Ciência Rural, Santa Maria, v.53:4, e20210208, 2023 http://doi.org/10.1590/0103-8478cr20210208

Ciência Rural

ISSNe 1678-4596
BIOLOGY

An estimation of ecosystem services provided by urban and peri-urban forests: a case study in Juiz de Fora, Brazil

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ABSTRACT: *Urban expansion has led to the replacement of natural landscapes and environmental degradation, making cities and their urban and peri-urban forests (UPFs) vulnerable to climate change, especially on the formation of heat islands. Using i-Tree Canopy program (v. 7.0), we estimate the ecosystem services provided by UPFs in Juiz de Fora (Minas Gerais State, Southeastern Brazil), through the analysis of the (1) annual removal of atmospheric pollutants, (2) annual removal of atmospheric carbon, (3) total carbon stock in vegetation, and (4) the monetary benefits of sequestered and stocked carbon, based on Future Carbon Credit (CFI2Z1) as a monetary proxy. The results showed an average total amount of removal of 4.45 thousand tons of air pollution annually. The average annual total carbon storage was 158 thousand tons and the equivalent CO_2 was 580 thousand tons, with an estimated total value of R$ 173 million per year. Significant values of the gross carbon stock (3.98 million tons) and equivalent CO_2 (14.59 million tons) were found, being valued at R$ 4.35 billion. We concluded that the Juiz de Fora UPFs have a great potential for socio-environmental and economic benefits.*
Key words: *urban forests, urban trees, carbon sequestration, i-Tree Canopy, environmental valuation.*

Uma estimativa dos serviços ecossistêmicos fornecidos pelas florestas urbanas e peri-urbanas: um estudo de caso em Juiz de Fora, Brasil

RESUMO: *A expansão urbana levou à substituição de paisagens naturais por paisagens urbanas e à degradação ambiental, tornando cidades e suas florestas urbanas e peri-urbanas (FUPs) vulneráveis às mudanças climáticas, especialmente à formação de ilhas de calor. Utilizando o software i-Tree Canopy (v.7.0), estimamos os serviços ecossistêmicos promovidos pelas UPFs em Juiz de Fora (Minas Gerais, Sudeste do Brasil), por meio da análise de (1) remoção anual de poluentes atmosféricos, (2) remoção anual de carbono atmosférico, (3) estoque de carbono na vegetação e (4) os benefícios monetários do carbono sequestrado anualmente e estocado, utilizando o Mercado de Crédito de Carbono Futuro (CFI2Z1) como um proxy monetário. Os resultados apresentam uma quantidade total média de remoção de 4,45 mil toneladas de poluentes do ar, anualmente. O armazenamento médio anual de carbono total foi de 158 mil toneladas e o de CO_2 equivalente foi de 580 mil toneladas, com um valor total estimado anual de R$ 173 milhões. Foram encontrados expressivos valores do estoque bruto de carbono (3,98 milhões de toneladas) e CO_2 equivalente (14,59 milhões de toneladas), sendo avaliado em R$ 4,35 bilhões. Concluímos que as FUPs de Juiz de Fora possuem um grande potencial para benefícios socioambientais e econômicos.*
Palavras-chave: *florestas urbanas, árvores urbanas, sequestro de carbono, i-Tree Canopy, valoração ambiental.*

INTRODUCTION

The latest report from the United Nations (UN) "World Population Prospects 2019" (United Nations - Department of Economic and Social Affairs, 2019) estimated 7.7 billion people worldwide, where approximately 56% are residing in urban areas. The world's population will continue to grow, and the UN projections indicate that the global population could grow to around 8.5 billion in 2030 to 10.9 billion in 2100, with increasing concentrations in cities (UN-HABITAT, 2020). Thus, cities will increasingly be spaces of anthropic actions, which requires adequate planning of environmental sustainability. Cities are now consuming land faster than they grow in population due to sprawl, a common phenomenon associated with developed countries of North America and that now is occurring in cities all over the world (UN-HABITAT, 2020). According to the UN-HABITAT report (2020), this accelerated expansion of urban areas has profound implications for environmental degradation, energy consumption, greenhouse gas emissions, and climate change. Therefore, ways to mitigate expansion are needed, especially in developing countries where urban environmental planning tends to be less efficient (SUN et al., 2020; NATHANIEL et al., 2021).

