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Environmental consequences of policies in construction sector: combining economic simulation with consequential LCA

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Abstract. Consequential Life Cycle Assessment (CLCA) can be particularly relevant for studying the changes proposed by new policies since they may result in important displacements of environmental, social and economic impacts. For example, the financial aids for encouraging the use of new technologies may increase the demand for some materials of which production is constrained and the marginal suppliers may be more impacting than the average ones. The goal of this project was to propose a method for calculating the potential environmental burdens and benefits from new policies in the construction sector. Consequential Life Cycle Inventory must include all processes that are actually affected by the studied changes, considering the market effects. The economic models can be helpful on this matter. The proposed method couples a Stock-Flow Consistent (SFC) to the CLCA methodology to obtain the flows and stocks that are affected by the new policy. The model goes further in order to obtain the second-order effects, i.e., the monetary redistribution effects resulting from an economic perturbation. The main result is a novel method that couples an SFC model to CLCA. It is tested in a case study where the evolution of carbon tax in France (economic shock) leads to an increase in thermal retrofitting works in the French existing built stock. These results may help the construction sector to anticipate important rebound effects that are not usually included in the current studies used for decision and policy-making.

1 Introduction

Buildings and construction sector are a key actor in achieving the sustainable development goals proposed by United Nations member states in 2015. The sector has the largest shares of energy consumption and greenhouse gas (GHG) emissions in a global perspective, responding for 36% of total final energy consumption and 37% of total CO_2 emissions in 2020[1]. The sector's contribution to total gross domestic product (GDP) varies over countries, from 1.4% in Egypt to 10.5% in Albania in 2020. In France, in 2018, for example, the sector's activities represented 5.6% of total GDP[2], 5.5% of total employees [3], while

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the GHG emissions of residential and tertiary sector were around 19% and total manufacture industry (including construction) was around 18% of total emissions [4]. Concerning consumption of final energy, residential and tertiary sectors represented around 46%, and industries (including the construction industry) represented 19% [5].

These numbers show that buildings and construction sector affect differently the fields of economy, environment and society. Therefore, a new policy must take into account this complexity, knowing that it will imply changes in demand for some products, systems and services, affecting the interactions between the environment and human activities. The classic attributional LCA methodology has numerous limitations in this context, mostly addressed by the consequential approach [6]–[8]. This research work develops an approach that consists in coupling the Life Cycle Assessment (LCA) methodology with a macro-economic Stock-Flow Consistent model (SFC). The choice for using an SFC model is justified by a previous review on the economic models used in consequential assessments [9].

In this context, the goals of the paper were two-fold: (1) to provide a method to evaluate environmental consequences of new policies to help decision-makers in construction sector and (2) apply the method into a case study, which is the evolution of carbon tax in France, in particular, its implications on the thermal retrofitting of the French built stock.

2 Methods

The economy is composed of industries (here non-financial corporations, NFC), financial corporations (FC), households (HH), general government (GG) and the rest of the world (RoW). Households consume goods and services from non-financial corporations, pay taxes to the government and transfer the remaining money at the end of each period to financial corporations. Industries receive money from selling their products and services to the government and to households; they take loans from financial corporations to buy new production means. Figure 1 shows the main transactions (taxes, deposits, consumption, interests and loans), represented in a flow diagram of the model, as commonly presented in SFC models [10], [11].

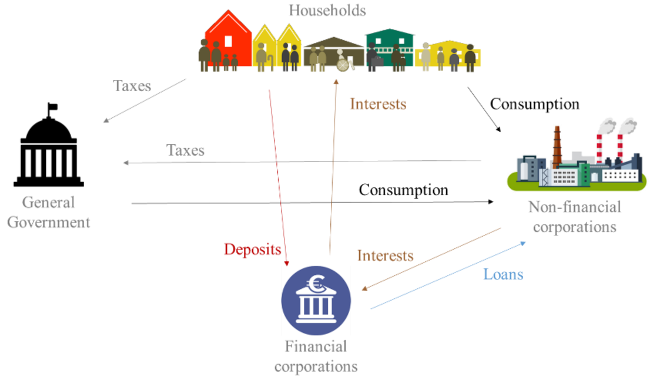

Fig. 1. Transactions between sectors

The proposed method is based on an input-output analysis (IOA) for obtaining the life cycle inventory (LCI), as well as the changes in flows and stocks. The latter are accounted in a Transactions-Flow Matrix (TFM), as described by Godley and Lavoie [12]. The extra money received by households, i.e. their change in income, is then expended to buy products and services in a second round of distribution. The rounds are linked by the so-called ‘propensity to expend out of income’ and also by the interests paid from banks to households and from industries to banks.

