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Review Article

# A Short Review on Carbon Footprint

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## Abstract

This short review presents studies published in high impact journals regarding regulation mechanisms over emissions, monitoring, sequestration (capture) and carbon credits, mainly focusing on the forest sector. The search for studies was performed using the ScienceDirect and Scopus databases. A gap was identified regarding studies that present actions with the private sector, equipment and processes and urban mobilities, in contrast, several studies were found that present significant contribution on gas emissions and climate change (carbon footprint) and mathematical models on the carbon market, especially in developed countries.

**Keywords:** Carbon market; Greenhouse gas emissions; Environment; Climate Change; Forest Policy.

## Introduction

The concept of carbon credit arose from the growing awareness of the need to reduce greenhouse gas emissions to combat global warming, formalized in the Kyoto protocol [1]. There is a broad consensus that humanity must reduce carbon emissions to mitigate global warming. It is generally accepted that carbon trading is one of the most effective market mechanisms for reducing the amount of carbon emissions [2]. Forests are important from a climatic point of view because they allow carbon to be sequestered, forming from biomass or stored in forest products [3]. They act as carbon sinks, contributing significantly to climate change mitigation efforts [4].

The environmental and livelihood benefits of forests extend beyond mitigating climate change, reforestation programs that are normally motivated only by carbon benefits also have the potential to improve livelihoods, reduce gender disparities and provide non-carbon ecosystem benefits with appropriate land selection and involvement of local communities in governance [5]. In a long-term perspective, the European Commission (2011) proposed a roadmap for the transition to a competitive low-carbon economy by 2050. This roadmap proposes reductions in green basins between 80 and 95% by 2050 compared to the 1990 level. It focuses on reaching this cost range efficiently, implying that the inclusion of low-cost reduction options, such as forest carbon extraction, needs to be evaluated. However, carbon credit markets suffer from seemingly inescapable failures that may justify alternative approaches, such as carbon taxes, a complete elimination of carbon dioxide emissions or a global carbon fund. In the coming years, we must remember that credits are not the only sensible policy options for responding to climate change [6].

Within this context, this short review study presents the mechanisms for monitoring and regulating emissions and carbon credits, mainly addressing the forestry sector, seeking to contribute to the evolution of the theme.

## Literature review

### Actions in the Forest Sector

Senadheera [5] proposes the Hiniduma Bio-link Project which is maintained by the Conservation Carbon Company in Sri Lanka. In addition to the direct benefit of protecting forests in reducing carbon emissions and increasing carbon sequestration, forest projects generate indirect benefits called co-benefits that can be linked to the national agenda for Sustainable Development Goals (SDGs) and the impacts of forest carbon in forest carbon projects. Equal or more important for buyers of emission reductions. Hiniduma Bio-link offers carbon credits with added value for socially and

environmentally conscious organizations and people. It is a reforestation project to establish a biodiversity corridor between two large remaining patches protected from the Sri Lankan forest - Singharaja and Kanneliya. In addition to mitigating the broader issue of climate change, the project helps to (1) conserve limited woodland forests by providing buffers and a safe corridor between the two protected forest fragments to help reduce threats to local biodiversity and wildlife in communities adjacent human activities, and (2) improve livelihoods for farmers and local landowners, providing training and income generation opportunities. The Bio-Link Project accomplishes this through the reforestation of home gardens by traditional farmers in the lowland wetland region through the concept of analog forests. Along with the baseline biomass estimate for the selected pilot phase project, the carbon savings of newly planted trees were calculated and recorded for carbon credits.

MoorFutures® is the world's first carbon credit scheme based on a new peat refill. So far, MoorFutures® rely on proxies (types of greenhouse gas emission sites or GESTs to estimate emission reductions. Günther [7] test the profitability of including direct measurements of greenhouse gases ( GHG) of project emissions for a range of re-humidification costs and vegetation scenarios based on a hypothetical MoorFutures® project In almost all scenarios, GEST assessments underestimated emission reductions compared to direct measurements. direct measurements was profitable in> 50% of all vegetation / rehumidification scenario combinations with net profits ranging from EUR - 8.18 to 26.31 per certificate Profitability was achieved by recovering costs of € 5400 ha-1 for more sophisticated GHG measurements have become profitable at twice the cost of re-humidification. In cases where direct flow measurements do not generate profit, they can strengthen the reliability and reliability of buyers and thus bear higher certificate prices.

