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# BIOFUELS AND ABSOLUTE COUPLING. POTENTIAL AND CHALLENGES FOR A SUSTAINABLE FUTURE

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***Abstract***

*Absolute decoupling is an economic and sustainability concept that refers to the complete separation of economic growth from natural resource use and environmental impact. This form of decoupling is observed when an economy sustains its growth while the consumption of resources and greenhouse gas emissions decline, signifying an enhancement in resource efficiency and a reduction in environmental impact. Absolute decoupling is considered essential to achieving sustainable development goals, as it offers a solution to developing economies without exacerbating ecological problems such as climate change, biodiversity loss and soil degradation. In this context, biofuels have a significant role, because their utilization can aid in reducing carbon dioxide emissions, thereby facilitating the decoupling of greenhouse gas emissions from economic growth. However, their positive effects depend on several factors, such as cultivation methods, the types of biomass used and the efficiency of the production process, so that the negative ecological impact of their use does not counteract the benefits offered by reducing $CO_2$ emissions. Another relevant aspect of the relationship between biofuels and absolute decoupling is their potential to encourage innovation in the energy sector. By investing in and developing second- or third-generation bioenergy technologies that use organic waste and residues, biofuels can become more sustainable, this approach contributes to reducing natural resource consumption and minimizing ecosystem impact. The current study undertook a bibliographic analysis focused on the objective of absolute decoupling and the role of biofuels in achieving this goal, and on the other hand from the collection, processing and interpretation of statistical data regarding energy consumption, $CO_2$ emissions, production and the consumption of biofuels. The findings revealed a steady rise in these factors, suggesting a direct correlation between economic expansion and its environmental impact. The growth in biofuel production and consumption illustrates the effort regarding the transition to more sustainable energy sources. However, $CO_2$ emissions continue to have an upward trend, which requires the intensification of efforts to increase the share of renewable energy and reduce the intensity of emissions, so that economic growth is sustainable and with minimal effects on climate change.*

***Key words:*** *absolute decoupling, biofuels, climate change, efficiency*

## INTRODUCTION

Climate change and the need to reduce greenhouse gases are topics that have long concerned political factors, as well as specialists and non-specialists, worried about the impact they will have on the future of humanity. Conversely, some researchers advocate for a balanced strategy that emphasizes adaptation and the advancement of low-emission technologies, rather than an overly aggressive push for rapid emission reductions, which could adversely impact global well-being. In this context, the challenges related to the need to obtain reliable and cheap energy, especially in developing countries, and the global objectives of reducing emissions must be met. Forecasts indicate that fossil energy sources will continue to dominate until 2050, particularly in developing nations, raising concerns about meeting the 'Net Zero' target of limiting global warming to below 1.5°C relative to pre-industrial levels [27].

In this context, in the 2000s, another concept was brought into discussion, that of absolute decoupling, which supports the objectives of the Paris Agreement, as it promotes the transition to cleaner energy sources and provides a theoretical and practical framework for reducing emissions and consumption of natural resources, while economies continue to grow [8]. By means of the OECD report from 2002, entitled "Indicators to Measure Decoupling of Environmental Pressure from Economic Growth", absolute decoupling was defined and analyzed in detail, with indicators and evaluation methods being proposed of how economic growth can continue without intensifying the impact on environment [17, 26].

Therefore, absolute decoupling implies the adoption of clean energy solutions, but studies show that these solutions are expensive and resource-consuming [3], and therefore there is a need to focus on the adaptation and development of low-emission technologies, instead of a pressure exaggerated for rapid reductions in emissions, which could have negative effects on global well-being [2].

Alongside various strategies encompassing renewable energy, carbon capture and storage, sustainable agriculture, enhanced energy efficiency, and energy demand management, bioenergy and biofuels serve as crucial resources that can be further advanced to bolster decarbonization initiatives without hindering economic growth or global welfare [4, 13]. For instance, bioenergy with carbon capture and storage (BECCS) merges bioenergy with carbon capture technologies, leveraging plants to sequester $CO_2$ while capturing and storing emissions produced during biomass combustion. On the other hand, biofuels, which could be obtained from plant biomass, agricultural and industrial waste or vegetable oils, can reduce the impact on agricultural land, given that the world's growing population already puts a high pressure on obtaining food and other necessary resources, thus gaining popularity due to their ecological advantages [11, 15].

