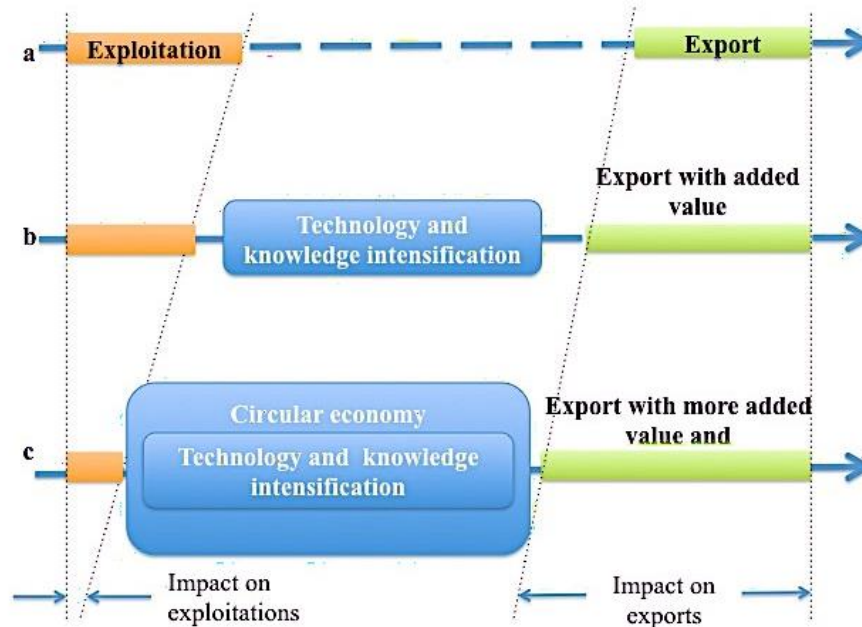
**Table 1.** Level I of the value chain of nanotechnology. Examples of application of different types of nanomaterials obtained from different mineral sources

Nanoparticles		Application	Reference
Mn-Mg Ferrites	Space	Magnetic nanoparticles for spatial applications	[27]
SiO <sub>2</sub>	Optics	Base covers with anti-reflective composites	[28], [29]
Gd, Pd	Optics	Exchangeable mirrors (Intelligent glass)	[30]
Ag	Optics	Films of different color	[31]
Ag	Biology and printed electronics	Conduction films obtained at low temperature	[32]
Ag	Biosensors	Quality Control in animal products, food and biological materials	[33]
Au	Medicine	Superficially functionalized nanoparticles with DNA for molecular diagnose	[34]
Carbon nanotubes	Catalysis	Decoration with Au nanoparticles Au, for catalytic applications	[35]
CuO	Catalysis	Diverse applications	[36]
(1-x)α-Fe <sub>2</sub> O <sub>3</sub> -SnO <sub>2</sub> (x=0.0 – 1.0)	Sensors	Detection of gases	[37]
xZrO <sub>2</sub> -(1-x)α-Fe <sub>2</sub> O <sub>3</sub> (x=0.1, 0.5)	Sensors	Detection of CO	[38]
Fe <sub>3</sub> O <sub>4</sub>	Biology	Ferro-flows as contrast mediums in biological tissues	[39]
ITO (90% wt In <sub>2</sub> O <sub>3</sub> - 10% wt de SnO <sub>2</sub> )	Electronics	Smartphones, GPS, LCD, OLED, solar panels	[40]

In particular, automotive sector is recognized worldwide as the spearhead of economic and social development because multiple spill overs onto a wide range of industrial fields, so consumer products and automotive manufacturing represent the largest potentially applicable markets for 3DP as they are predicted to have a combined share of 86% in the total manufacturing market [22]. In this context, it is



worth noting that the Colombian automotive industry faces the challenge of appropriating 3DP processes for metallic materials, polymers and ceramics to develop in the country different components, and enhancing the products that are already produced nationally through traditional manufacture process, including suspensions, steering, exhaust, transmission and cooling systems, friction materials, electric parts such as batteries and wiring, wheels, chassis racks, metal parts and various accessories, among others. Despite the complexity and non-linearity of the Colombian business cycle [44], according to DANE (the National Administrative Department of Statistics of Colombia), the Colombian automotive industry had contributed 4% of the total industrial production in the country, of which 1,1% corresponds to motorcycle assembly. The transport of goods and services is not only vital for the productive apparatus of Colombia; it is a social and economic dynamic, generating 10% of the jobs in the country and contributing COP 33.4 trillion to its GDP.