Man [8] investigated the inventory of three actively managed forest properties located in the coastal, central interior and northern British Forest regions to estimate the cost of producing carbon credits ($ per carbon credit) when harvesting is reduced below the reference level. The financial analysis was carried out in a range of discount rates (0–16%) and the total cost included the opportunity cost due to the reduction in the harvest and cost of the Carbon project (the initial establishment and validation cost of the Carbon project and the cost of continuous verification for two frequencies (1 year and 5 years) .When the opportunity cost was not included, the cost per Carbon credit was similar to previous results (lower cost per carbon credit for a higher location index (or maximum height in meters at 50 years old. However, when the opportunity cost was included, the cost per Carbon credit was higher for the highest site rates that corresponded to the highest average value per hectare harvested (AVHH) ( that is, the wood revenue multiplied by the average harvested volume per hectare per year). The reversal of trends is the result of the average wood revenue being higher for the higher site indexes, which resulted in a higher cost opportunity and greater AVHH. The opportunity cost represented 58% to 97% of the cost per carbon credit. Compared to the 5-year verification, the 1-year verification frequency increased the total cost per carbon credit by 1% to 22%, the smallest increase when the cost of the carbon project represented a small percentage of the total cost. The estimates for the three forest properties analyzed here represent three points on a larger spectrum, and identify the cost per carbon credit in a range of local indices (14.7 to 25.6 meters maximum height at 50 years), AVHH ( 12.2 to 63.7 thousand dollars). ha-1 year-1) and net wood revenue (US $ 4 to US $ 35 m-3). Further research is needed to determine whether the trends found in this study remain over a more densely populated spectrum.

Juutinen [9] examined the feasibility and impacts of a short-term carbon payment mechanism on forest management in boreal forests. Unlike long-term carbon sequestration commitments over a rotation period, landowners can, in this scheme, sell temporary carbon credits stored for one year and reissue them annually. Using numerical optimization, we show that the short-term carbon payment mechanism has a profound effect on the time and intensity of thinning, and the optimal duration of rotation, showing itself in higher wood yield and greater profitability. A comparison of the case where all carbon or just additional carbon above the reference value for wood management is accounted for by the short-term payment scheme shows that optimal forest management remains more or less the same. However, the increase in forestry profitability introduced by carbon credits is relatively small, if only additional carbon is credited. Therefore, the short-term mechanism can only be viable at high carbon prices and would probably increase the rotation length of mature stands with the requirement for additionality in boreal forests.

The work from Barua [10] contributes to the economy of deforestation, presenting a dynamic model, with an infinite formal horizon, describing the use of tropical forest resources. As an alternative to clearing the forest, a landowner has the option of selling it to an international carbon credit program. The model is used to investigate the corrective incentive programs needed to ensure a socially optimal level of forest resources. Optimal conditions for a land income tax and a carbon offset fee are derived. The article shows that the optimization of national carbon offset policies depends crucially on taxing land rent. In the presence of an ideal land income tax subsidy program, the government may need to pass on to owners the same carbon offset it receives from the international community to ensure a socially optimal tropical forest stock. However, the government may need to over-transfer or sub-transfer carbon offset, depending on whether the pre-existing property income tax is below or above the optimal level,

respectively. This suggests that the pre-existing sub-optimization in the taxation of land rent in a given country can be corrected by adjusting the carbon offset. Therefore, a carbon offset scheme must take into account existing national policies that affect forest clearing.

The country's familiar forest lands can be an important contributor to carbon sequestration efforts. However, very little is known about how family forest landowners view programs that allow them to sell carbon credits generated from the growth of their forests and the compensation that would be needed to encourage a significant level of participation. To address this information gap, Miller [11] conducted a study to identify and quantify the interest of the family's forest landowners in participating in a voluntary carbon market trading program in the States of Lake, USA. A mail survey was administered to 2,200 randomly selected family forest owners in Michigan, Wisconsin, and Minnesota. The questionnaire assessed the interest of rural landowners in participating in a hypothetical carbon credit trading program and sought information on landowners' objectives and practices, perspectives on carbon credit programs and forest land characteristics. A total of 850 useful responses were received. A logistic regression model was developed to examine the factors that affect participation in a forest carbon offset project by family forest owners and to estimate the likelihood of landowners' participation.

The results show that the characteristics of the carbon program, together with the characteristics of the owner and the parcel, are associated with the decision to participate in a carbon credit program. Specifically, amount of carbon credit payment, duration of the contract, gender, amount placed in other non-market forest amenities, need for additional income, attitude towards climate change, absentee status, land tenure and total acres were considered determinants significant. Our findings indicate that carbon sequestration management can align with the ownership goals of many family forest owners in the Lake States.

