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The effect of a cap-and-trade policy on the economy, welfare and carbon intensity in Morocco: a dynamic computable general equilibrium approach.

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Abstract:

We studied the impact of a cap-and-trade policy for the country of Morocco, on the economy, main macroeconomic aggregates, households' welfare and carbon intensity, since this policy is one of the main policies to reduce carbon emissions and bring a solution to the problem of global warming. To do so, we used two scenarios, a scenario of 1% less emissions than the last baseline year for five years, then a second scenario of 1% less than the baseline year for two years followed by 2% less than the baseline year for three years. The scenarios were simulated using a dynamic general equilibrium model PEP (1-t), with the software GAMS.

The results showed that the policy can limit carbon emissions without affecting that much economic growth and households' welfare, especially for the first scenario, while at the same time decreasing slightly carbon intensity which is good. Therefore, we are encouraging such a policy, especially the decrease by 1% of emissions compared to the last baseline year.

Key-words: Cap-and-trade, GDP, welfare, carbon intensity, dynamic computable general equilibrium model.

Introduction:

In this article we are concerned with the outcomes of implementing a cap-and-trade policy in Morocco for a period of 5 years, in order to settle the issue of carbon emissions which is the main cause of global warming, since it is the one of the most, if not the most serious threat to the environment and thus life on Earth. To do so, we propose to study the implementation of this policy for the Moroccan case by using a dynamic computable general equilibrium model type PEP (1-t), in order to assess its efficiency in handling the problem of carbon emissions for a developing country like Morocco. By efficiency we mean reducing emissions without hindering development and growth.

We examine the impact of a cap-and-trade policy fixing the cap of emissions to 1% less than the last baseline year for five years, as well as a similar policy fixing this cap to 1% less than the last baseline year for the two first years, and 2% less than the baseline year for the three last years of the considered five years period. We are particularly interested in the impact of these policies which automatically reduce carbon emissions, on other macroeconomic aggregates such as production, consumption, imports, exports, households' welfare, GDP and finally carbon intensity of the economy.

To achieve this, we will after this introduction, explore the existing literature about this issue, then present our methodology about how we gather data and develop our economic model (we have added two environmental equations to the PEP(1-t) model of Decaluwé et al., (2013)), show the results of the simulations of our model before finally drawing the main conclusions.

1. Literature review:

One of the more important issues facing any country wishing to implement a cap-and-trade policy is the fear that the tax could negatively impact GDP and/or households' welfare. Some authors have found that the decrease in GDP and/or households' welfare is minimal following the implementation of a cap-and-trade policy and they represent the majority of the existing literature while others have found that it was the other way around. In the following we will present summaries of some of the works that have found that a cap-and-trade policy has a negligible impact on GDP and or households' welfare.

Dissou and Karnizova (2016) develop a cross-sector business cycle model to analyze the stochastic impact of carbon emissions reductions through carbon allowances and carbon taxes in the presence of multiple sources of macroeconomic uncertainty. The model has been adjusted to reflect the US experience. Similar to previous studies using single-sector versions of the

African Scientific Journal
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Vol : 3, Numéro 23, Avril 2024

model, they find that cap-and-trade systems have lower volatility in real variables than tax systems, but that the latter is better from a welfare perspective. It turns out that there is a good possibility.

However, their cross-sector analysis shows how important the causes of shocks are for the classification of the two financial products, and that they can go beyond single-sector analysis to assess their merits. It highlights what is desirable. They find that there is no significant difference between the cap system and the tax system when the shock originates from the non-energy sector. On the other hand, a cap is less volatile than a tax on energy production shocks but has higher welfare costs.

Chan (2020) investigates the expected macroeconomic and environmental impacts of carbon policy based on the E-DSGE model. His E-DSGE model extends the model of Annicchiarico and Di Dio (2015) by incorporating carbon policy news shocks with different announcement times. He examines three CO2 policies: CO2 taxation, emissions trading, and intensity regulation. It brings his three notable results to the literature.

First, he shows that the expected carbon tax rate increase has a similar unintended effect, as carbon emissions decrease immediately after the directive's announcement. As in the case of an unexpected increase in carbon tax rates, companies anticipating future increases in carbon tax rates will reduce capital expenditures, resulting in worse overall production and thus reduced carbon emissions. However, an expected tax increase differs from an unexpected tax increase in two ways.

(i) Only unexpected political shocks can lead to significant reduction efforts. Companies that anticipate tax increases in the future will continue to make efforts to reduce their tax rates. (ii) Early announcements of tax hikes ease the initial decline in production. Still, production will fall to even lower levels in the meantime. In other words, the economy will experience a significant decline in output over time.

The expected CO2 tax increase is also compared to the expected capacity and intensity reduction targets. A comparison with the tax system shows that the expected reduction in intensity could lead to a significant reduction in its CO2 emissions for the time being. However, under a cap-and-trade system, CO2 emissions remain constant over time. As far as addressing production and capital investment is concerned, cap-and-trade and intensity systems have similar effects. Both would result in significant reductions in production and investment (compared to the tax) before the effective date. On the other hand, both types of declines increase sharply immediately after the implementation of a new policy.

African Scientific Journal
ISSN : 2658-9311
Vol : 3, Numéro 23, Avril 2024

Third, regarding the welfare analysis, he concludes that pre-announcement of a carbon tax rate increase (from 1% to 5%) leads to initial consumption losses that increase with the timing of the announcement. Specifically, the consumption loss could reach 0.081% if announced one year ago (fourth period), and 0.114% if announced three years ago (12th period). In addition, the unexpected increase in carbon taxes exceeded expectations. Compared to the projected carbon tax policy, consumption under the new cap-and-trade and intensity policies will not initially decline as sharply and will bottom out in a short period of time.

Furthermore, unlike carbon tax policies where the economy always suffers consumption losses, planned cap-and-trade and intensity policies lead to consumption increases in the long run (after 25 periods). Regarding the ranking among his three planned measures, he concludes that an intensity system is preferable to a cap-and-trade system, and that a cap-and-trade system is preferable to a carbon tax system.