**Figure 5.** Productive local chain perspective around disruptive technologies as 3DP and NT in Colombia

The two alternatives exposed until this point are represented in figure 5, which include the traditional dynamics for exploitation and exportation of some commodities in Colombia in a first scenario (figure 5a). In a second scenario, technology intensification is done in NT and nano–intermediate products (figure 5b). In a third place, using 3DP of recycled materials and products a circular economy [17] is (complementary) constructed from production-consumption systems that maximizes the service produced from the linear and previous throughput flow (figure 5c). Figure 5 intends to indicate that in order to generate complex productive capacities that add value to non-renewable resources, and progressively migrate the status of a country from exporter of commodities and main sources, to that of producer of intermediate assets, and even final assets, it is important to invest in the design of technological supply chains (but also entrepreneurship, business models and high quality education), with the aim of formulating a research agenda to enable Colombia to reach its full potential for the future.

### 3.3. Local sustainability perspective on 3DP and NT for some mining resources in Antioquia

As a single and final example, between the 32 departments of Colombia the Department of Antioquia is most populated province and the country's largest economy after Bogotá. The investment in R&D is about 0,28% of its GDP, that even though it is slightly higher than the national investment, it is still

low compared to international standards [45]. According to the Chamber of Commerce in Medellín, between 2001 and 2010 the exportations from Antioquia went from USD 2.006 million to USD 4.714 million (with a yearly growth rate made up by 10%). Nevertheless, the per capita GDP of Antioquia (without Medellín city and the Aburrá Valley) decrease to USD 3.685 per year, compared with the one of Medellín; which is about USD 6.105 yearly. This is caused by the productive structure in the most delayed parts of the Department, where besides the commerce, tourism, and the basic agriculture, there is mining exploitation. Technically and technologically, the mining activity in Antioquia is developed in a high percentage under inadequate conditions, resulting in the loss of deposits and a minimum management regarding environmental issues. For the department it is fundamental to reach a higher level of quality in the mining activity but with added value [46]. This makes sense if it is also considered that being Antioquia the largest gold producer of the country, the presence of other resources, as coal, limestone, and construction materials, represent an important source of the income for the department since pre-Colombian times, so the mining activity has settled in the culture and the economy of all the department.

### *3.3.1. Industrial and construction minerals*

In Antioquia there is exploitation of metallic minerals, non-metallic minerals, and mining-energy resources. These different minerals are materials-type that could easily support the development of nano-intermediates and novel 3DP process in Antioquia. Notwithstanding, the chain of non-metallic minerals concentrates its production in cement, concrete products, and ceramic covers. Its exporting vocation is focused on glass and its products, as well as ceramic products for home use. Even though an important part of the sales are abroad, there is still space for the growth of exportations for industrial and construction minerals. The mineral rocks obtained in the quarries (marbles, granites, limestone, and slates, among others) can be useful for the development of coatings, made up by nanoparticles resistant to corrosion and the microbial flora. Together with the current popularity of construction, as sources of construction materials, in the Aburrá Valley the quarries in Bello on the Medellín-Bogotá highway, Copacabana, and Caldas are very well known. In the east of the department there are quarries in the San Nicolás Valley; including El Retiro, La Unión, and Rionegro. Regarding the quarries exploited for ornamental use (marble) there are locations in La Danta, and Río Claro. Marble is also extracted in Amalfi, Puerto Nare, Segovia, and Jordán. In Valdivia and Yarumal there are blocks of slate with grey to green tones know as Valdivia stones, of broad architectonical use in the department [47].

The greatest calcareous deposits are in Puerto Nare; which also include Puerto Berrío, Puerto Triunfo, San Luis, and Sonsón. The production of limestone, marble, and clay in 2010 was of 1097, 724.800, and y 720.000 tons respectively, with the district of Puerto Nare having an average production, projected to 2019 of 3.400.000 tons of limestone, according to the General Comptrollership of Antioquia [46]. This inventory accounts for the mineral deposits, evidencing the reserves of calcareous rocks (mainly marble), whose exploitation supplies, in a large measure, the cement industry in Antioquia, one of the most important in the continent. Such rocks are also exploited as ornamental rocks and as a source for agricultural and industrial salts. It is feasible to work in the direction of expanding the benefit and use, through NT, of minerals from Antioquia and Colombia, as supplies for the production of agrochemicals of interest in the fertilization of fields, as well as to improve the productivity and economic efficiency of the agricultural and farming activity in Colombia.