In Norway, family forest owners own 80% of productive forest areas and play a central role in the management of the country's forests. However, little is known whether these landowners would be interested in increasing carbon sequestration on their land and selling carbon credits. Only a handful of studies have examined the factors that motivate family forest owners to participate in carbon offset programs, and all of these studies have been conducted in the United States. Håbesland [4] addressed this information gap using data from a mail survey of 1500 Norwegian family forest owners. A logistic regression model was developed to examine the effect of various characteristics of the carbon, forest and landowner program on participation in a hypothetical carbon offset program. The results suggest that there is a considerable amount of interest among Norwegian family forest owners and that the most important indicators of participation are the amount of payment offered, the barriers perceived by management actions, the importance given to non-market forest amenities and attitudes towards climate change.

## Actions in the Private Sector

Zhang & Li [12] carried out a risk analysis of six Chinese banks involved in carbon finance. The copulation factor is introduced to simulate the corresponding carbon finance credit risk and the market risk for latent variables in an indirect method. In short, the four common factors in carbon finance - exchange rates, interest rates, CER prices and Brent oil prices - are analyzed and explored in a copula factor approach that incorporates KMV, GARCH two-step models . KMV and GARCH models are used to generate data that reflect the overall credit and market risk associated with each bank. Both normal copula and t-copula functions are used to simulate parameter estimates for comparison in a new way. The value at risk for each of the six banks is calculated using Monte Carlo simulation and compared. In addition, we calculate shock estimates for each factor to explore changes in credit risk and market risk, given economic shocks, and we also do a hypothetical analysis of the impact of the financial crisis on common factors. Overall, our results reveal that exchange rates and oil prices are the key factors to be considered in carbon finance. Ping and Bank is facing the highest risk of all the banks in the sample, while the Industrial and Commercial Bank of China is presenting the lowest risk. The results of this analysis provided some information on the internal carbon trade and the connectivity of the carbon markets.

## Equipment & Process Actions

Kumar [13] performed the thermal and economic evaluation of an active hybrid solar distillation system (PVT) incorporating the subsidy effect, tax benefit, inflation and maintenance costs is presented for the climatic condition of New Delhi (India). The analysis is based on annualized costing and the expected life span of 15 and 30 years. In addition, $CO_2$ emission / mitigation and revenue from carbon credits are taken into account in accordance with the Kyoto Protocol standards for India. The energy production factor (EPF) and the life cycle conversion efficiency (LCCE) are 5.9% and 14.5%, respectively, for the expected useful life of 30 years. The costs of producing energy and spirits are found at Rs. 0.85 / kWh and Rs. 0.75 / L, respectively, accounting for earned carbon credit. The cost payback period is estimated at 4.2 years, if the distillate is sold at a rate of Rs. 6.0 / L in the local market.

The implementation of reverse logistics for waste electrical and electronic equipment (WEEE) and its components has been a major concern for the Brazilian government and the private sector in recent decades. Caiado [14] proposes a description of the Brazilian market for adequate disposal or reverse logistics credits (RLC) and also an analogy with the carbon credit market. Therefore, a descriptive research was carried out, focusing on the study of the WEEE RLC market in Brazil. Some experts involved in this context

were consulted on their perspectives for this market and the main motivations for the environmentally appropriate disposal of WEEE. It has been found that most stakeholders agree that the reverse logistics credit market is a possibility, but there are currently several obstacles to its implementation. Regarding the comparison of RLC with the carbon credit market, there are still many aspects to be developed before the RLC market becomes a reality. The Brazilian RLC market still has no legal support to work with, no organization to control and audit the market and no government support.

Agrawal & Tiwari [15] performed the performance analysis in terms of the effect of the carbon credit earned on the uniform annualized cost of the hybrid photovoltaic thermal air collector based on the annual thermal energy and exergy were analyzed for the New Delhi climatic conditions. The effect of interest rates on the annualized uniform cost was also assessed. During the analysis of the useful life (30 years), the reduction in carbon emissions reaches Rs 109,242 and Rs 25275.6 based on the general thermal energy and exergy basis. It was also observed that there is a significant reduction in the annualized uniform cost due to the carbon credit earned.