Huang *et al.* (2020) examine the impact that carbon policy and green technology can have on the integrated inventory of a two-tier supply chain, considering carbon emissions during production, product transportation and storage. All three carbon emissions policies, a cap on total carbon emissions, a carbon tax and cap-and-trade, were considered in the study. The proposed model can help companies determine the optimal production quantity, delivery quantity, and corresponding amount of green investment, aiming to minimize the costs of different carbon emission policies.

Furthermore, they also bring practical significance to the government in introducing appropriate policies and regulations to balance the trade-off between environmental protection and economic growth. Finally, the results show that companies adopting carbon tax policies prefer to invest in relatively efficient green technologies. In terms of carbon emission sources, the impact of unit carbon emissions during production and unit transportation distance is the largest, and the ceiling has a greater impact than the carbon emission reduction coefficient of green technology. In addition, the government should set carbon emission limits within reasonable ranges under cap-and-trade policies to prevent suppliers from overtrading their carbon emission limits.

Chan and Morrow's (2019) emissions trading programs that are designed to minimize the total cost of pollution control by allowing businesses with low treatment costs to effectively reduce emissions on behalf of Enterprises with low treatment costs have higher emissions reductions. However, these transactions redistribute emissions where they are produced, which has important implications for welfare because many pollutants have different environmental and health impacts depending on the environment where they are discharged. They compiled and

African Scientific Journal
ISSN : 2658-9311
Vol : 3, Numéro 23, Avril 2024

analyzed a national dataset of power plant emissions to assess the impact of the Regional Greenhouse Gas Initiative (RGGI), a program to cap-and-trade carbon dioxide (CO_2) in relation to nine US states, for emissions and damage from co-pollutants.

Their results showed that in addition to achieving the target of reducing CO_2 emissions, the program also reduced sulfur dioxide (SO_2) emissions and related damages in the affected area. However, there are two factors that reduce the overall benefits of the program. First, in the RGGI region, commercial activity shifts electricity generation to locations with higher marginal SO_2 losses. Second, there is leakage of electricity generation and emissions to neighboring countries, although the latter impacts are more modest than what previous analyzes predicted.

Taken together, their results suggest that RGGI produces significant benefits. It reduces CO_2 emissions while providing significant ancillary benefits through reduced SO_2 emissions and damage. Although some of the benefits of SO_2 reduction are offset by redistribution of SO_2 to the most damaged areas, the net effect is still positive for the RGGI region.

Similarly, if they find evidence of leakage to neighboring states in terms of power generation, this shift in generation is unlikely to erode the overall benefits of the RGGI program for several reasons. Firstly, leaking generation is generally cleaner and less carbon-intensive than marginal generation in the RGGI states, largely due to the different fuels used. Secondly, co-pollutants tend to be less damaging in the leakage region than in the RGGI states. Overall, this ex-post analysis provides strong evidence that RGGI has not only been effective in lowering CO_2 emissions,which is its primary policy objective, but has also generated substantial co-benefits through reduced SO_2 damage.

Ed-daoudi and Oubejja (2023) analysed cap-and-trade, or the enforcement of pollution permits, as a means of reducing CO_2 emissions, the main cause of global warming, in the case of Morocco. To do this, they used a partial equilibrium model for the cereals market and the energy sector by simulating three scenarios for total emissions limits, a 1% forced decrease in emissions, a 5% forced decrease in emissions, and a 7.5% forced decrease in emissions.

They showed that this forced emissions reduction has a very small impact on the reduction in income representing households' welfare, remaining unchanged even in the 7.5 decrease scenario, as well as increased production and consumption of solar energy. Therefore, an emissions trading system with a reasonable cap would reduce emissions without much impact on households' welfare, while also encouraging renewable energy production.

Mackenzie and Ohndorf (2012) the implementation of market-based environmental regulation, such as emissions taxes and cap-and-trade programs, often creates rents that are contested by agents. They create a framework that compares social welfare from alternative market-based environmental policy instruments in the presence of rent-seeking. They show that, contrary to popular opinion, non-revenue generating instruments (NRRI) are in many cases preferable to revenue generating instruments (RRI). They note that the choice of instrument depends on the importance of a potential income recycling effect and the level of pre-allocated rents.

Their objective is to compare the results of alternative market-based environmental policy instruments in the presence of rent-seeking. They provide a framework that facilitates the analysis of market-based instruments as agents, in groups, invest in occupancy activities to capture the rents generated by management process. Comparing social welfare, they find that revenue collection instruments (RRIs) are not always the best instruments to maximize social welfare, even for revenue recycling effects pretty huge. In emerging emissions trading markets, liberal allocation approaches are often used, and significant political effort is often invested to extract rents.

However, in order to make fair comparisons between other market-based environmental policies, it must be recognized that rents are also generated under RRI. These rents, generated through the use of tax revenues, can also be contested through the use of political influence. Thus, as their analysis shows, if socially unnecessary rent-seeking is taken into account for both types of instruments, the relative advantage of using RRI is no longer warranted.

In the above articles, the authors found that a cap-and-trade policy has a minimal impact on GDP and welfare, while of course reducing emissions and for some carbon intensity. However, this position while dominant in the literature, is not unanimous, as other authors have found that a cap-and-trade policy has a significant negative impact on GDP and/or welfare. We will present summaries of their work in what follows.

Li *et al.* (2017) cap-and-trade and carbon tax are the two main policies aimed at lowering carbon emissions. Unlike previous literature and practice, they examine the problems of outsourcing production and transportation of a two-tier supply chain under the cap-and-trade policy and the joint policy of cap-and-trade and carbon tax. Business operations are divided into two stages:

ordering and transportation outsourcing decision. At the order stage, the retailer sets its order schedule for the manufacturing plant for execution, and at the transportation outsourcing decision stage, the manufacturer decides the optimal freight volume based on consumption of energy.

Furthermore, they construct a base model without carbon policy and two extended models with carbon policy and the optimal solutions of the solved models. Numerical examples are provided and three models are compared. They show that the extended model with carbon policies is more beneficial to emission reduction, and the emission reduction effect gradually becomes softer as the carbon price increases; A common policy of emissions trading and a carbon tax would be more effective in reducing emissions, especially when carbon prices are lower.