There is also an important number of commercial nanoparticles, derived from the same sources of industrial minerals that can be used to make a variety of nanocomposites. In this context, organic clays or nanostructured montmorillonite, or commonly denominated nanoclays, are the most researched nanoparticles for different polymer nanocomposites [48] in a broad range of promising 3DP applications [49]. Other uses of nanoclays are in the development of adsorbents, catalysts, and diverse

biomaterials [50], [51] through 3DP [52]. Antioquia has been a known producer of plastic clays, aluminates, and diverse kaolins since the late 20th century. Natural clay (bentonite) in Antioquia, contains besides montmorillonite, glass, kaolin, quartz, zeolites, and carbonates. The main industries that demand clays and kaolins are the ceramic, paint, refractory, and cement industries. In Rionegro (Llanogrande) and in El Carmen de Viboral there is extraction of homogeneous mixtures of plastic and aluminous clays, both for ceramic and refractory use [46]. In the municipality of La Unión, besides clay for ceramic, there is also exploitation of kaolins that are submitted to different benefit and treatment processes, to generate products that are mainly used in paints and pigments, sanitary and electrical porcelain. Unprocessed kaolin is used in the cement industry. Besides these resources, there are red clays and slits of broad use in the construction industry as a main source for the production of bricks and roof tiles. In the municipalities of Valparaiso, Angelópolis, Amagá, Abejorral, and Santa Fe de Antioquia there is exploitation of compacted clays and other types of clays that are useful in the production of ceramic tiles, and in a lower proportion, for the production of bricks and roof tiles. Other clays with variable contents of iron, calcium, sodium, potassium, alumina, and silica, are of interest for the production of grey cement and are generally exploited close to the cement factories [47]. All these materials could be also useful for the additive manufacture of ceramic components [53], [54].

A third group of applications of nanomaterials and development of intermediate products is found in the talc mineral. This one can be used as a nano-additive for lubricant oils to reduce friction [55], or as nanoparticles that reinforce thermoplastic matrixes [56], among other uses. In this context, the municipality of Yarumal in Antioquia has traditionally been a producer of this mineral. Generally, the talc extracted is submitted to processes of trituration, milling, and classification and is used according to the level of purity in paints, pigments, plastics, soaps, rubbers, clays, papers, and ceramics, but not precisely in local applications related to nanotechnology.

Assisted by the current popularity of the civil industry, one of the construction materials that are mostly used for housing, besides limestone, dolomite, and other types of materials is plaster. This material is being studied by nanotechnology for the performance of innovations in the construction industry, especially because of its potential uses in systems for the control of pollution, self-cleaning mediums, and photo sterilization, through the addition of nanoparticles of titanium dioxide ( $\text{TiO}_2$ ) [57]. In Antioquia, there is exploitation of a plaster deposit, formed by volcanic activity and located in the municipality of Anzá, throughout the Niverengo creek. The exploited material, depending on its purity, is used by the cement and construction industries, in this last case for the fabrication of stuccos and ornamental plasters [47] and could be used for cultural heritage applications [58] through 3DP. In general, the use of nanoparticles in cement materials results in a broad range of possible innovations, defined by their functionality and an improved mechanical performance, even with the potential energetic expense associated to new manufacturing techniques. The effect of chemical inertia of these type of materials, added to their growing consumption by the cement industry, is showing better results in the hydration times, concentration phenomena, and pre structure; favouring the levels of disinfection and tenacity [59]. These properties have been found to be modifiable and adaptable according to the need as a function of the size of the added nanoparticles (calcium and magnesium carbonates, clays, silica, unprocessed kaolin, among others). Complementarily, the analysis of the life cycle of different products show that the photo-catalytic reactivity of  $\text{TiO}_2$ , can compensate possible environmental damages [57]. With these conditions, the nanoparticles with base of limestone and dolomite, and other types of minerals, can also revolutionize the construction industry in Antioquia, through the creation of new cement based composite materials (CCM); adapted according to their structure and properties for different structural or functional requirements [60]. CCMs, reinforced with carbon nanotubes tell a recent story, in which the fabrication methods, the structural, mechanical, electrical, and piece-sensitive properties, as well as thermal and shock or bullet proof properties, continue to be the object of improvements, both in performance, and in cost, towards a broad range of

applications [61]. Here there are more opportunities for the development of nano-intermediate products from the mineral sources in Antioquia, as long as there are important reserves of limestone (calcium oxide, calcium carbonate) and dolomite (calcium and magnesium carbonate), mainly used for the cement industry. The cement plants are located in the east and northeast areas of the department, in the zones of Río Claro and Río Nare and in the southeast, in Abejorral and Santa Bárbara. There is also limestone in Sonsón, Amalfi, Cocorná, Remedios, Yarumal, San Carlos, Jordán, Puerto Berrío, and occurrences with possibility for exploitation in Río Verde and Togoridó, to the west of the department [47]. The limestone from Río Claro, besides cement, is considered a value-added product since it is destined for use in white paper for printing and writing, besides dull, varnished, cardboards and water based paints, varnishes, inks, stuccos, lacquers, plastics and rigid and flexible PVC products, hoses, cables, pharmaceutical and food products, dental paste, cosmetics, abrasives, water sealing products, soaps, and others.