Received 03.15.21 Approved 04.02.22 Returned by the author 06.17.22
CR-2021-0208.R1
Editors: Leandro Souza da Silva Ignacio Javier Diaz-Maroto

The concept of urban and peri-urban forest (UPF) is well defined by the United Nations document “Guidelines on urban and peri-urban forestry” (FAO, 2016). Whereas all cities share a similar physical texture, comprising “gray” infrastructure (i.e.: residential and industrial buildings, roads, and parking lots), “blue” infrastructure (i.e.: rivers, lakes, ponds, and water channels), and “green” infrastructure (i.e.: trees, shrubs and grasses in parks, forests, gardens, and streets). The UPFs circumscribe the set that forms the entire “green” infrastructure, encompassing: forests and peri-urban forests, municipal parks and urban forests (> 0.5 ha), parks and gardens with trees (< 0.5 ha), trees on public streets or squares and other green spaces with trees (i.e.: agricultural plots, sports fields, vacant lots, riverbanks, cemeteries and vegetable gardens). UPFs play an important role in urban environments, providing an array of public benefits including recreational opportunities and inspiration for culture, art, and design. However, the main benefits of UPFs are in terms of ecosystem services, the natural services beneficial to mankind, especially on a planet undergoing rapid global warming, including reducing atmospheric pollution by pollutants and particulates removal and sequestering and storing atmospheric carbon, thereby ameliorating the urban heat island effect (ENDRENY, 2018).

As mentioned by RILEY & GARDINER (2020), in the past few years a large number of tools have been developed to quantify ecosystem services and their value. One of the most popular and used for urban forests worldwide is the i-Tree platform (https://www.itreetools.org/), a free suite of software program backed by peer-reviewed research that allows obtaining estimates of the ecosystem services and monetary value of UPFs based on a variety of data collection techniques. For example, the i-Tree Canopy (2020) program uses a methodology to produce a statistically valid estimation of land cover through aerial images available on Google Maps, and provides some important outputs like the quantity of pollutants removal (and their equivalent monetary value (based on US medical services), the quantity of atmospheric carbon (CO_2 equivalent) removal, and the total carbon stocked in the vegetation, as well those monetary values. In this context, we used the i-Tree Canopy program (v. 7.0) (2020) to estimate the ecosystem services provided by UPFs in Juiz de Fora municipality (Minas Gerais state, southeastern Brazil), through the analysis of the annual removal of atmospheric pollutants and atmospheric carbon (CO_2), total carbon stock in vegetation, and the monetary benefits of annually removed and total stocked carbon.

MATERIALS AND METHODS

Study area

Juiz de Fora (21º41’20” S and 43º20’40” W) is a medium-sized municipality with 573.285 inhabitants (IBGE, 2020) located in the southeast of the state of Minas Gerais, Brazil, in the geographical mesoregion of Zona da Mata (Figure 1). It is situated in a landform called Mar de Morros, which is characterized by a large number of hills and valleys at altitudes ranging from 600 to 1000 msm, where are found clayey soils, mostly of the Latosol type, with high levels of organic carbon (NUNES et al., 2001; CAMPBELL et al., 2019). The climate has a well-defined seasonality, classified as subtropical in altitude (Cwa, *sensu* Köeppen) defined by two distinct seasons, with lower temperatures and precipitation between the months of May to September, and warmer and with greater precipitation between October and April. The average annual precipitation is approximately 1500 mm, with an average annual temperature of around 19 ºC (CESAMA, 2020. The predominant forest phytophysiognomy is the Seasonal Semideciduous Forest (IBGE, 2012). According to BARROS (2015), in an analysis based on high-resolution Rapideye images from 2007 (scale 1: 2000), the urban fabric of Juiz de Fora has an impressive 1,122 forest fragments with sizes greater than 0.5 ha, composing a total forest area of 9,662 ha, which is equivalent to 24% of the total surface of the municipality’s urban network. The native vegetation present in the urban landscape is formed by fragments with different sizes and histories of forest regeneration, ranging from areas of earthworks and abandoned pastures to remnants that were little impacted and are protected in conservation units (BORGES et al., 2020; PYLES et al., 2020).