They show that all optimal solutions of the model can be expressed in terms of expressions involving carbon prices and carbon taxes, directly and indirectly. From the perspective of emission reduction, in addition to no-carbon policy decisions, decentralized decisions will be more beneficial for emission reduction. Carbon prices and carbon taxes can be applied to reduce supply chain emissions. When carbon prices are so low that emissions cannot be effectively reduced, a general policy of cap-and-trade and a carbon tax will be more beneficial in reducing emissions. From a cost optimization perspective, a centralized decision is more beneficial in reducing supply chain costs. Carbon limits determine whether producers can profit from carbon market emissions, but carbon taxes must increase costs for producers.

Stuhlmacher *et al.* (2019) one of the most popular policy mechanisms to regulate greenhouse gas emissions is cap-and-trade, a market-based approach that has become dominant partly due to its flexibility. However, flexibility makes it possible to aggregate greenhouse gas emissions. To understand whether emissions trading leads to local cluster emissions changes, they perform a systematic spatial-economic assessment of the European Union's Emissions Trading System “E.U ETS”. They analyze the spatial structure of changes in emissions from different EU plants and how this structure evolved during the first two phases of ETS implementation.

They found that there was a series of changes in emissions at EU and national level, peaking at the start of the second period, but decreasing as the EU ETS matured. They also found that iron and steel, coke ovens and refining had higher concentrations and volatility than other industries. Because of the air quality impacts of these cluster emissions, certain countries and industry types may require additional attention when designing or redesigning ETS. They made a unique contribution by systematically assessing the spatio-temporal impacts and equity of emissions distribution in emissions trading systems.

Li *et al.* (2018) governments often use various carbon emissions regulations to ensure sustainable corporate energy consumption and thereby improve overall social welfare. They applied a game theoretic model to analyze how manufacturers' operational decisions related to sustainable energy consumption and low-carbon production will be altered by the variation of official cap-and-trade policies. They provide the government with additional analysis to make specific decisions. They indicate that a manufacturer may receive more incentives to improve its filtration technology in a market that favors low-carbon products compared to a market that has little preference to low-carbon products.

African Scientific Journal
ISSN : 2658-9311
Vol : 3, Numéro 23, Avril 2024

In addition, governments should limit cap-and-trade policies and encourage manufacturers to improve filtration technology when consumer preferences for low-carbon products are relatively high. They demonstrate that when consumers demonstrate a strong preference for low-carbon products, manufacturers must make socially optimal decisions for their business. When consumers express moderately low carbon preferences, significant conflicts arise between optimizing social welfare and improving purification technology. Therefore, if technological upgrades are needed, promoting policies that increase consumer preferences for low carbon emissions is an essential element to maximize total social welfare.

Zhang *et al.* (2019) examine a socially responsible supply chain under the cap-and-trade mechanism. Stylized centralized and decentralized models are established to characterize corporate social responsibility (CSR) in this supply chain. Their analytical results reveal that the centralized model always achieves a higher socially responsible profit than the two decentralized models, but whether the centralized model achieves a higher pure profit than the decentralized scenarios depends on the importance given to CSR:

when the importance is modest, the centralized model realizes a higher pure profit, while a greater importance given to CSR leads to a higher pure profit for the two decentralized cases. They then examine how the level of CSR concern and a government policy of cap-and-trade carbon emissions affect the operations of this socially responsible supply chain.

Higher levels of CSR concern result in higher profits for socially responsible chains, regardless of their structure. However, the net sector benefits increase in both decentralized models but decrease in the centralized case when the supply chain places more emphasis on CSR. Higher levels mean the Stackelberg leader gives up more pure profits to improve CSR, which gives more pure profits to followers in socially responsible decentralized channels. Higher carbon prices reduce demand and damage CSR, leading to lower net profits and lower retailer social responsibility, which are indirectly affected by the carbon cap-and-trade regime. For industrialists and the directly related sector, their pure profits and social responsibility will first decrease, then carbon trading prices will increase if the cap is more restrictive. But they will continue to increase carbon trading prices if governments are lax in limiting carbon emissions.

Xu *et al.* (2017) study production and pricing issues in an MTO (make-to-order) supply chain consisting of an upstream manufacturer that produces two products based on MTO production and a retailer downstream. The manufacturer must follow cap-and-trade regulations and determine the wholesale price for both products. To comply with regulations, manufacturers can buy or sell emissions permits through external markets. The retailer determines its order quantity to meet price-sensitive demand. They calculate the total emissions and optimal

African Scientific Journal
ISSN : 2658-9311
Vol : 3, Numéro 23, Avril 2024

production quantities of the two products, and on that basis, they analyze the impact of the emissions trading price on the optimal production decisions and optimal profits of the two companies.

Emissions trading decisions follow a two-threshold policy and an optimal increase in total emissions within the limits. However, counter-intuitively, the optimal production quantities of both products can fall within the ceiling. The manufacturer's optimal profit is to reduce (increase) the buying (selling) price of emission permits, and the retailer's optimal profit is to reduce the buying (selling) price of emission permits. The optimal total amount of emissions falls in the buying or selling price of emission permits, but the optimal production quantity of both products can increase (decrease) the buying (selling) price of emission permits. They give numerical examples to illustrate their conclusions and some management ideas are presented.

By analyzing the impact of emissions caps and trading prices on production decisions, they find several regulatory signals:

(1) decisions regarding emissions trading comply according to the policy at two thresholds. If the ceiling is lower (higher) than another threshold (threshold), the producer buys (sells) emission permits in the external market, and if the ceiling is between the two thresholds, the producer does not buy or sell emission permits ; (2) if the reduction in marginal benefit of product 1 is greater than the reduction in product 2 when using unit emission permits to produce product 1 (product 2), the producer will allocate more emission permits for product 2 when the cap increases, otherwise he will allocate all emission permits to product 1. So the manufacturer can produce product 1 (product 2) or both products, which suggests that cap-and-trade regulation may not be able to incentivize manufacturers to produce with low carbon emissions. some products; (3) the total emissions and optimal production quantity of product 2 decrease in the purchase or sale price of emission permits, while the optimal production quantity of product 1 can increase in the purchase or sale price of emission permits waste.