Rajoria [16] investigated a new approach in the cash flow diagram to investigate the effect of the energy return time and carbon credits gained in the life cycle cost of different photovoltaic thermal panel systems, for this three types of configurations were considered, namely: (i) opaque type PVT arrangement (case A), (ii) solar cell arrangement (SCT) (case B) and (iii) semitransparent arrangement (case C). The performances of all the cases above were calculated using three basic metrics. These are the energy return time (EPBT), the energy production factor (EPF) and the life cycle conversion efficiency (LCCE). When the EPBT effect is considered in the cash flow of the PVT arrangement system, the annualized uniform cost increased by 7.0% for the lowest value and 16.5% for the highest value, both in the energy base and in the base of exergy. The values reflected in this approach are more realistic than the conventional approach. Considering the effect of earned carbon credits and EPBT on the annualized uniform cost of the PVT arrangement system, the higher value of the annualized uniform cost is indicative of a better and more efficient system that has the ability to offset the cost incurred in the system. It was also observed that, among all cases, case C is a better performance in terms of energy and exergy.

In addition to contributing to sustainable development by recovering energy in the form of methane, carbon credits can be claimed by applying advanced anaerobic processes in the treatment of wastewater to reduce greenhouse gas emissions. As granular anaerobic systems are capable of withstanding high organic loads concomitant with high-strength effluents and short hydraulic retention times, they could yield far more carbon credits than other conventional anaerobic systems. As granular anaerobic systems are capable of withstanding high organic loads concomitant with high-strength effluents and short hydraulic retention times, they could yield far more carbon credits than other conventional anaerobic systems. Granular anaerobic processes have become an attractive treatment technology option, especially for high-strength wastewater, considering the fact that, in addition to efficient waste degradation, carbon credits can be used to generate revenue and finance the project .

Within this context, Show & Lee [17] present an emission reduction scenario based on a methane recovery and use project. An example of analysis on emission reductions and future trends is also described. Wong [1] investigated the carbon credit potential derived from laboratory scale anaerobic sludge blanket (UASB) reactors based on a carbon balance analysis. The reduction in methane emissions can be calculated by calculating the difference in UASB reactors and open lagoon treatment systems. Based on the bench-scale 2.5 l reactor, the total reduction in $CH_4$ emissions was calculated as 29 kg $CO_2$ / year. By climbing to a typical full-scale anaerobic digester, the total reduction in $CH_4$ emissions could achieve a reduction of 46,420 tons of $CO_2$ per year. The estimated carbon credits would be US $ 278,500 per year, assuming a carbon price of US $ 6 per metric ton of $CO_2$ reduction. The analysis postulated that it is financially viable to invest in the advanced system of granular anaerobic treatment from the revenue generated by carbon credits.

## Actions on Urban Mobility

Traffic congestion contributes to the problem of air pollution due to increased idling, braking and acceleration behaviors. Li [18] proposes an optimal dynamic credit collection scheme that can redistribute traffic flows to achieve mobility and emission goals. First, the cell transmission model is used as a dynamic network loading model to capture the flow spread and the user's dynamic balance (DUE) is formulated to investigate the flow redistribution in terms of simultaneous and departure path choices in the carbon credit collection scheme. Based on this, a two-level formulation is proposed to describe Stackelberg's game between the road manager and the road users. For the higher level, the road manager seeks to minimize the system's travel time and emissions by implementing credit collection schemes. For the lower level, heterogeneous users find the user's dynamic balance through simultaneous options of path and departure time under certain credit collection schemes. Given the non-convex property of the two-level model, this article proposes the pattern search algorithm incorporated into the projection method. Computational results in the X-shaped network, Ziliaskopolous and Nyguen-Dupuis are given to show the applicability of the proposed algorithm in networks of reasonable size. The results show that the minimum travel time design does not always generate effective commuting and starting switches for all user groups, especially for users with high travel time value, while the minimum emissions credit design produces behavioral

adjustments desirable. In addition, the minimum travel time credit project does not always generate minimum carbon emissions in the network, especially in networks with complex pairs and O-D paths. This research sheds light on how to program a time-varying credit collection scheme to achieve mobility and issuance targets. The political implications of the credit collection scheme are provided.

Performance-based environmental regulation has gained popularity as a political tool to prevent climate change. California implements a Low Carbon Fuel Standard regulation to reduce the average carbon intensity of fuels by 10%, without specifying technologies to achieve the target. A carbon trading market is established to facilitate fuel producers who generate revenue by producing second generation low carbon renewable fuels. There is a knowledge gap in the understanding of the interactions between the commodities and carbon trading markets under performance-based regulation. Hu & Chen [19] proposes a mathematical program with an equilibrium constraints model to find the equilibrium transport energy portfolio under the environmental protection policy. The model uses the Karush-Kuhn-Tucker optimality conditions to represent the profit maximization of fuel suppliers. Profit is counted in the commodities market and in the carbon trading market. Our results show that carbon credit encourages the production of second-generation biofuels, which plays a critical role in the success of the Low Carbon Fuel Standard. The price of carbon credit is driven by compliance with carbon intensity regulations, which we have proven through mathematical formulation and analysis of empirical data. Reducing carbon intensity is the key to promoting the low performance of biobutanol based on the low carbon fuel policy. The proposed structure, with minor adjustments, can be used to assess performance-based regulation in other fields.