Over time, there have been several generations of biofuels: the first generation, obtained from food crops (corn, sugar cane, etc.); the second generation obtained from agricultural and forestry waste that contributes to the implementation of the circular economy and to the reduction of pollution through the efficient use of resources (biogas, cellulosic bioethanol); the third generation obtained from microalgae and other aquatic sources. These advanced generation biofuels have a much smaller impact on land use and do not compete with food production, while also having, according to studies, the potential to reduce greenhouse gas emissions by up to 85% [12]. Fourth-generation biofuels are more advanced than third-generation ones, and their production is based on the metabolic engineering of algae with the advantage of absorbing $CO_2$ and having a high production rate [18]. However, there are certain economic and feasibility challenges, as the production technology is still in the research and development stage, and the conversion of raw materials into final biofuel requires new technologies [19, 20].

Thus, although biofuels are considered essential in the transition to a low-carbon economy, it is found that there are significant challenges in their widespread adoption, namely: competition for resources between biofuel production and food production, considering the fact that in many regions, the allocation of agricultural land for biofuel crops may drive up food prices and limit access to essential food resources; furthermore, the intensive cultivation of biofuel feedstocks can result in deforestation, soil degradation, and a decline in biodiversity; although biofuel production technologies are continually advancing, their costs remain elevated in comparison to conventional fuels; moreover, the infrastructure required for biofuel production, transport, and distribution demands significant investment; in many countries, the regulations are not yet clear or favorable enough to stimulate the transition to biofuels, and coordinated international policies are needed to support investments in technologies for the production and use of biofuels, which can at the same time guarantee compliance with the standards of environment and social [1, 9, 16, 21, 24].

Biofuels therefore have an important role to play in the relationship between absolute decoupling and large and rapid emission reductions, providing a lower carbon alternative to fossil fuels. They can be incorporated into existing fuel infrastructures, supporting the transition toward a more sustainable economy without hindering economic growth [10]. In the context of

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absolute decoupling, biofuels allow the reduction of economic dependence on fossil resources and allow the continuation of economic development without a proportional increase in greenhouse gas emissions [25].

To support large and rapid emission reductions, biofuels can be used especially in hard-to-electrify sectors such as aviation, shipping and heavy industry, where the transition to electricity is complex and expensive. By using biofuels, these sectors can substantially reduce carbon emissions, thus contributing to the objective of absolute decoupling [14].

Thus, biofuels can be part of an absolute decoupling strategy that pursues sustainable economic growth with low environmental impact, while simultaneously supporting short- and long-term climate goals.

Moreover, absolute decoupling and large and rapid reductions in emissions are complementary concepts, essential for effectively addressing the climate crisis [28].

Factors that have a direct and indirect influence on natural resources and greenhouse gas emissions are represented by demography, economic development and energy use.

In this context, the aim of this research was to examine how absolute decoupling may impact the relationship between energy intensity, greenhouse gas emissions and the use of biofuels in order to evaluate how the impact on the environment can be reduced, in the conditions of maintaining growth economic.

## MATERIALS AND METHODS

The analysis was carried out for the period 2000-2023, taking into account the estimates for the time horizon 2030 and 2050. To carry out the research, data taken from world and European statistics were used, which were processed and analyzed, but the purpose of formulating the research results, which they were the basis for formulating conclusions regarding the importance of this extremely present and necessary subject for ensuring the future of generations to come.

## RESULTS AND DISCUSSIONS

Significant population growth means greater demand for resources and energy to support the population, which will intensify the pressure on the environment, making it more difficult to achieve absolute decoupling. In this sense, absolute decoupling implies the need for solutions that will have the effect of maintaining the consumption of resources and emissions, at a low level per inhabitant, even in the conditions of population growth.

According to estimates, the world population will exceed 8.5 billion inhabitants in 2020, will reach over 9.70 billion inhabitants in 2050 and over 11 billion inhabitants in the year 2100 (Figure 1).