2. Methodology and model:

2.1. Methodology:

The social accounting matrix (SAM) used in this work synthesizes Moroccan economic activity for the year 2018. The construction of this matrix is made on the basis of the one published by the High Commission for Planning (HCP) in 2018 (semi-definitive matrix) while referring to the national accounts namely the Resources and Employment Table (TRE) and the Integrated Economic Accounts Table (TCEI) for the same year. The disaggregation of account C01 of the SAM into natural gas and coal (oil being imported refined in its entirety), is done with the help of the Moroccan energy balance of 2018 as published by the United Nations, as well as the calculation of the emission factors of the polluting products is done with the help of the SAM jointly with the energy balance.

The nomenclature used for the SAM accounts is that of the 1993 System of National Accounts. The matrix of the Moroccan economy presents 71 accounts divided into six blocks. The first block includes two production factor accounts (capital and labor). The second block includes four economic agent accounts (households, firms, government and the rest of the world) with a decomposition of the government account into three accounts, namely direct taxes, the tax on imports and indirect taxes. The tax on exports is non-existent in Morocco and therefore absent from our model. The third block contains 21 industry accounts. The fourth block contains 23 composite product accounts, while the fifth block contains 17 exported product accounts. Finally, the last block includes two accumulation accounts, including Gross Fixed Capital Formation (GFCF) and changes in inventories.

We propose to adapt the PEP (1-t) model (Decaluwé et al., 2013) to the structure of the Moroccan economy in order to evaluate the environmental and economic implications of different cap-and-trade levels on GDP, households' welfare and carbon intensity. It is a dynamic neoclassical model based on the Walrasian theory. Markets operate in an environment of pure and perfect competition where the decisions of economic agents are based on an optimization program of their objectives under specific constraints. The model considers only relative prices (real prices) which are expressed in relation to the price of an arbitrarily chosen good (Decaluwé et al., 1986). The CGE model that we adopt includes 9 blocks of equations (we have added two equations, one for emissions, and another for carbon intensity), namely:

- The production block;
- The income, savings and inter-institutional transfers block;
- The demand block;
- The supply and foreign trade block;
- The price block;
- The block of equilibrium equations and macroeconomic aggregates;
- The households' welfare block;
- The block of CO2 emissions.
- The block of carbon intensity of the economy.

We are interested in the quantities of CO2 emitted as a result of intermediate consumption and private consumption of the following products: natural gas, coal and oil, by multiplying their consumption levels by the emission factors of each of the products. We have adopted a classical

African Scientific Journal
ISSN : 2658-9311
Vol : 3, Numéro 23, Avril 2024

closure that assumes that the value of investment adjusts to the level of available savings in order to satisfy the equality between these two variables. Moreover, public consumption is considered exogenous and adjusts with public savings, which is an endogenous variable. CO2 emissions are exogeneous too since we are imposing a cap level thru cap-and-trade policy. International prices are assumed to be given since Morocco is a price taker and has no influence on international prices.

2.2. Model:

The model we used is composed of equations grouped in 9 blocks as follows:

- The production block:

$VA_{j,t} = v_j XST_{j,t}$ (1)

$CI_{j,t} = io_j XST_{j,t}$ (2)

$$VA_{j,t} = B_j^{VA}\left[B_j^{VA} LDC_{j,t}^{-\rho_j^{VA}} + \left(1 - B_j^{VA}\right) KDC_{j,t}^{-\rho_j^{VA}}\right]^{\rho_j^{-1/VA}} \quad (3)$$

$$LDC_{j,t} = \left[\frac{B_j^{VA}}{1-B_j^{VA}} \frac{RC_{j,t}}{WC_{j,t}}\right]^{\sigma_j^{VA}} KDC_{j,t} \quad (4)$$

$$LDC_{j,t} = B_j^{LD}\left[\sum_l \beta_{l,j}^{LD} LD_{l,j,t}^{-\rho_j^{LD}}\right]^{\rho_j^{-1/LD}} \quad (5)$$

$$LD_{l,j,t} = \left[\frac{\beta_{l,j}^{LD} WC_{j,t}}{WTI_{l,j,t}}\right]^{\sigma_j^{LD}} \left(B_j^{LD}\right)^{\sigma_j^{LD}-1} LDC_{j,t} \quad (6)$$

$$KDC_{j,t} = B_j^{KD}\left[\sum_k \beta_{k,j}^{KD} KD_{k,j,t}^{-\rho_j^{KD}}\right]^{\rho_j^{-1/KD}} \quad (7)$$

$$KD_{k,j,t} = \left[\frac{\beta_{k,j}^{KD} RC_{j,t}}{RTI_{k,j,t}}\right]^{\sigma_j^{KD}} \left(B_j^{KD}\right)^{\sigma_j^{KD}-1} KDC_{,jt} \quad (8)$$

$DI_{i,j,t} = aij_{i,j} CI_{j,t}$ (9)

- The income, savings and inter-institutional transfers block :

$YH_{h,t} = YHL_{h,t} + YHK_{h,t} + YHTR_{h,t}$ (10)

$YHL_{h,t} = \sum_l \lambda_{h,l}^{WL} \left(W_{l,t} \sum_j LD_{l,j,t}\right)$ (11)

$YHK_{h,t} = \sum_k \lambda_{h,k}^{RK} \left(\sum_j R_{k,j,t} KD_{k,j,t}\right)$ (12)

$YHTR_{h,t} = \sum_{ag} TR_{h,ag,t}$ (13)

$YDH_{h,t} = YH_{h,t} - TDH_{h,t} - TR_{gv,h,t}$ (14)

$CTH_{h,t} = YDH_{h,t} - SH_{h,t} - \sum_{agng} TR_{agng,h,t}$ (15)

$SH_{ht} = PIXCON_t^{\eta} sh0_{h,t} + sh1_{h,t} YDH_{h,t}$ (16)

African Scientific Journal
ISSN : 2658-9311
Vol : 3, Numéro 23, Avril 2024

$YF_{f,t} = YFK_{f,t} + YFTR_{f,t}$ (17)

$YFK_{f,t} = \sum_k \lambda_{f,k}^{RK} (\sum_j R_{k,j,t}\, KD_{k,j,t})$ (18)