While the urban forest is considered an eligible source of carbon offset credits, little is known about its market potential and the credit quality aspects. As credit providers increase in number and credit buyers become more interested in buying carbon credits, it is unclear whether and how urban forest carbon credits can outperform other types of carbon credits available on the market. market. The delivery of quality credits would be crucial, especially in voluntary markets such as the USA, where buyers are more likely to commit to reducing their GHG emissions and maintaining a positive public image than just complying with regulations. Using the results of a national survey of local governments Poudyal [20] evaluated the quality aspects of urban forest carbon credits. It is concluded that the municipalities and municipalities of the United States, acting as sellers of carbon credits, have resources and capacity to be competitive in the carbon credit markets. In addition, they have the capacity and resources to implement carbon projects that will meet the main quality criteria (for example, additionality, permanence and verification).

The difficult social issues faced by non-governmental organizations in relation to the planning, management and evolution of refugee camps have led to the assessment of alternative development strategies. In fact, innovative technologies could be promoted to improve the local economy in a sustainable way. Manni [21] present a model suggesting the exploitation of high-albedo materials to generate fresh oases in warm climate contexts. The benefits derived from this proposal were investigated by simulating the application of high albedo devices in shelters in Zaatari, so the avoided carbon emissions were quantified, and various scenarios were discussed. Under the Emissions Trading System, carbon credits, which can be obtained and sold contributing to the process of mitigating global warming, are estimated at around 150,000 tons of $CO_2$-eq. Considering the market trends presented during COP21 in Paris, the intervention proved to be sustainable in economic and environmental terms. The payback period is estimated at three years in the most reliable scenario. The work presents the main results of a broader research that also included considerations on the urban planning of the camps.

## Actions on Gas Emissions and Climate Change

The Kyoto Protocol, a global governmental response to climate change, signatories to the protocol make an effort to reduce their greenhouse gas emissions. South Korea is not included in the list of countries in Annex I; however, South Korea is the seventh largest $CO_2$ emitter. The South Korean government has enacted a number of institutional policies to encourage reductions in greenhouse gases. Although previous studies have focused on guidance that reflects the position of suppliers in the carbon market, the study by Roh [22] focuses on the real demand of South Korean companies for forest carbon credits. When applying the contingent valuation method, we estimate the willingness of domestic companies to pay for forest carbon credits. Then, we apply a logistic regression ordered by classification to confirm whether the classification of forest carbon credits, in comparison with any other carbon credit, is influenced by the characteristics of a company. The results showed that Korean companies are willing to pay 5.45USD / t $CO_2$ and 7.77 USD / t $CO_2$ for forest carbon credits in national and international forest carbon projects, respectively. Therefore, the introduction of forest carbon credits in the Korean carbon market seems reasonable. The analysis of the priority rankings of forest carbon credits, however, demonstrated that forest projects were less likely to be classified by companies as their first priority. Although the relative preferences for forest carbon credits have been influenced by the individual characteristics of the companies, such as previous experience of environmental activities related to CSR and if the company has established an emission reduction plan, the impact of perceived behavior control, if the company was included in the management of emissions targets forest carbon

credits scheme was insignificant. Therefore, forest carbon credits are not a viable solution without strong government support or institutional instruments. The results of this study are expected to provide policymakers with realistic approaches to formulating policies related to climate change.

The shift to renewable energy options and low-carbon technologies, in response to concerns about energy security and climate change, is proceeding more slowly than many would like. The usual argument against the rapid deployment of new technologies is the costs imposed on the economy, generally interpreted in terms of initial costs to be borne or involving large transfers of money to finance, for example, efforts to preserve tropical forests. Mathews [23] argues that such a perspective provides a continuous barrier to effective action, while a perspective based on the creation and use of carbon credits provides a means of avoiding the shock of abrupt industrial changes. Carbon credits granted for carbon load reductions in good faith could be created through private initiative, for example, by commercial banks, to constitute a market that will complement regulatory-based initiatives, such as national emissions trading systems. This is not a new idea; in fact, it is the way in which capitalism has financed all major changes, including the Industrial Revolution, through the creation of credit. The emergence of a global carbon credit economy is likely to precede a global regulatory system that governs climate change and will undoubtedly help to stimulate the emergence of such a global system.