Urban and peri-urban forest (UPF)

The concept of urban and peri-urban forest (UPF) adopted in this research follows that recommended by the United Nations document “Guidelines on urban and peri-urban forestry” (FAO, 2016) for the green infrastructure (i.e.: trees, shrubs, and grasses in parks, forests, gardens, and streets), where the UPFs circumscribe the set that forms the entire green infrastructure, encompassing: forests and peri-urban forests, municipal parks and urban forests (> 0.5 ha), parks and gardens with trees (< 0.5 ha), trees on public streets or squares and other green spaces with trees (i.e.: agricultural plots, sports fields, vacant lots, riverbanks, cemeteries and vegetable gardens).

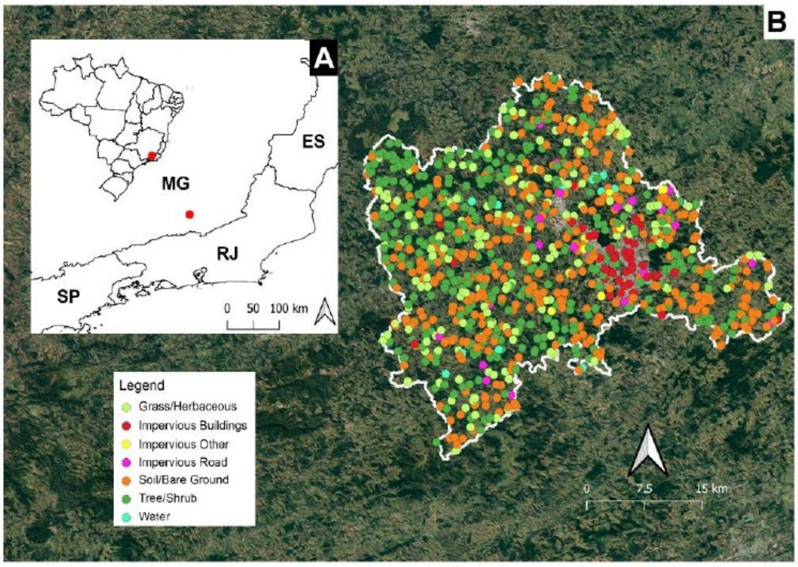

Figure 1 – Localization of the study area. (A) Location of the Juiz de Fora municipality in Brazil and the state of Minas Gerais. (B) Urban and peri-urban zones delimitation of Juiz de Fora with the random points of land cover information collected.

Data collection

In order to estimate the area (km²) and the percentage of different classes of land cover in Juiz de Fora, data collection was performed using the software i-Tree Canopy v. 7.0. (2020). The computer application, freely distributed and designed by the United States Department of Agriculture's Forest Service (USDA), uses the random sampling method, providing easy data acquisition. Therefore, it is widely used internationally to evaluate the benefits promoted annually by vegetation (PARMEHR et al., 2016; DEL MORETTO et al., 2018; BUCCOLIERI et al., 2020; XU et al., 2020). Additionally, the vegetation data collected by satellites on the i-Tree tools have a strong correlation ($R^2 = 0.9$) with the results acquired through more sophisticated and costly tools, such as Light Detection and Ranging (LiDAR) operated by air vehicles (PARMEHR et al., 2016). Throughout the analysis of satellite images, the program uses its results to measure some of the ecosystem services promoted by urban vegetation, and jointly monetarily estimate the values of several of these ecosystem services and their importance to the community (NOWAK et al., 2018).