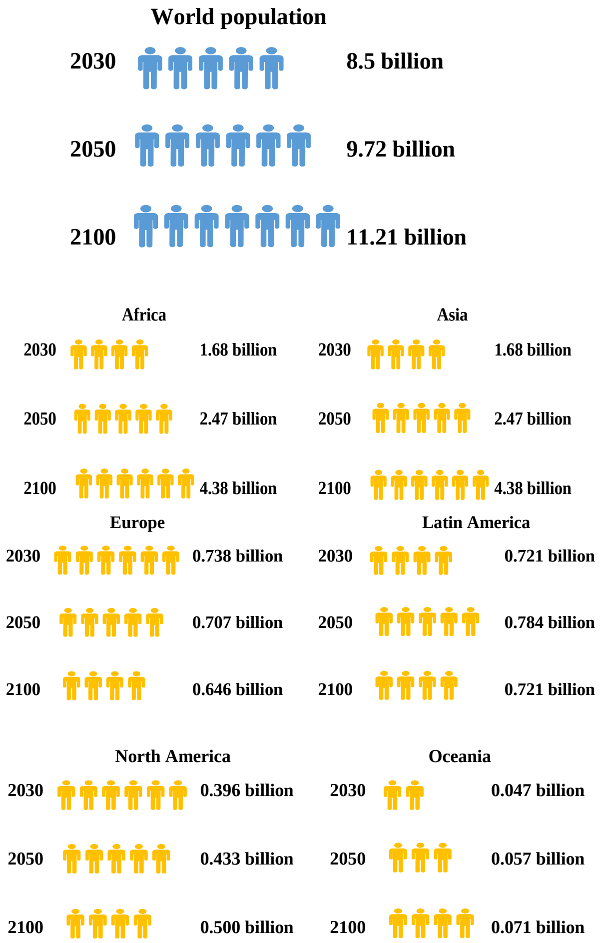


Fig. 1. Population evolution in the period 2030-2100
Source: [7].

Africa and Asia are the engines of population growth, given that at this currently the largest countries in the world are Nigeria, Bangladesh, China, India, Indonesia, Pakistan. To these are added Brazil, Mexico, the USA and Russia. Europe and North America are regions expected to experience population declines, with reductions projected to reach up to 15% in certain countries, including Romania.

Therefore, as the population grows, so does the global demand for energy. That is why, especially in emerging economies, where demographic growth is faster, biofuels offer an affordable solution to cover energy needs, especially in the transport and agriculture sectors. However, in order to meet a large and growing demand, biofuels must be produced efficiently and sustainably, given that the production of biofuels involves the use of energy crops (such as corn, soy or sugar cane) that require extensive areas of agricultural land. Thus, as the population grows, agricultural land will be in greater demand for food production, which may create competition between the use of land for biofuels and land for food production. This can lead to increased food prices and deforestation to create new agricultural land, negatively impacting the environment. In this context, second-generation biofuels, which use residues and waste instead of food crops, are a greener and more sustainable alternative.

In densely populated regions and expanding cities, biofuels can play a major role in supporting a sustainable energy transition by reducing greenhouse gas emissions in congested urban areas. At the same time, biofuels from urban waste can be a sustainable solution that reduces dependence on energy crops and contributes to waste management in large urban agglomerations. Furthermore, in regions with accelerated population growth, there is greater pressure on governments to provide affordable energy and stimulate local economies, therefore biofuel production can create jobs in rural areas and contribute to local economic development. However, policies must balance the need for biofuels with the impact on food security and the environment to ensure sustainable development.

Therefore, the analysis must be completed with information about the relationship between energy consumption and population growth.

Thus, it is found that worldwide, energy consumption has continuously increased, so compared to the years 2000, when the consumption was 397 TWh, according to the estimated data, it will be doubled by 2030, which is due to both economic growth, but especially urbanization. The reduction in consumption in 2019 and 2020 is the consequence of the cessation of industrial activity due to the emergence of the Covid-19 pandemic. It is observed that the impact of the economic crisis from 2007-2009 had a direct impact on energy consumption ( Figure 2).

The increase in this consumption in the following period highlights a growing demand for energy resources and, implicitly, the increase in pressure on the global energy infrastructure.

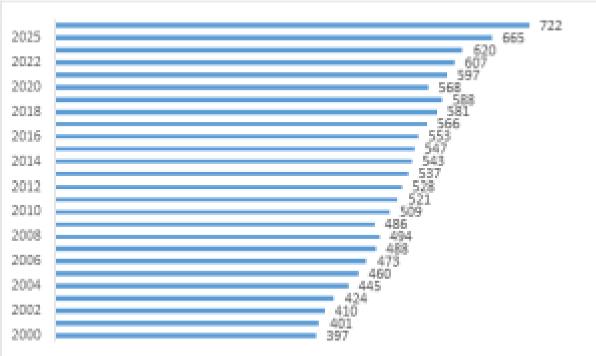


Fig. 2. The evolution of energy consumption, worldwide
Source: own processing based on the data from [22].