The Paris Agreement establishes a mechanism that allows a Party to benefit from reductions in greenhouse gas emissions conducted in a host Party to fulfill its nationally determined contribution. In this context, Gavard & Kirat [24] aimed to improve the understanding of carbon offset pricing dynamics compared to regular carbon market concessions. We combine a cointegration approach with risk premium considerations to compare the price dynamics of European Union (US) Permits and Certified Emission Reductions (CER) in the second phase of the European carbon market. Taking into account the breaks identified in the series, we found that, although the US and CER return a comparable dynamic mainly driven by fuel switching, the long-term relationships between the price of these two types of allowances and their drivers differ significantly. While the US price is well explained by a demand effect, the impact of energy prices on the CER price suggests that there is an supply-side effect for credits. We note that the price elasticity of allowances in relation to coal and gas prices is negative in periods of low economic activity and positive during the remaining time. We explain the first with the fact that the market is not tight and the second with the effect of economic activity on the price of commodities and energy.

The internal rate of return (IRR) is a tool widely used in the classification of capital budget projects and eventual decisions of acceptance or rejection. In their study Dhavale & Sarkis [25] considered an investment decision involving a sustainable, energy-efficient, greenhouse gas (GHG) reduction asset incorporating the value of carbon emission allowances for the investing company. These concessions create cash flows that can be characterized by significant volatility and uncertainty. The methodology developed in this document allows decision makers to integrate their knowledge of carbon trading markets and the cash flows that result from the sale of emissions credits. The new methodology uses a Bayesian model for IRR that uses a Gibbs sampler. The analysis of the results shows that the IRR is influenced by the volatility and uncertainty of cash flows from carbon credits. Ignoring these characteristics of uncertainty and simply using the expected cash flow values can result in a significantly inaccurate rate of return on investment. When compared to deterministic IRR calculations, the results show that the occurrence of very high and very low cash flows positively affects the IRR, while the greater variability in the cash flow distribution negatively affects the IRR of the GHG-reducing asset. In other words, frequent large or small cash flows are preferred over floating cash flows. The results can also provide a justification for the existence of anomalous consumer behavior, known as the energy efficiency gap.

Dye & Yang [26] carried out a study on credit decisions and sustainable trade replacement with demand linked to credit under carbon emission restrictions considering sustainability issues in the context of joint commercial credit and inventory management where demand depends on duration the credit period offered by the retailer to its customers. We quantify the impacts of the crediting period and environmental regulations on the inventory model. Starting with some moderate assumptions, we first analyze the model with widespread demand and default risk rates under the Carbon Cap-and-Trade policy, and then make some extensions to the model with the Carbon Compensation policy. We further analyzed the effects of carbon emission parameters on the retailer's credit and commercial replacement strategies. Finally, a pair of numerical examples and sensitivity analysis are given to illustrate the characteristics of the proposed model, which is followed by final observations.

Hua [2] investigated how companies manage carbon footprints in inventory management under the carbon emissions trading mechanism. We obtain the optimal quantity of orders and analyze analytically and numerically the impacts of carbon trading, the price of carbon and the carbon cap on order decisions, carbon emissions and total cost. We make interesting observations from the numerical examples and provide managerial insights from the analytical results. The imminent risks associated with climate change have forced the global community to devise a marketable pollution permit or "cap and trade" approaches to control the release of greenhouse gases. In the USA, soils have the potential to offset about 10% of annual $CO_2$ emissions; however, if

carbon credits are included in greenhouse gas control programs, the organic carbon sequestration rates (SOC) associated with agricultural land uses must be computed on a hydrographic basin scale. In this context, used the water quality model of the Soil Water Assessment Tool (SWAT), the erosion model of the Water Erosion Prediction Project (WEPP) and the carbon model CENTURY 4.0 soil to simulate carbon sequestration rates in 160 sub-basins in the Big Creek basin (, 312,300 hectares). In annual crops, only no-tillage in corn-soybean rotation, on low to moderate slopes, results in net gains in SOC. Substantial annual rates of SOC sequestration occur only under perennial crops, such as Conservation Reserve (PCR; 0.14 t / ha without erosion; 0.08 with erosion), pasture (0.67 t / ha without erosion; 0.58 with erosion), hay (0.88 t / ha without erosion; 0.52 with erosion) and forest (2.66 t / ha without erosion; 2.49 with erosion). Erosion therefore has a great effect on the spatial distribution of SOC measured in the field, moving it downwards and increasing its spatial variability. For this reason, carbon credit programs must be based on field practices, thus targeting the locations where atmospheric carbon sequestration actually occurs and minimizing monitoring costs. The development of estimates based on rate models for hijacking field activities in many locations would thus serve, to a large extent, the needs of carbon credit programs.