$YFTR_{f,t} = \sum_{ag} TR_{f,ag,t}$ (19)

$YDF_{f,t} = YF_{f,t} - TDF_{f,t}$ (20)

$SF_{f,t} = YDF_{f,t} - \sum_{ag} TR_{ag,f,t}$ (21)

$YG_t = YGK_t + TDHT_t + TDFT_t + TPRODN_t + TPRCTS_t + YGTR_t$ (22)

$YGK_t = \sum_k \lambda_{gvt,k}^{RK} (\sum_j R_{k,j,t}\, KD_{k,j,t})$ (23)

$TDHT_t = \sum_h TDH_{h,t}$ (24)

$TDFT_t = \sum_f TDF_{f,t}$ (25)

$TPRODN_t = TIWT_t + TIKT_t + TIPT_t$ (26)

$TIWT_t = \sum_{l,j} TIW_{l,j,t}$ (27)

$TIKT_t = \sum_{k,j} TIK_{k,j,t}$ (28)

$TIPT_t = \sum_j TIP_{j,t}$ (29)

$TPRCTS_t = TICT_t + TIMT_t + TIXT_t$ (30)

$TICT_t = \sum_i TIC_{i,t}$ (31)

$TIMT_t = \sum_i TIM_{i,t}$ (32)

$TIXT_t = \sum_i TIX_{i,t}$ (33)

$YGTR_t = \sum_{agng} TR_{gvt,agng,t}$ (34)

$TDH_{h,t} = PIXCON_t^{\eta} ttdh0_{h,t} + ttdh1_{h,t} YH_{h,t}$ (35)

$TDF_{f,t} = PIXCON_t^{\eta} ttdf0_{f,t} + ttdf1_{f,t} YFK_{f,t}$ (36)

$TIW_{l,j,t} = ttiw_{l,j,t} W_{l,t} LD_{l,j,t}$ (37)

$TIK_{k,j,t} = ttik_{k,j,t} R_{k,j,t} KD_{k,j,t}$ (38)

$TIP_{j,t} = ttip_{j,t} PP_{j,t} XST_{j,t}$ (39)

$TIC_{i,t} = ttic_{i,t}[(PL_{i,t} \sum_{ij} PC_{ij,t}\, tmrg_{ij,i})DD_{i,t} + \Big((1 + ttim_{i,t})PWM_{i,t} e_t +$

$\sum_{ij} PC_{ij,t} tmrg_{ij,i}\Big) IM_{i,t}]$ (40)

$TIM_{i,t} = ttim_{i,t} PWM_{i,t} e_t IM_{i,t}$ (41)

$TIX_{i,t} = ttix_{i,t}(PE_{i,t} + \sum_{ij} PC_{ij,t}\, tmrg_{ij,i}^{X})EXD_{i,t}$ (42)

$SG_t = YG_t - \sum_{agng} TR_{agng,gvt,t} - G_t$ (43)

$YROW_t = e_t \sum_i PWM_{i,t} IM_{i,t} + \sum_k \lambda_{row,k}^{RK}(\sum_j R_{k,j,t} KD_{k,j,t}) + \sum_{agd} TR_{row,agd,t}$ (44)

$SROW_t = YROW_t - \sum_i PE_{i,t}^{FOB} EXD_{i,t} - \sum_{agd} TR_{agd,row,t}$ (45)

African Scientific Journal
ISSN : 2658-9311
Vol : 3, Numéro 23, Avril 2024

$SROW_t = -CAB_t$ (46)

$TR_{agng,h,t} = \lambda^{TR}_{agng,h} YDH_{h,t}$ (47)

$TR_{gv,h,t} = PIXCON^{\eta}_t tr0_{h,t} + tr1_{h,t} YH_{h,t}$ (48)

$TR_{ag,f,t} = \lambda^{TR}_{ag,f} YDF_{f,t}$ (49)

$TR_{agng,gvt,t} = PIXCON^{\eta}_t TR^{O}_{agng,gvt} pop_t$ (50)

$TR_{agd,row,t} = PIXCON^{\eta}_t TR^{O}_{agd,row} pop_t$ (51)

- The demand block:

$PC_{i,t} C_{i,h,t} = PC_{i,t} C^{MIN}_{i,h,t} \gamma^{LES}_{i,h} (CTH_{h,t} \sum_{ij} PC_{ij,t} C^{MIN}_{ij,h,t})$ (52)

$GFCF_t = IT_t - \sum_i PC_{i,t} VSTK_{i,t}$ (53)

$PC_{i,t} INV^{PRI}_{i,t} = \gamma^{INVPRI}_i IT^{PRI}_t$ (54)

$PC_{i,t} INV^{PUB}_{i,t} = \gamma^{INVPUB}_i IT^{PUB}_t$ (55)

$INV_{i,t} = INV^{PRI}_{i,t} + INV^{PUB}_{i,t}$ (56)

$PC_{i,t} CG_{i,t} = \gamma^{GVT}_i G_t$ (57)

$DIT_{i,t} = \sum_j DI_{i,j,t}$ (58)

$MRGN_{i,t} = \sum_{ij} tmrg_{i,ij} DD_{ij,t} + \sum_{ij} tmrg_{i,ij} IM_{ij,t} + \sum_{ij} tmrg^{X}_{ii,j} EXD_{ij,t}$ (59)

- The supply and foreign trade block:

$XST_{j,t} = B^{XT}_j \left[\sum_i \beta^{XT}_{j,i} XS^{\rho^{XT}_j}_{j,i,t}\right]^{\rho^{1/XT}_j}$ (60)

$XS_{j,i,t} = \frac{XST_{j,t}}{\left(B^{XT}_j\right)^{1+\sigma^{XT}_j}} \left[\frac{P_{j,i,t}}{\beta^{XT}_{j,i} PT_{j,t}}\right]^{\sigma^{XT}_j}$ (61)

$XS_{j,i,t} = B^{X}_{j,i} \left[\beta^{X}_{j,i} EX^{\rho^{X}_{j,i}}_{j,i,t} + (1-\beta^{X}_{j,i}) DS^{\rho^{X}_{j,x}}_{j,i,t}\right]^{\rho^{1/X}_{j,i}}$ (62)