The economic perturbation represents the functional unit of LCA, in this case, the change in demand for products and services, with the functions and durations consistent with the new policy. The change in demand is therefore the change in final demand in the IOA.

3 Case study

The method described in the previous section was applied to the evolution of carbon tax in France. The government introduced the carbon tax in the Finance Bill for 2014 [13] at the initial value of 7 €/tCO_2. In 2015, the law on energy transition for green growth (free translation of *Loi de Transition Energetique pour la Croissance Verte*, *LTECV*) set a growing objective to obtain a rate of 100 €/tCO_2 in 2030. However, the social crisis in 2018 (resulting in the yellow jackets protests) made a pressure to freeze the carbon tax value at 44.6 €/tCO_2.

This paper investigates the case in which the government imposes now the evolution of carbon tax as it was recommended by the LTECV. For that, the LTECV's target (100 €/tCO_2) is set to 2030 and the yearly increase from the current value (44.6 €/tCO_2) is obtained proportionally year by year.

The increase in carbon tax affects directly the households that purchase fuels for their needs in housing (heating, domestic hot water, cooking, etc.) and in transport. Therefore, they would be encouraged to conduct thermal retrofitting services in their homes with an imposed increase in the carbon tax rate. This means that they would drop their fossil fuel consumption by replacing their fossil-based heating system or by improving the energy efficiency of their homes (e.g. decreasing the thermal losses through better insulation).

To calculate the amount of new efficient equipment and the saved energy, we used a French econometric model, developed by the French Environmental Agency (ADEME), called MENFIS (for "Model ENergie FIScalité des logements" in French)[14]. This latter is a prospective model that simulates in a yearly basis the impact of incentive policies aimed at reducing energy consumption in France. It includes a thermal module that provides changes in energy consumption according to the evolution of the number of retrofitting works (services). These are listed in terms of the number of new heat pumps (air/air, air/water), number of new boilers (gas and fuel condensing boilers and wood boilers), the surface of new insulating materials (wall/roof/attic insulation) and surface of new windows installed in national territory. Therefore, the simulations were conducted using the values of carbon tax as previously explained and all the outcomes of the MENFIS modelling are presented in Table 1. All thermal retrofitting services that are listed here below are taken into account in the results provided in this paper.

Table 1. Additional thermal retrofitting services from 2020 to 2030 (in thousands)

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Heat pump air/air (units)	294	222	228	230	216	193	193	191	189	146	124
Heat pump air/water (units)	19	27	37	70	96	124	156	192	223	276	353
Fuel condensing boiler (units)	109	148	185	217	242	259	272	282	281	276	256
Gas condensing boiler (units)	208	217	229	244	262	280	306	343	376	406	433
Wood boiler (units)	47	47	47	46	46	46	46	45	45	45	44
Wood burning fireplace inserts (units)	325	375	397	444	474	492	521	523	549	555	539
Wall Insulation (m^2)	417	471	527	584	603	619	681	710	762	757	751
Roof/attic insulation (m^2)	470	514	538	589	647	700	707	736	743	747	774
Windows(m^2)	716	720	737	754	775	793	819	849	879	906	910

Each thermal retrofitting service (installation of heat pumps, wall insulation, etc.) was modelled using the monetary input-output (industry x industry) from EXIOBASE (version 3.3.15)[15]. EXIOBASE is a multi-regional input-output (MRIO) database that was initially developed from 2007 to 2011 under the 7th framework program of the European Commission, more precisely as a result of the EXIOPOL project [16].