Van Voorhees [27] studied what must be done to obtain credit for the amounts of carbon dioxide inevitably stored in association with improved carbon dioxide recovery ($CO_2$ -EOR). The study explores this issue with special emphasis on several recent developments in December 2015 that will directly affect responses to this question in the context of the United States Environmental Protection Agency (EPA) regulatory scheme to control greenhouse gas emissions (GHG). In 2015, the EPA finalized a fundamental regulatory framework for the control of GHG emissions from generating units powered by fossil fuels, new and existing. In doing so, the EPA conditioned the use of CCS in quantifying stored carbon dioxide through reports from Subpart RR of the reporting requirements of Part 98 GHG, the reporting approach developed primarily for geological sequestration in salt formations. And the Subpart RR report would be required regardless of whether carbon dioxide storage is achieved through geological sequestration or in association with enhanced carbon dioxide oil ($CO_2$ -EOR) recovery. Numerous concerns were raised in comments on the proposed rules and in response to the final rules on the ability of EOR operations to meet Subpart RR reporting requirements, and from 2010 to 2015 no one reported under Subpart RR because all projects injecting the carbon dioxide in salt formations qualified for research exemptions, and no EOR operation had voluntarily chosen to report under subpart RR instead of subparts W and UU.

## Mathematical Models and Carbon Market

Yu & Mallori examined the impact of exchange rates on the carbon market. We analyzed this effect through the European Union's Emissions Trading Scheme (EU-ETS), which mainly uses two replaceable fossil energy inputs for electricity generation: coal and natural gas. The European coal market is driven directly by the global coal markets that are denominated in USD, while natural gas is imported mainly from Russia and is denominated in Euros. The impulse response functions of a structural vector autoregression model (SVAR) demonstrate that a shock in the euro / dollar exchange rate can be transmitted through the energy substitution channel between coal and natural gas and influence in the carbon credit market .

Feng [28] examined the carbon price volatility using data from the European Union's Emissions Trading Scheme from the point of view of nonlinear dynamics. First, we use a random walk model, including serial correlation and rate of variance tests, to determine whether historical carbon price information is fully reflected in the current carbon price. The results of the empirical research show that the carbon price is not a random walk: historical price information is not fully reflected in the current carbon price. Second, use R / S, modified R / S and ARFIMA to analyze the history of carbon price history. For the period from April 2005 to December 2008, the modified Hurst index of the carbon price is 0.4859 and the value of d ARFIMA is -0.1191, indicating the short-term memory of the carbon price. Third, we use chaos theory to analyze the influence of the internal carbon market mechanism on the carbon price, that is, the positive and negative market feedback mechanism and the heterogeneous environment. Chaos theory proves that the correlation dimension of the carbon price increases. Lyapunov's maximum exponent is positive and large. There is no obvious complex endogenous phenomenon of nonlinear dynamics to carbon price fluctuation. The carbon market is slightly chaotic, showing the characteristics of the market and the fractal market. The price fluctuation is not only influenced by the internal market mechanism but is also affected by the heterogeneous environment. Finally, we offer suggestions for regulation and development of the carbon market.

Ibrahim & Kalaitzoglou [29] investigated why carbon prices and price volatility change. The authors proposed a microstructural pricing model for asymmetric information, in which the price responses to information and liquidity vary according to each transaction. Bid-ask quotations and price components are responsible for learning, incorporating expectations of change in the volume traded rate (trading intensity) and the risk level of incoming trades. The analysis of future carbon transactions in Europe considers that the expected intensity of trading simultaneously increases the information component and decreases the liquidity component of price changes, but at different rates. This explains some conflicting results in the previous literature. In addition, the expected persistence in trading intensity explains most of the level's autocorrelations and the conditional variation of the price change; helps to predict hourly patterns in returns, variation and bid-ask

spread; and differentiates the impact of purchase price versus sale and continuity versus business reversal.