First, the shapefile delimitation of the city limits was inserted in the i-Tree Canopy. For this study, high-resolution aerial images, recorded in 2020, from satellites of the Center National d'Etudes Spatiales / Airbus made available by Google Earth, were evaluated. Subsequently, from the defined area, the software automatically focuses on different sites of the city, with a yellow cross sign, representing a category of land cover (Figure 2). The categorization was performed by only one interpreter, for greater reliability in the results, as recommended by the software authors. The cover classes are grasses / herbaceous (H); waterproof buildings/homes (IB); waterproof roads (IR); other categories of waterproof construction (IO); soil / exposed soil (S); trees/shrubs (T); water (W).

The developers of the tool indicate between 300 to 500 random observations with the classification of land cover. In this study, 1001 random points were collected (Figure 1), to increase the precision of the results and decrease the standard error which, in the software, works as a measure of the uncertainty of the land cover (PARMEHR et al., 2016). After collecting and classifying the soil cover at each point, the software automatically calculated and generated a bar graph, with the area corresponding to each category, its percentage, as well as the standard error (SE).

Ecosystem services and monetary valuation

In addition, using the estimated area of vegetation cover by i-Tree Canopy, we estimated the ecosystem services provided through annual

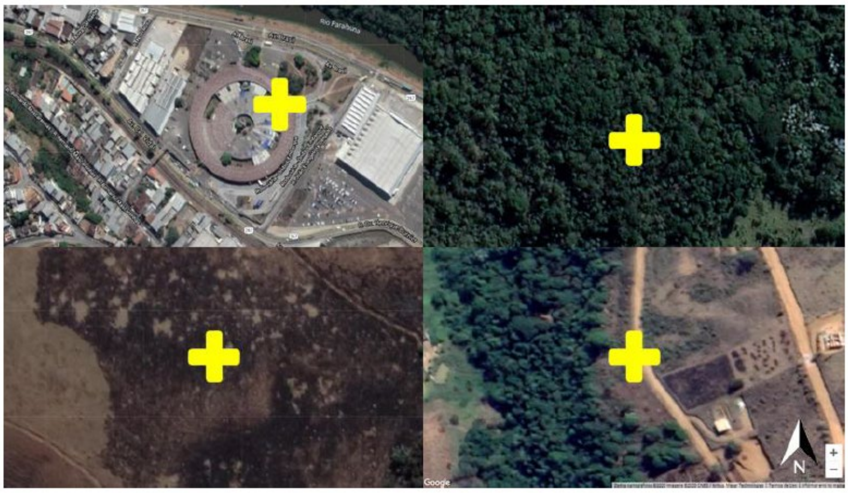

Figure 2 – Random delimitation of land cover classes performed in i-Tree Canopy v. 7.0. * The point to be analyzed by the user (yellow cross) was digitally increased for better visualization.

tree removals of the following parameters: carbon sequestration (C); equivalent carbon dioxide (CO_2 Equiv.); carbon monoxide (CO); nitrogen dioxide (NO_2); ozone (O_3); sulfur dioxide (SO_2); particulate material < 2.5 micrometres ($PM_{2.5}$); and particulate material between 2.5-10 micrometres (PM_{10}). Estimates of carbon and carbon dioxide equivalent are presented in kilotonnes (kt), with the remaining parameters being presented in tons (t). We also collected the amount (kt) of carbon and equivalent carbon stored in the municipality's trees, followed by the monetary valuation of the benefits promoted, indicated in reais (R$).

For the monetary valuation of air pollutants removal, including CO_2 Equiv., one of the aims of this study, the developers of the software used several metrics related to the costs of the associated impacts of pollution on human health, in the reduction of productivity, hospital admissions, and mortality (NOWAK et al., 2014). However, since this kind of valuation is indexed with the variables cited above, and considering the American Healthcare System, which is discrepant from the reality that we experience in Brazil, since The State provides a Universal Health Care, which is called Unified Health System (SUS), completely free of charges. For an estimation of the monetary value of the ecosystem services provided, we used equivalent carbon dioxide (CO_2 Equiv.) values. For this purpose, we used values from the carbon credit market, namely "CFI2Z1- Future Carbon Credit" based on the trade price on March 12, 2021 (€ 42,85), operated at the London Stock Exchange (LSE). After calculating the monetary values, we converted its currency to reais (R$).