Global global energy consumption faced significant differences between OECD and Non-OECD regions. If in the case of OECD countries there is a moderate increase, from 282 TWh in 2020 to 309 TWh in 2030, reflecting both energy efficiency and the transition to green energy, it is found that Non-OECD regions, especially in Asia and Africa, there is an increase in consumption during the analyzed period, from 332TWh to 413 TWH, which is due to economic growth and urbanization. North America and Europe, which are two mature energy markets, are experiencing slow growth due to stability and adaptation to environmental regulations. Asia is an emerging region, whose growth is determined by the development of the economies of countries such as China and India. Thus, in this region, consumption growth will go from 173 TWH in 2020 to 224

TWh in 2030, thus becoming a driver of global energy demand.
The Middle East and Africa have moderate increases reflecting industrial development and economic growth.
The particularity of these regions is represented by a consumption/capita that remains low compared to the other regions, but also the fact that the energy sources are represented by resources that lead to increased pollution (wood, plant residues, etc.), so it is immoral to asks the residents to keep their energy consumption so low (Table 1). Therefore, the elimination of energy poverty in these regions requires the development of reliable energy sources, but also with affordable costs, and these sources can only be represented by fossil fuels.
Moreover, once the population increases, there will also be an increase in $CO_2$ emissions.

Table 1. The evolution of energy consumption, by region, in the period 2020-2030

| Region | 2020 | 2025 | 2030 |
|---|---|---|---|
| OECD | 282 | 295 | 309 |
| North America | 148 | 157 | 166 |
| Europe | 89 | 91 | 95 |
| Asia | 44 | 46 | 48 |
| Non-OECD | 332 | 371 | 413 |
| Europe and Eurasia | 69 | 74 | 79 |
| Asia | 173 | 197 | 224 |
| Middle East | 31 | 34 | 38 |
| Africa | 22 | 24 | 27 |
| Central and South America | 37 | 41 | 46 |
| Total World | 613 | 665 | 722 |

Source: own processing based on the data from [5].

That's why we decided to continue to analyze the data related to $CO_2$ emissions recorded worldwide.
Thus, there is an increase in $CO_2$ emissions from 25.5 billion metric tons in 2000 to 37.55 billion metric tons in 2023, with some fluctuations in the analyzed period (Figure 3). Annual growth is relatively constant, as a consequence of intensified global industrial and economic activities, with notable declines in 2009 and 2020 due to the global financial crisis and the COVID-19 pandemic, respectively. After 2020, emissions resume their upward trend, reaching 37.55 billion metric tons in 2023, which shows the need to take measures to reduce emissions and transition to more ecological energy sources, such as biofuels.

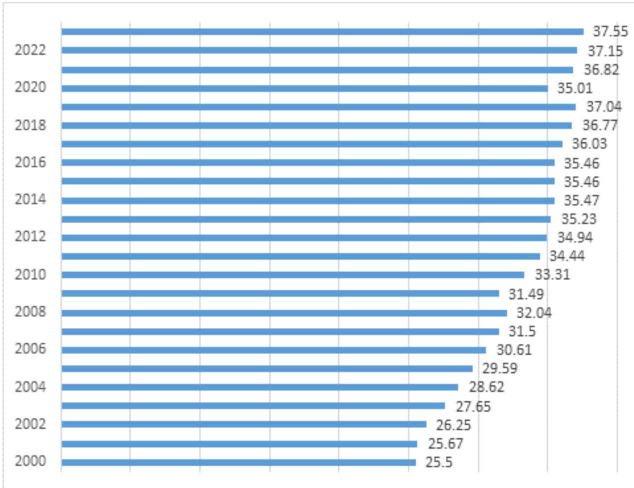


Fig. 3. Evolution of $CO_2$ emissions, worldwide
Source: own processing based on the data from [23].

Biofuel production has increased over the years, from 315 Mb/d in 2000 to 2,810 Mb/d in 2022, driven by increased demand for renewable energy sources.
The main contributors are ethanol and biomass-based diesel.
Ethanol increased from 299 Mb/d in 2000 to 1,828 Mb/d in 2022, while biomass diesel saw higher growth, from 16 Mb/d in 2000 to 983 Mb/d in 2022.
Although total production declined in 2020 due to disruptions caused by the COVID-19 pandemic, it has since recovered, highlighting the importance of biofuels in the global decarbonisation and green energy transition strategy (Table 2).
Biofuel consumption has increased from 300 Mb/d in 2000 to 2,778 Mb/d in 2022, along with increasing demand for renewable energy sources. Ethanol and biomass-based diesel contributed to this growth.
Thus, ethanol consumption increased from 285 Mb/d in 2000 to 1,834 Mb/d in 2022, while biomass diesel consumption rose from 14 Mb/d in 2000 to 943 Mb/d in 2022 (Table 3).