$EX_{j,i,t} = \left[\frac{1-\beta^{X}_{j,i}}{\beta^{X}_{j,i}} \frac{PE_{i,t}}{PL_{i,t}}\right]^{\sigma^{X}_{j,i}} DS_{j,i,t}$ (63)

$EXD_{i,t} = EXD^{O}_i pop_t \left(\frac{e_t PWX_{i,t}}{PE^{FOB}_{i,t}}\right)^{\sigma^{XD}_i}$ (64)

$Q_{i,t} = B^{M}_i \left[\beta^{M}_i IM^{-\rho^{M}_i}_{i,t} + \left(1 - B^{M}_i DD^{-\rho^{M}_i}_{i,t}\right)\right]^{\rho^{-1/M}_i}$ (65)

$IM_{i,t} = \left[\frac{\beta^{M}_i}{1-\beta^{M}_i} \frac{PD_{i,t}}{PM_{i,t}}\right]^{\sigma^{M}_i} DD_{i,t}$ (66)

- The price block :

$PP_{j,t} = \frac{PVA_{j,t} VA_{j,t} + PCI_{j,t} CI_{j,t}}{XST_{j,t}}$ (67)

$PT_{j,t} = \left(1 + ttip_{j,t}\right)PP_{j,t}$ (68)

$PCI_{j,t} = \frac{\sum_i PC_{i,t}DI_{i,j,t}}{CI_{j,t}}$ (69)

$PVA_{j,t} = \frac{WC_{j,t}LDC_{j,t}+RC_{j,t}KDC_{j,t}}{VA_{j,t}}$ (70)

$WC_{j,t} = \frac{\sum_l WTI_{l,j,t}LD_{l,j,t}}{LDC_{j,t}}$ (71)

$WTI_{l,j,t} = W_{l,t}(1 + ttiw_{l,j,t})$ (72)

$RC_{j,t} = \frac{\sum_k RTI_{k,j,t}KD_{k,j,t}}{KDC_{j,t}}$ (73)

$RTI_{k,j,t} = R_{k,j,t}(1 + ttik_{k,j,t})$ (74)

$PT_{j,t} = \frac{\sum_i P_{j,i,t}XS_{j,i,t}}{XST_{j,t}}$ (75)

$P_{j,i,t} = \frac{PE_{i,t}EX_{j,i,t}+PL_{i,t}DS_{j,i,t}}{XS_{j,i,t}}$ (76)

$PE_{i,t}^{FOB} = (PE_{i,t} + \sum_{ij} PC_{ij,t}tmrg_{ij,i}^{X})(1 + ttix_{i,t})$ (77)

$PD_{i,t} = (1 + ttic_{i,t})(PL_{i,t} + \sum_{ij} PC_{ij,t}tmrg_{ij,i})$ (78)

$PM_{i,t} = (1 + ttic_{i,t})(\left(1 + ttim_{i,t}\right)e_tPWM_{i,t} + \sum_{ij} PC_{ij,t}tmrg_{ij,i})$ (79)

$PC_{i,t} = \frac{PM_{i,t}IM_{i,t}+PD_{i,t}DD_{i,t}}{Q_{i,t}}$ (80)

$PIXGDP_t = \sqrt{\frac{\sum_j PVA_{j,t}VA_j^O \sum_j PVA_{j,t}VA_{j,t}}{\sum_j PVA_j^O VA_j^O \sum_j PVA_j^O VA_{j,t}}}$ (81)

$PIXCON_t = \frac{\sum_i PC_{i,t} \sum_h C_{i,h}^O}{\sum_{ij} PC_{ij}^O \sum_h C_{ij,h}^O}$ (82)

$PIXINV_t^{PRI} = \prod_i \left(\frac{PC_{i,t}}{PC_i^O}\right)^{\gamma_i^{INVPRI}}$ (83)

$PIXINV_t^{PUB} = \prod_i \left(\frac{PC_{i,t}}{PC_i^O}\right)^{\gamma_i^{INVPUB}}$ (84)

$PIXGVT_t = \prod_i \left(\frac{PC_{i,t}}{PC_i^O}\right)^{\gamma_i^{GVT}}$ (85)

- The block of equilibrium equations and macroeconomic aggregates :

$Q_{i,t} = \sum_h C_{i,h,t} + CG_{i,t} + INV_{i,t} + VSTK_{i,t} + DIT_{i,t} + MRGN_{i,t}$ (86)

$\sum_j LD_{l,j,t} = LS_{l,t}$ (87)

$\sum_j KD_{l,j,t} = KS_{k,t}$ (88)

$IT_t = \sum_h SH_{h,t} + \sum_f SF_{f,t} + SG_t + SROW_t$ (89)

African Scientific Journal
ISSN : 2658-9311
Vol : 3, Numéro 23, Avril 2024

$IT_t^{PRI} = IT_t - IT_t^{PUB} - \sum_i PC_{i,t}VSTK_{i,t}$ (90)

$\sum_j DS_{j,i,t} = DD_{i,t}$ (91)

$\sum_j EX_{j,i,t} = EXD_{i,t}$ (92)

$GDP_t^{BP} = \sum_j PVA_{j,t}VA_{j,t} + TIPT_t$ (93)

$GDP_t^{MP} = GDP_t^{BP} + TPRCTS_t$ (94)

$GDP_t^{IB} = \sum_{l,j} W_{l,t}\, LD_{l,j,t} + \sum_{k,j} R_{k,j,t}KD_{k,j,t} + TPRODN_t + TPRCTS_t$ (95)

$GDP_t^{FD} = \sum_i PC_{i,t}\left[\sum_h C_{i,h,t} + CG_{i,t} + INV_{i,t} + VSTK_{i,t}\right] + \sum_i PE_{i,t}^{FOB}\, EXD_{i,t} -$
$\sum_i e_t\, PWM_{i,t}IM_{i,t}$ (96)

- The block of dynamic equations:

$KD_{k,j,t+1} = KD_{k,j,t}\left(1 - \delta_{k,j}\right) + IND_{k,j,t}$ (97)