RESULTS AND DISCUSSION

Our results showed that soil / bare ground is the dominant land cover class in the city (37.96%), followed by trees/shrubs (35.86%) (Figure 3) that represent UPFs. According to the analysis (Table 1), the average total amount of pollution removal in 2020 by UPFs in the municipality of Juiz de Fora was 4.45 thousand tons. The largest amount of air pollutants removal was for ozone (O_3 = 2.8 thousand tons), and the lowest value for carbon monoxide (CO = 52.3 tons).

Concerning the carbon stocked in the year 2020, the average total carbon storage was 158 thousand tons and the CO_2 equivalent was 580 thousand tons, which generated an estimated total value for the annual inventory of approximately R$ 173.5 million (Table 2). One must also consider the expressive values of the gross carbon stock (3.98 million tons) and CO_2 equivalent (14.59 million tons) of the municipality's tree vegetation, which consolidates a gross carbon stock valued at approximately R$ 4.35 billion (Table 2).

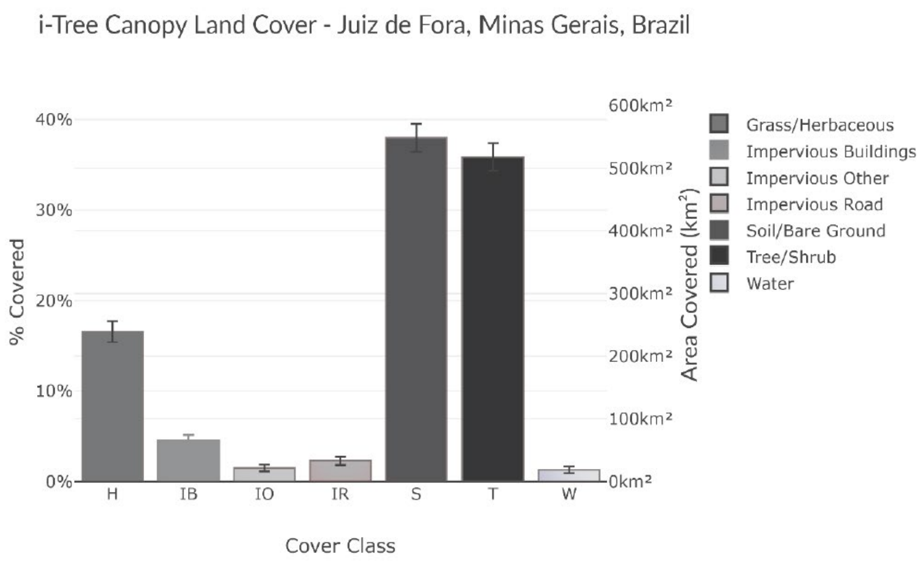

Figure 3 – Percentage occupied in the territory and coverage area (km²) of the different classes analyzed in the i-Tree in Juiz de Fora, Minas Gerais, Brazil .

One of the most expressive results of this study was the potential for ecosystem benefits provided by the ability to remove air pollutants and carbon stock from trees. NOWAK et al. (2014) used the same parameters to model the ability to remove air pollutants from trees throughout the US, relating to financial health costs, and showed that urban areas are the most benefited in mitigating health impacts, being able to avoid about 670 thousand cases of acute respiratory symptoms and avoiding costs estimated at almost US$ 7 billion per year. For the present work, although the simulations of the i-Tree Canopy software generated estimates of health costs avoided with the annual removal of 4.45 thousand tons of air pollutants in Juiz de Fora (total estimate of R$ 8.77 million at the year), financial data were not included as the simulation takes into account cost parameters of the US healthcare system, which are distinct from the Brazilian system.