Table 2. The evolution of biofuel production, worldwide, in the period 2000-2022

| Year | Production (Mb/d) | Fuel ethanol (Mb/d) | Biomass - based diesel (Mb/d) |
|---|---|---|---|
| 2000 | 315 | 299 | 16 |
| 2001 | 345 | 324 | 21 |
| 2002 | 405 | 378 | 27 |
| 2003 | 498 | 465 | 33 |
| 2004 | 553 | 511 | 42 |
| 2005 | 650 | 585 | 65 |
| 2006 | 786 | 682 | 104 |
| 2007 | 1,035 | 866 | 169 |
| 2008 | 1,420 | 1,158 | 262 |
| 2009 | 1,564 | 1,251 | 313 |
| 2010 | 1,814 | 1,459 | 355 |
| 2011 | 188 | 1,446 | 442 |
| 2012 | 1,894 | 1,422 | 572 |
| 2013 | 2,040 | 1,513 | 527 |
| 2014 | 2,205 | 1,611 | 594 |
| 2015 | 2,219 | 1,673 | 546 |
| 2016 | 2,300 | 1,686 | 614 |
| 2017 | 2,387 | 1,729 | 658 |
| 2018 | 2,601 | 1,846 | 755 |
| 2019 | 2,778 | 1,932 | 847 |
| 2020 | 2,586 | 1,738 | 848 |
| 2021 | 2,650 | 1,735 | 914 |
| 2022 | 2,810 | 1,828 | 983 |

Source: own processing based on the data from [5].

Table 3. The evolution of biofuel consumption, worldwide, in the period 2000-2022

| Year | Consumption (Mb/d) | Fuel ethanol (Mb/d) | Biomass - based diesel (Mb/d) |
|---|---|---|---|
| 2000 | 300 | 285 | 14 |
| 2001 | 283 | 265 | 18 |
| 2002 | 336 | 314 | 22 |
| 2003 | 387 | 359 | 28 |
| 2004 | 484 | 446 | 38 |
| 2005 | 565 | 500 | 65 |
| 2006 | 764 | 651 | 113 |
| 2007 | 984 | 811 | 173 |
| 2008 | 1,326 | 1,092 | 234 |
| 2009 | 1,555 | 1,280 | 274 |
| 2010 | 1,751 | 1,414 | 336 |
| 2011 | 1,832 | 1,394 | 438 |
| 2012 | 1,831 | 1,374 | 457 |
| 2013 | 1,978 | 1,480 | 498 |
| 2014 | 2,120 | 1,563 | 557 |
| 2015 | 2,217 | 1,687 | 530 |
| 2016 | 2,274 | 1,676 | 599 |
| 2017 | 2,315 | 1,685 | 631 |
| 2018 | 2,502 | 1,794 | 708 |
| 2019 | 2,669 | 1,883 | 787 |
| 2020 | 2,498 | 1,677 | 822 |
| 2021 | 2,660 | 1,777 | 883 |
| 2022 | 2,778 | 1,834 | 943 |

Source: own processing based on the data from [6].

Although consumption dipped temporarily in 2020, it quickly recovered and continued to increase starting the following year.

This evolution demonstrates the importance of biofuels in the global energy mix and its contribution to reducing carbon emissions.

These data demonstrate the existence of increased pressure on energy resources, which requires the formulation of sustainable policies, adapted to regional specificities, which balance economic development, concomitant with environmental protection measures.

## CONCLUSIONS

In the context of globalization and rising global energy demand, biofuels have emerged as a promising alternative to conventional energy sources. They provide an effective solution for reducing dependence on fossil fuels and lowering greenhouse gas emissions, a core objective in international climate change mitigation efforts. However, their necessity and associated challenges require a detailed analysis of their impact on the economy, environment and society as a whole.

Although they are necessary to reduce the negative impact of fossil fuels on the environment and promote a sustainable economy, the challenges they pose cannot be ignored. Investments in research and development, the adoption of coherent policies and responsible management of resources are essential to maximize the benefits of biofuels and minimize their associated risks in the context of a globalized and interconnected economy.

Maintaining this balance is essential for fully leveraging the potential of biofuels as a clean, renewable energy source, supporting a sustainable future and advancing global climate objectives.

Absolute decoupling through the use of biofuels is not a simple solution, but a complex one, which involves balancing the climate advantages with the impact on natural resources and biodiversity. Only well-designed policies and sustainable agricultural practices can ensure that biofuels support absolute decoupling, playing an important role in reducing fossil fuel dependence and combating climate change.

As developing countries experience growing energy demand, biofuels can serve a pivotal role in providing dependable, clean energy and in mitigating energy poverty.

In conclusion, although biofuels have the potential to support absolute decoupling, reducing dependence on fossil fuels and contributing to lower $CO_2$ emissions, their production involves challenges, such as competition for agricultural resources and their impact on biodiversity. For biofuels to be a sustainable solution, it is necessary to adopt ecological production practices and integrate them into a wider energy transition strategy, alongside renewable sources.

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