$IT_t^{PUB} = PK_t^{PUB} \sum_{k,pub} IND_{k,pub,t}$ (98)

$IT_t^{PRI} = PK_t^{PRI} \sum_{k,bus} IND_{k,bus,t}$ (99)

$PK_t^{PRI} = \frac{1}{A^{K\_PRI}} \prod_i \left[\frac{PC_{i,t}}{\gamma_i^{INVPRI}}\right]^{\gamma_i^{INVPRI}}$ (100)

$PK_t^{PUB} = \frac{1}{A^{K\_PUB}} \prod_i \left[\frac{PC_{i,t}}{\gamma_i^{INVPUB}}\right]^{\gamma_i^{INVPUB}}$ (101)

$IND_{k,bus,t} = \phi_{k,bus} \left[\frac{R_{k,bus,t}}{U_{k,bus,t}}\right]^{\sigma_{k,bus}^{INV}} KD_{k,bus,t}$ (102)

$U_{k,bus,t} = PK_t^{PRI}(\delta_{k,bus} + IR_t)$ (103)

$U_{k,pub,t} = PK_t^{PUB}(\delta_{k,pub} + IR_t)$ (104)

- The households' welfare block:

We used as a measure of households' welfare noted U, their total consumption of products in volume (quantity).

$U_t = CTH_{h,t}^{REAL}$ (105)

- The block of CO2 emissions and carbon intensity:

$TQCO2_t = \sum_{h,i} FE_{i,t}C_{i,h,t} + \sum_{j,i} FE_{i,t}DI_{j,i,t}$ (106)

$INT_t = \frac{TQCO2_t}{GDP_t^{MP}}$ (107)

African Scientific Journal
ISSN : 2658-9311
Vol : 3, Numéro 23, Avril 2024

3. Numerical analysis and results:

To analyze the impact of different cap-and-trade levels on the main macroeconomic aggregates, including GDP, as well as on CO2 emissions, carbon intensity and households' welfare, we used two simulations represented by two scenarios in a dynamic model expanding over five years and comparing the results between the fifth year of a given policy or scenario with the fifth year of the absence of such policy or scenario by giving the differences in the form of percentage deviations.

The first scenario is the implementation of a cap-and-trade of one percent less than the last year before the policy throughout the five years of the simulation, and the second is the implementation of a cap-and-trade of one percent less than the last year before the policy in the two first years of the simulation and of two percent less than the year before the simulation for the last three years. We present the results and interpretation of these two simulations in what follows.

3.1. Scenario 1 : Cap-and-trade of 1% less emissions of baseline year for the five years:

A cap-and-trade policy reducing the level of emissions of baseline year for the five years of the scenario give these results compared to the absence of such a policy at the fifth year after implementing the policy: a decrease of production both domestic and exports to decrease the emissions that would naturally increase throughout the years without an environmental policy wich leads to the decrease of national demand, namely consumption and importation. The investment decreases also since it is a component of demand except for agriculture, building and public works and real estate, rental and business services sectors because they benefit from public investment as a national policy. The percentage variations of which by product are given in the following tables:

Table 1: Variation of consumption in % after a cap-and-trade decreasing the emissions of baseline year by 1%.

Product	Variation of consumption in %
AGRP	-8,752243471
PAQP	-10,14976922
C03P	-11,07083033
IATP	-8,747667276
ITCP	-10,73741057
ICPP	-10,81543588
IMMP	-10,86881165
AINP	-10,60220093
RPEP	-11,27487267
EAUP	-9,272126593
BTVP	-9,048309997
COMP	-9,054352082
HRSP	-8,484958351
TRAP	-10,14049707
PTCP	-8,213033855
AFAP	-8,841948952
IMLP	-9,05690598
ADMP	-10,33447071
MNOP	-10,42950664
OPOP	-8,644931197

Source: Authors.

African Scientific Journal
ISSN : 2658-9311
Vol : 3, Numéro 23, Avril 2024

Table 2: Variation of production in % after a cap-and-trade decreasing the emissions of baseline year by 1%.

Product	Variation of production in %
AGRP	-3,359326099
PAQP	-5,559806772
C02P	-1,27279086
C03P	-0,816326504
IATP	-5,524506781
ITCP	-1,45289732
ICPP	-1,21794532
IMMP	-3,526110968
AINP	-3,722902528
RPEP	0,212854315
EAUP	-5,42134786
BTVP	-8,922549834
COMP	-4,56545008
HRSP	-6,239367254
TRAP	-4,260636402
PTCP	-6,036183074
AFAP	-5,29770155
IMLP	-4,510324639
ADMP	1,804442882
MNOP	-0,111080884
OPOP	-6,990792808

Source: Authors.

African Scientific Journal
ISSN : 2658-9311
Vol : 3, Numéro 23, Avril 2024

Table 3: Variation of imports in % after a cap-and-trade decreasing the emissions of baseline year by 1%.

Product	Variation of imports in %
AGRP	-14,313025
PAQP	-9,962252173
GASP	-4,120210398
COALP	-4,093813078
C02P	-5,496602705
C03P	-2,733012854
IATP	-16,29467388
ITCP	-5,612166521
ICPP	-5,199350865
IMMP	-8,617407249
AINP	-9,01350269
RPEP	-4,238314971
EAUP	-13,38154193
HRSP	-16,9329551
TRAP	-11,74089334
PTCP	-17,63760126
AFAP	-14,58280829
IMLP	-14,22162505
OPOP	-16,75124427

Source: Authors.

African Scientific Journal
ISSN : 2658-9311
Vol : 3, Numéro 23, Avril 2024

Table 4: Variation of exports in % after a cap-and-trade decreasing the emissions of baseline year by 1%.

Product	Variation of exports in %
AGRP	-12,71304901
PAQP	-7,997301271
C02P	-11,01216022
C03P	-10,87956679
IATP	-11,59343975
ITCP	-8,77588432
ICPP	-9,775902207
IMMP	-8,248800801
AINP	-9,417108302
RPEP	-8,701096285
EAUP	-10,05548558
HRSP	-11,14801503
TRAP	-11,41148661
PTCP	-11,8331007
AFAP	-11,3193737
IMLP	-13,04892092
OPOP	-9,565184577

Source: Authors.