Information for obtaining the life cycle inventory of each equipment category was taken from the environmental product declarations (EPD) that are publicly available from INIES website†. Market shares were applied to choose the appropriate EPD or a combination of sheets was applied when needed for a better representation of the retrofitting services. For example, MENFIS provides the amounts of square-meters of wall insulation, which is a generic information knowing that the EPDs concern the specific product (e.g. 1m² of rock wool, with a thermal resistance of x m²K/W). Therefore, the share of the types of insulation materials available on French market was considered to select the EPDs that would better represent the demand for 1m² of wall insulation.

Concerning the energy savings, MENFIS provides the amount of energy saved yearly in relation to a reference year, by energy source. The outcomes of simulations in MENFIS are presented in Table 2.

Table 2. Energy savings (TWh)

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Natural gas	-2.1	-4.2	-7.3	-10.6	-14.5	-18.8	-23.2	-27.7	-32.6	-37.7	-42.8
Diesel	-2.4	-4.7	-8.1	-12.3	-17.4	-22.6	-28.0	-33.1	-37.5	-41.2	-44.2
Electricity	-0.9	-1.6	-2.0	-2.0	-1.5	-0.6	0.6	1.9	3.1	4.3	5.3
Wood pellets	0.3	0.5	0.9	1.7	2.6	3.6	4.6	5.6	6.3	6.7	6.9
District heat	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	-0.1	-0.2
Total	-5.0	-10.0	-16.4	-23.1	-30.6	-38.3	-45.9	-53.3	-60.8	-68.0	-75.0

As well as equipment and insulation materials, the energy sources were modelled using the monetary input-output table of EXIOBASE (version 3.3.15). For that, the physical flows (in TWh) from Table 2 were converted into monetary flows (in million euros) using the basic prices from EXIOBASE.

In this case study, the main financial transactions are presented in Figure 2.

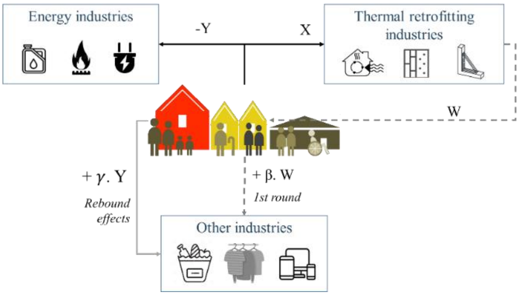

Fig. 2. Illustrative representation of rebound effects and 1st round of monetary distribution effects

Households, center of the figure, expend X euros in thermal retrofitting services. Thermal retrofitting industries use a part of this money to pay their employees, through wages and salaries (represented by W). One part (β) of this extra money received by households is then expended buying other goods and services. Here, we call this expending as the 'first distribution round effects' **(**1st round**)**. We only considered the first round of distribution; however, the multiplier effects occur indefinitely and could be computed even further. EXIOBASE provides the value-added for each industry, including the wages and salaries disaggregated by level of income (high-skilled, medium-skilled and low-skilled).

On the other hand, households save energy and reduce their energy bills by Y euros. One part of this money (γ) is then used to buy other goods and services, here called 'rebound effects'. Please note that no energy rebound effect, i.e. associated with energy consumption is included (e.g. increase in energy consumption by rising the comfort temperature).

† INIES website (https://www.inies.fr) makes available the EPDs for construction products and building equipment, provided by manufacturers and trade associations obtained in accordance with the European standard EN 15804.

It is important to note that Figure 2 does not present all flows balanced because its purpose is to illustrate the rebound effects that are studied in this case study. However, the other part of saved money ($(1-\beta).W$ and $(1-\gamma).Y$) goes to financial corporations. Obviously, W is smaller than X, and (X-W) goes one part to the government in the form of taxes, contributions etc, one part is reinvested in the industries and one part goes to financial corporations to pay interests on loans taken in previous periods. Another important assumption is who finances the new retrofitting services, or, where the X euros come from. In this example, we considered that 50% come from free-interest loans and 50% from household saving accounts.

4 Results

The flows and the changes in stocks computed in the end of the first period of monetary (re)distribution are presented in the Transactions-Flow Matrix (TFM) in Table 3.