In general, the greater the coverage of trees, the greater the capacity to remove air pollution. However, NOWAK et al. (2014) comment that trees also affect air quality in ways not analyzed by the i-Tree Canopy software. Trees reduce the temperature of the air, which in itself can lead to reductions in emissions from various anthropogenic sources. Trees around buildings alter the use of energy and, consequently, emissions. Conversely, trees reduce the speed of the wind, reducing the dispersion of pollutants, which can lead to an increase in the concentrations of pollutants. Trees also emit varying levels of volatile organic compounds that are chemical precursors of O_3 and particulate formation, indicating that more research is needed on how these factors combine to affect air pollution concentrations. In any case, it is possible to observe as a balance the great environmental benefit generated by UPFs to human well-being, especially considering that urban populations will continue to expand and removals will continue to increase.

Concerning the carbon stored in the UPFs, the average CO_2 equivalent storage of 580 thousand tons generated an estimated total value for the annual inventory of approx. R$ 173 million. It also impresses the expressive values of the gross carbon stock (3.98 million tons) and CO_2 equivalent (14.59 million tons), with a gross carbon stock estimated at R$ 4.35 billion (approx.). Although, NOWAK et al. (2014) do not specify in detail the financial calculation criteria used in the i-Tree Canopy, the annual CO_2 equivalent stock data can be valued at the current value in the carbon market, such as we did in this research. Considering the value of a carbon credit (equivalent to one ton of CO_2 Equiv.) traded at € 42.85 on March 12, 2021 (https://br.investing.com/commodities/carbon-emissions-historical-data), equivalent to R$ 298.66 (€ 1,00 = R$ 6,97 on March 12, 2021), the

Table 1 - Estimates of the ecosystem benefits promoted annually by trees concerning the removal of air pollutants in the municipality of Juiz de Fora, Minas Gerais, Brazil.

Abbreviation	Air pollution	Amount (t ± SE)
CO	Carbon Monoxide	52.33 ± 2.21
NO_2	Nitrogen Dioxide	285.33 ± 12.06
O_3	Ozone	2.841.78 ± 120.11
SO_2	Sulfur Dioxide	179.81 ± 7.60
PM_{10}	Particulate Matter greater than 2.5 microns and less than 10 microns	951.89 ± 40.23
$PM_{2.5}$	Particulate Matter less than 2.5 microns removed annually	138.09 ± 5.84
Total		4.449.22 ±188.06

estimated values for the municipality's UPFs generate an approximate value of R$ 173 million annually.

The carbon credit market is complex, and according to DUARTE et al. (2020), Brazil adopts the CDM (Clean Development Mechanism) as an instrument of participation in the carbon market, after formalizing its commitments to reduce greenhouse gas emissions with the United Nations Framework Convention on Climate Change through the establishment of the National Policy on Climate Change - PNMC (Federal Law 12,187 / 2009). In the context of the CDM, projects for the removal (sequestration or stockpile) of CO_2 by vegetation fall under the category of "Agriculture, Forest, and Other Land Use" and are called Forest and Reforestation projects. According to the definitions of the United Nations Framework Convention on Climate Change in the Marrakesh agreement (COP7 in 2001), afforestation consists of planting forests in areas that do not contain forests for a period of at least 50 years, and reforestation consists of the planting of forests in areas that do not contain forest since December 31, 1989. The setting of such dates for ascertaining the existence or not of forests in the project area aims to prevent the deforestation of forested lands for the implementation of carbon credit projects, once that deforestation can cause the return of stored carbon to the atmosphere. BRANCALION et al. (2020) also pointed out that, when concerning the carbon market, the age of a forest plays a major role in carbon stocks. These authors also showed that second-growth forests have cheaper management prices when contrasted with plantations.

Data generated by satellites have an extraordinary potential for decision-making processes. The generated results can predict, using machine learning, various environmental impacts, from susceptibility to landslides to flood propensity (ARABAMERI et al., 2018; KHOSRAVI et al., 2019). In addition, mainly due to the ease of

Table 2 - Quantity of benefits promoted by trees concerning carbon, carbon equivalent, and estimates of their values regarding annual sequestration and stock in tree biomass in the municipality of Juiz de Fora, Minas Gerais, Brazil. Legend: CO_2 Eq. = CO_2 equivalent.