Finally, regarding quartz sands ( $\text{SiO}_2$ ), that are basically a sub-product of the benefit and treatment processes of kaolins, their industrial uses are broadly related to the ceramic and glass industries. In Antioquia there is exploitation of layers of hard sands in Angelópolis-Amagá and of pheldespatite in La Ceja and Montebello, and in lower amounts, in Envigado, La Pintada, and Alejandría. The opportunities derived from nanotechnology regarding the use of  $\text{SiO}_2$  include different fields, that go from water purification and advanced filtering means, medical and dental applications, development of composite materials, fabrication of glass products, the construction and abrasive tools sectors, among others [62], [57].

### 3.3.2. *Metallic minerals*

Copper, lead, iron, and zinc minerals have been extracted in the department of Antioquia in the mines of Zaragoza, Remedios, and Segovia. There are also indications of minor explorations and exploitations of copper and silver in La Ceja, and copper, molybdenum, lead, and zinc in Murindó, Urrao, Dabeiba, and Salgar. Other metals that have been exploited in the department in an organized or artisanal, isolated and interrupted manner are manganese in the La Loma creek in Santa Bárbara and in Dabeiba. In this case, the use of the manganese mineral is directly related to the brick and ceramic industry, but also, after being processes as manganese sulfate and potassium manganite, it has been used to make fungicides in the chemical and pharmaceutical industries [47]. According to Colciencias, one of the reasons adduced by the experts for the low efficiency of agriculture (except for some exceptions such as sugarcane, flowers, or oil palm) and the Colombian farming activity, is the scarce use of adequate fertilizers and other agricultural supplies for the improvement of the crops and pastures. One of the main reasons is the price that most of these products, that are imported, tie their cost to the price of the energy needed for their extraction, processing, and transportation [63]. In such sense, it is feasible to work in towards the expansion of the benefit and use, through NT, of local and national minerals, as supplies for the production of agrochemicals of interest in the fertilization of the crops, and to improve the productivity and economic efficiency of the Colombian agricultural and farming activity. The use of mineral products of national origin, besides the manganese sulfates in Santa Bárbara and Dabeiba, added to phosphates, potassium chloride, sulfur, borax, dolomitic limestone, and other derivative from hydrocarbons such as urea and ammonia, have a strong justification for the development of the fertilizer and agricultural supplies industry in the country, due to the importance of their participation in the cost structure of the agricultural and farming sector, and to the low participation of the national industry in their production. Other applications for manganese sulfate and potassium manganite are found in the chemical and pharmaceutical industries, in water nano-filtering systems, in nanostructured catalyzers to eliminate bad smells and in the bleaching of textiles. Besides manganese, there have been chrome exploitations in the Santa Elena region, to the east of Medellín. Traditionally, this mineral has been used as foundry sand and in the production of colored vitreous chips. Chemical derivations of this mineral have also been used in leather treatment processes, as pigments for inks and paints, besides textile processing [47].

#### 4. Conclusions

The mining opportunities must continue enhancing the life quality of the regions, aiming to position the country in other aspects, not only the exportation, but also the generation of knowledge and high levels of productive specialization. It is not an innovation, but is possible to imitate successful experiences from the strategies of some developed countries. So, it is not exaggerated to say that if Colombia takes good advantage of its mining, it can jump to sustainable development. The emphasis in the mining sector is a unique opportunity to give the country a push regarding infrastructure, and to end poverty to a large part of the 46% of Colombians that do not have enough income for a dignifying life. Particularly, in Antioquia Colombia, as well in many other regions in the country, there are clear opportunities for the rational benefit and with higher added value of different resources that can supply the large material demands implied by current and future technological developments. The essential ingredient in the exporting sophistication for mining is innovation in key of sustainability. Thus, the productive structure of diverse sub-regions in the department could be favourably impacted if they carry out projects of productive development in mining, together with the objective of developing nanomaterials as example, and looking for better levels of efficiency regarding the exploitation and the commercialization of resources with a higher added value through 3DP.

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