Table 3. TFM compiling the uses (Use) and resources (Res) of sectors in the first year (million €)

	NFC		**FC**		**GG**		**HH**		**RoW**		**Sum**
	Use	**Res**	**Use**	**Res**	**Use**	**Res**	**Use**	**Res**	**Use**	**Res**	
Final consumption (domestic products)		2.198					2.198				0
Final consumption (imported products)	0.393									0.393	0
Gross fixed capital		3.356					3.356				0
Wages, salaries	4.208							4.208			0
Taxes less subsidies	0.285					0.285					0
Other taxes	0.206					0.206					0
Taxes on income						1.136	1.136				0
Subsidies					0.416			0.416			0
Operating surplus	2.120	0.853						1.267			0
Currency and deposits			1.678	4.161	1.211		2.558	1.678	0.393		0
Loans		0.805	4.966	2.483				1.678			0
Sum	0		0		0		0		0		

Households are richer by 2.558 million euros. However, this money is not distributed equally to the three income groups: low-skilled detain 5%, medium-skilled, 39% and high-skilled 56%, showing that there is a concentration of revenue in this first period. These results are preliminary and the dynamics in the economy (e.g. evolution of interest rates, marginal propensity to expend, etc.) shall be included for computing the TFM of the following years.

The GHG emissions comprising the whole life cycle of new equipment and materials, the energy saved, the first round of monetary distribution and the rebound effects as described in Session 3 are presented in Figure 3.

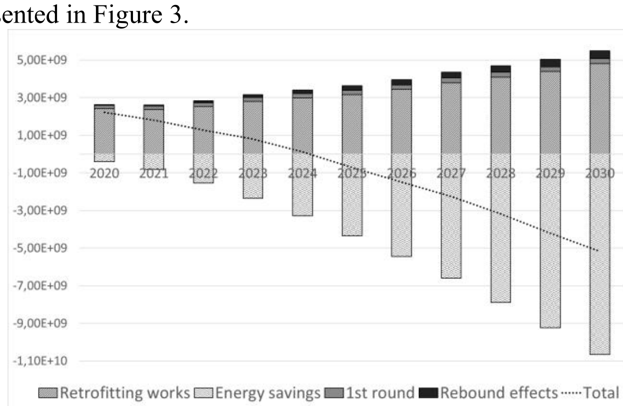

Fig. 3. GHG emissions of increasing carbon tax in France from 2020 to 2030 ($kgCO_2e$)

The results obtained from the proposed method show that, from 2024 onwards, the GHG emissions associated with the saved energy are greater than the sum of the life cycle emissions from the equipment and insulating materials used in thermal retrofitting services plus the 1st round of distribution and rebound effects (as defined in the previous section).

Some important limitations must be pointed out. Firstly, the results presented in this paper only consider the emissions from industries in France even though EXIOBASE provides a complete multi-regional input-output table. This is justified by the long computation required when considering the global data. Second, all life cycle stages of the equipment and insulation (window and walls/attic/roof insulation) take place in the same year, i.e. it is not a dynamic LCA. It means that any thermal retrofitting service is a replacement and the end-of-life of the newly installed equipment is outside of the time horizon studied (lifespan of equipment and insulation is longer than 10 years). Third, no change in behaviour is included to obtain the first round of distribution or the rebound effects on money saved from energy bills. The fourth limitation consists in not taking into account any change in price during the years, which is a very strong assumption and should be included in dynamic economic assessments.

5 Conclusions and Perspectives

This paper presents the first results of applying a novel method that assesses income distribution and the associated life cycle GHG emissions in a case study. These preliminary results show that an increase in carbon tax in France encourages thermal retrofitting works. Considering the limitations of our study, the preliminary results show that a thermal retrofitting program reduces the net GHG emissions in the short run.

However, in these preliminary results, monetary distribution resulting from carbon tax concentrates income to richer people, which can be a blocking point for implementing the policy. It is recommended to go further and understand the marginal utility associated with an increase in carbon tax in France.

The method proposed here can be used to assess a variety of economic, social and environmental indicators. Complementary works on this method in the building context are developed by the authors in a Ph.D. project entitled “Development of a consequential LCA methodology applied to the construction sector” that will be defended in the summer of 2022.

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