Parameter	Carbon (kt ± SE)	CO_2 Eq. (kt ± SE)	Value (R$ ± SE)
Quantity sequestered annually in trees	158.43 ± 6.70	580.92 ± 24.55	173,500,181.34 ± 6,552,345.00
The total quantity stored in the city trees	3.978.87 ± 168.18	14.589.20 ± 616.64	4,357,276,123.40 ± 164,553,967.00

acquisition, satellite image data and multi-attribute decision-making techniques are widely used by managers to encourage participatory planning, since the results, usually with strong visual appeal, are easily assimilated by laypeople (TAHRI et al., 2021). We also point out that the i-Tree Canopy proves to be an excellent tool for decision-makers, especially in the decision processes of creating new protected areas, since, in a simplified way, it is possible to obtain values of carbon sequestration of a given area, and consider this as an important factor in the face of climate change and maintenance of ecosystem services. In addition, by providing an economic valuation, which tends to have greater public appeal, the use of the i-Tree Canopy can be present, in an uncomplicated way, helping to justify the protection of green spaces, especially in urban areas.

Considering all of this information, there is a need to estimate the age of the city's forest spots, and, surely, depreciation is expected in terms of the financial values shown in the present analysis, which depends on the fluctuation of the market, and mainly on-site validation (carbon stock), which tends to decrease the value obtained, but still generating a monetary return. GURGEL et al. (2019) modeled the monetary costs of Brazilian Nationally Determined Contribution (NDC) and found that country' s effort in the implementation of public policies could be financially attractive for the nation in the carbon market, representing, in 2030, a decrease of 0.7% in the GDP and only 0.2 percent in the GDP if the choice adopted is a cap-and-trade-system. Although, decreases in GDP are expected, the authors explain that Brazil could be benefitted from the observed and expected increases in carbon prices. Anyway, the carbon market is heated after the implementation of the Paris Climate Agreement (COP21 in 2015) and the present analysis shows the great potential of UPFs for economic benefits in the different sectors of the municipality.

CONCLUSION

The municipality of Juiz de Fora has 35.86% of its land covered by urban and peri-urban forests. Based on the year 2020, the estimated average total amount of pollution removal by these UPFs was 4.45 thousand tons, and the average total carbon storage and the total CO_2 equivalent sequestered were, respectively, 158 and 580 thousand tons. The amount of CO_2 equivalent sequestered generated an estimated total value for the annual inventory of R$ 155 million based on program default to R$ 173 million based on the carbon credit market (CFI2Z1- Future Carbon Credit). One must also consider the expressive values of the gross carbon stock (3.98 million tons) and CO_2 equivalent (14.59 million tons) of the municipality's UPFs, which consolidates a gross carbon stock valued at approx. R$ 4.35 billion.

Our results showed that the i-Tree Canopy computer program is a promising and useful tool for estimating ecosystem services in UPFs. Although the commercialization of carbon credits is incipient in Brazil and depends on other factors (eg. age of UPFs, sites validations, and market fluctuations), our analysis shows the great potential of UPFs for economic benefits in the municipality. Especially considering that the carbon market is heated after the implementation of the Paris Climate Agreement (COP21 in 2015) and the 2030 Agendas of nations and their municipalities.

ACKNOWLEDGEMENTS

The authors are grateful to the Graduate Program in Biodiversity and Nature Conservation of Universidade Federal de Juiz de Fora. This study was supported by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), Brasil. HMNC holds a CAPES scholarship (Finance Code 001). FAC holds a Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) productivity fellowship.

DECLARATION OF CONFLICT OF INTEREST

The authors declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

AUTHORS' CONTRIBUTIONS

All authors contributed equally for the conception and writing of the manuscript. All authors critically revised the manuscript and approved of the final version.

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