The study by Chevallier [30] is the first non-parametric modeling exercise applied to the carbon markets. The analysis chart is carefully detailed, and the empirical application unfolds in the case of Blue Next spot and ECX future prices. Data are collected on a daily basis from April 2005 to April 2010. First, we document the presence of strong nonlinearities in the functions of conditional means. Second, the conditional volatility functions reveal an asymmetric and heteroscedastic behavior that is dramatically different between carbon returns and future returns. The results for spot prices are also robust to the decomposition of subsamples. Third, we showed in an out-of-sample forecasting exercise that non-parametric modeling allows to reduce the prediction error by almost 15% compared to linear RA models. This latter result is confirmed by the Diebold-Marian pair-by-pair test statistic.

Following Chevallier [31] develops a carbon pricing model considering two fundamental factors of European Union permits: economic activity and energy prices. On the one hand, economic activity is represented by aggregated industrial production in the EU-27 (as it provides the best performance in a preliminary forecast exercise vs. other indicators). On the other hand, oil, natural gas and coal prices are selected as the main carbon price vectors (as highlighted by the previous literature). The interactions between the macroeconomic and energy spheres are captured in a two-state Markov change VAR model that is capable of reproducing the boom-bust business cycle. First, it appears that industrial production positively (negatively) impacts the carbon market during periods of economic expansion (recession), thus confirming the existence of a link between macroeconomics and the price of carbon. Second, the price of crude oil is confirmed as a leader in the formation of prices between the energy markets, since it impacts other variables through the structure of the Markov-switching model. Together, these results reveal new interactions between the newly created EU emissions market and the pre-existing macroeconomic / energy environment.

The aim of the study by Guðbrandsdóttir & Haraldsson [35] was to examine what drives changes in the price of carbon credits in the European Union's Emissions Trading Scheme (EU ETS) and to make predictions based on these relationships. The study is based on the United Kingdom (UK) energy market data set and global stock indices. The large data set is reduced in size using correlation analysis and predictions are made by multiple linear regression. Certified emission reduction units (CERs) prove to be the only market relationship on the same day that provides useful forecasts of European Union allowance prices (EUAs). No significant correlation is found between EUAs and the UK energy market and the theoretical price of carbon credits; switching price is a bad indicator of the price of carbon credits.

Carbon-restricted energy planning (CCEP) is a relatively new area of research dedicated to working with the regional carbon dioxide ($CO_2$) emissions limit through the implementation of various low-carbon technologies. One of these technologies is carbon capture and storage (CCS). Ooi & Foo [33] demonstrated the use of a recently proposed automated targeting (ATM) model for exchanging carbon credits (commonly known as "carbon emissions trading"), which is a growing interest among many parties that are required emission reduction commitments. A hypothetical example is used for illustration.

The study by Barros and Tiago Filho [34] aimed to obtain preliminary estimates on the potential of carbon credits for projects of Small Hydroelectric Plants (PCHs) in the Brazilian panorama, which was divided into two phases. In Phase I, a comparative analysis was carried out of the accumulated $CO_2$ emission values due to the expansion of the annual gross coal sources and the accumulated $CO_2$ emission values of the expansion of the installed gross annual capacity of SHPP for two scenarios, Scenario 1 and Scenario 2 The results demonstrated the advantages of using PCH as an energy source, with regard to greenhouse gas (GHG) emissions, despite the uncertainty of the values of the GHG emission factors. Phase II presents a case study based on data from a real-time series for a station located in the south of Minas Gerais, with an arbitrary value for the project's head of the project [35-50]. The calculation of the Stay Power, Energy Curve and values of Optimal Hydraulic Power Available (MW) and Optimal Flow Available ($m^3/s$) was possible thanks to the Microsoft®Excel® spreadsheet of CERPCH [11]. The calculation of net profit derived from carbon credit for SHP projects was done using the Microsoft®Excel® spreadsheet by Michellis Junior 18, based on the CDM guidelines, as recommended in the United Nations Convention on Climate Change, Ministry of Science and technology [51-61]. The results showed that the net revenues obtained by carbon credits in SHP projects located in the Isolated System were well above those obtained in the National Interconnected System.

## Final Considerations

This review study presents works published in high impact journals regarding carbon footprints, showing the main regulating mechanisms for monitoring, emissions, sequestration, and carbon credits, covering mainly the forestry sector. The search for studies was carried out using the ScienceDirect and Scopus scientific databases. As a main result, a gap was identified regarding studies that present actions with the private sector, equipment and processes and urban mobilities, in contrast, several studies were found that present a significant contribution on gas emissions and climate change (carbon footprint) and models mathematicians about the carbon market, mainly in developed countries.

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