Table 5: Variation of investment in % after a cap-and-trade decreasing the emissions of baseline year by 1%.

Product	Variation of investment in %
AGRP	-1,434319075
ITCP	3,770184045
IMMP	4,206312538
AINP	3,192908289
BTVP	-0,833469024
IMLP	-1,260597628
OPOP	0,039201496

Source: Authors.

The decrease in consumption and production led to the decrease in households' welfare by 9,3345135% and the decrease of GDP (wich means economic growth) by 2,7103203%, while carbon intensity decreased by 7,6923077%.

AFRICAN SCIENTIFIC JOURNAL
MANAGEMENT AND ECONOMIC DEVELOPMENT

African Scientific Journal
ISSN : 2658-9311
Vol : 3, Numéro 23, Avril 2024

3.2. Scenario 2 : Cap-and-trade of 1% less emissions of baseline year for the two first years and of 2% the three last years:

A cap-and-trade policy reducing the level of emissions of baseline year for the five years of the scenario give these results compared to the absence of such a policy at the fifth year after implementing the policy: a decrease of production both domestic and exports to decrease the emissions that would naturally increase throughout the years without an environmental policy wich leads to the decrease of national demand, namely consumption and importation. The investment decreases also since it is a component of demand. The percentage variations of which by product are given in the following tables:

Table 6: Variation of consumption in % after a cap-and-trade decreasing the emissions of baseline year by 1% the two first years and 2% the last three.

Product	Variation of consumption in %
AGRP	-3,990218964
PAQP	-2,274129633
C03P	-2,264313898
IATP	-3,654652225
ITCP	-1,140920655
ICPP	-1,206741257
IMMP	-0,859806116
AINP	-1,488324657
RPEP	-0,238727867
EAUP	-3,836720474
BTVP	-3,922966594
COMP	-4,453653157
HRSP	-4,062455265
TRAP	-2,607583497
PTCP	-4,396775948
AFAP	-4,096610189
IMLP	-4,184265689
ADMP	-2,513342804
MNOP	-2,371259465
OPOP	-3,399548464

Source: Authors.

Table 7: Variation of production in % after a cap-and-trade decreasing the emissions of baseline year by 1% the two first years and 2% the last three.

Product	Variation of production in %
AGRP	-7,012307254
PAQP	-6,084825052
C02P	-9,835332183
C03P	-9,673330012
IATP	-6,651337648
ITCP	-8,011538042
ICPP	-9,5713832
IMMP	-6,241492016
AINP	-7,254685971
RPEP	-13,01883603
EAUP	-6,169913527
BTVP	-1,09952199
COMP	-6,026553139
HRSP	-5,518081176
TRAP	-8,901084758
PTCP	-5,892296994
AFAP	-6,262127028
IMLP	-7,103107979
ADMP	-7,744011674
MNOP	-6,807243393
OPOP	-4,657319347

Source: Authors.

African Scientific Journal
ISSN : 2658-9311
Vol : 3, Numéro 23, Avril 2024

Table 8: Variation of imports in % after a cap-and-trade decreasing the emissions of baseline year by 1% the two first years and 2% the last three.

Product	**Variation of imports in %**
AGRP	-16,750151
PAQP	-11,653125
GASP	-4,8818393
COALP	-4,851191
C02P	-6,4240299
C03P	-3,189436
IATP	-19,080125
ITCP	-6,5930741
ICPP	-6,1134902
IMMP	-10,075262
AINP	-10,552312
RPEP	-4,9975351
EAUP	-15,675749
HRSP	-19,81693
TRAP	-13,764684
PTCP	-20,62757
AFAP	-17,053578
IMLP	-16,583549
OPOP	-19,592662

Source: Authors.

African Scientific Journal
ISSN : 2658-9311
Vol : 3, Numéro 23, Avril 2024

Table 9: Variation of exports in % after a cap-and-trade decreasing the emissions of baseline year by 1% the two first years and 2% the last three.

Product	Variation of exports in %
AGRP	-4,9702937
PAQP	0,62632177
C02P	-1,7744142
C03P	-0,6013777
IATP	-3,8255225
ITCP	-1,6489052
ICPP	-1,4675672
IMMP	-0,9608975
AINP	-1,0074196
RPEP	-0,6315534
EAUP	-1,8162459
HRSP	-3,3129351
TRAP	-2,1399087
PTCP	-4,0572979
AFAP	-2,8252344
IMLP	-3,6600307
OPOP	-1,9227033

Source: Authors.

Table 10: Variation of exports in % after a cap-and-trade decreasing the emissions of baseline year by 1% the two first years and 2% the last three.

Product	Variation of investment in %
AGRP	-12,226461
ITCP	-16,326649
IMMP	-16,585602
AINP	-16,030378
BTVP	-12,872424
IMLP	-12,850259
OPOP	-12,150956

Source: Authors.

The decrease in consumption and production led to the decrease in households' welfare by 11,030821% and the decrease of GDP (wich means economic growth) by 3,1718336% %, while carbon intensity decreased by 7,6923077%.

African Scientific Journal
ISSN : 2658-9311
Vol : 3, Numéro 23, Avril 2024

Conclusion:

We have simulated the effects of the environmental policy of cap-and-trade throughout a dynamic computable general equilibrium model with two scenarios, a scenario of a cap of 1% less emissions than the baseline year for 5 years, and a second scenario with 1% less the first two years and 2% less for the three other years. Both scenarios showed that consumption, production, imports and most investments decreased, while exports increased due to mechanisms explained in the results section.

Furthermore, the households' welfare and GDP also decreased in both scenarios but this decrease is small compared to the benefits of definitely limiting carbone missions to a reasonable cap, while decreasing carbon intensity at the same time. Also, the GDP and welfare decrease is relative to what would have happened the fifth year in the absence of policy, in absolute term both welfare and economic growth will keep increasing. Therefore, we strongly recommend the use of at least the policy of fixing the cap of emissions to 1% less than the last baseline year, with the implementation of a cap-and-trade system (market of pollution permits).

African Scientific Journal
ISSN : 2658-9311
Vol : 3, Numéro 23, Avril 2024

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