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A QUANTITATIVE ASSESSMENT OF GOVERNMENT'S INTERVENTION POLICIES TO SUPPORT CIRCULAR ECONOMY IN CONSTRUCTION

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ABSTRACT:
Circular Economy (CE) is expected to create net positive cash flows for construction stakeholders, while reducing embodied and operational carbon, through refurbishment, reuse, and recycling of building assemblies and materials. Besides owners, builders, and contractors, the suppliers of reclaimed materials, who in turn depend on the salvage from deconstructed facilities, are among the stakeholders to whom a CE Business Model (CEBM) is expected to create net positive cashflows. Given the considerably higher costs of deconstruction, compared to conventional demolition, an extra source of cash-in would be necessary to keep a CE business model, net positive. In practice, however, several parameters, including the low price of virgin construction materials (compared to reclaimed ones); comparatively low costs of landfilling; the expenses required for deviation from linear to circular supply chain; etc., challenge the financial profitability of CEBMs in the North American construction market. The role of government incentives and subsidies is overemphasized as the key feasible solution to bridge this gap. This paper investigates the impact of various government intervention levers, namely carbon price, landfill tipping fees, and long-term/low-interest loans, on creating net-positive CEBMs. We focus on Recycled Concrete Aggregate (RCA) as one of the most commonly accepted circular materials in the North American market and model the dynamics among key players, i.e., owner, concrete/RCA supplier, and deconstruction company. We first deviate from the linear to a circular process, aiming to maintain the profit margins for the key players, and then investigate the role of government by analyzing the sensitivity of RCA price to each of the three levers. The results show that while landfill tipping fees have the highest impact on reducing the RCA price to the extent of making it competitive with virgin aggregate, direct financial incentives, while necessary to enable a circular supply chain by supporting the CapEx, they do not have a significant impact on the price of concrete.

Keywords – Circular Economy in Construction, Circular Economy Business Model, Recycled Concrete Aggregate, System Dynamics, Price on Carbon, Landfill Tipping Fee

1. INTRODUCTION & CONCEPT

A circular Economy (CE) is an economic system where outputs captured from the consumption of resources in one sector are directed back towards providing the same or another function. This new method of managing resources in an industry sector is broadly recognized as a possible solution to limit the overconsumption of resources and significant carbon emissions in the construction industry. A key requisite of circular economy in construction is to replace the demolition of built facilities at their end of life, with a considerably costlier procedure, known as "deconstruction" and/or disassembly. This is necessary to generate reclaimed building materials, components, subsystems, etc. that can potentially have a salvage value to balance out the additional costs of deconstruction and generate net positive cashflows for stakeholders. In the North American construction industry, different factors such as the comparatively low price of virgin materials; low landfill prices; and the additional capital expenses (CapEx) required for creating refurbishment and recycling plants to support Circular Economy Business Models (CEBMs) have been challenging the financial profitability of CEBMs. Government intervention has been conventionally perceived as a solution to bridge this gap. Such intervention can be either in the form of penalizing linear practices (through tools such as tax on carbon landfills); incentives and subsidies (such as carbon credits) to push the industry towards adopting CE practices; or regulatory levers (to create a 'mandate' for transitioning from a linear to a circular economy). In this paper, we focus on various incentive and penalty mechanisms, as the government levers to support circular business models and investigate the feasibility, impact, and necessity of such mechanisms in realizing profitable CEBMs in the construction Canadian industry.

To this end, we focus on Recycled Concrete Aggregate (RCA) as one of the most commonly accepted circular materials in the North American construction market; and use system dynamics to create a net positive CEBM. Then, by focusing on three major government levers, i.e., tax incentives; funding and grant subsidies; and carbon pricing mechanisms, we analyze the sensitivity of the CEBM profitability toward decisions made for these mechanisms. The findings can not only be used by the companies aiming a migration towards a CE; but also, by the regulatory authorities to better prioritize their intervention to support the economic viability of sustainable practices for the Canadian construction industry.

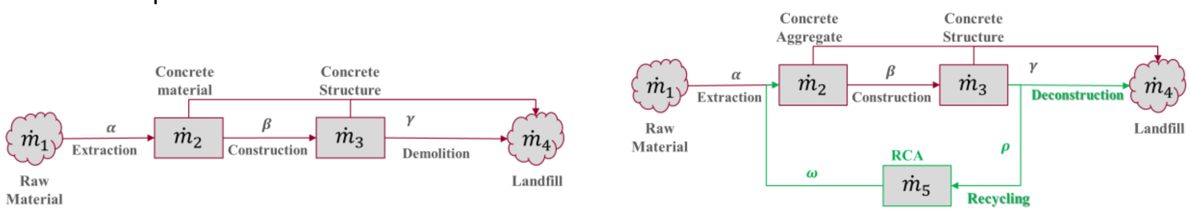
The role of government in supporting the migration from the status quo linear to a circular supply chain for construction can be perceived at various levels and in different forms. On the one hand, municipalities and provincial/state level governments, as the front-end actors are typically involved directly in the supply chain, as clients. Examples include DOTs (Department of Transportation) or some federal agencies such as the DOE (Department of Energy), who annually contract out millions of dollars of construction work. E.g., according to a 2024 report by the U.S. DOE, approximately 233.3 million metric tons of concrete are used annually for U.S. roadway construction and maintenance (Iyer *et al.*, 2024). DOTs and other state/province agencies can strongly support CEBMs by strategies such as bundling deconstruction (removal) and construction/repair services, to create joint incentives for both actors. They can also deviate from short- to long-term contracts, as several CEBMs are feasible only when studied in longer decision horizons. In this paper, we refer to this form of intervention, as 'Market-Structural Support'. On the other hand, the importance of the government's direct intervention through regulatory frameworks, financial incentives for circular practices, or penalties on carbon-intensive activities, which we refer to, as 'Financial Support', has been emphasized in past studies. The current study aims to take a closer look, through a quantitative lens, at the impact level of each of these tools, on maintaining a desirable profit margin for stakeholders involved in a CEBM.

To this end, we consider a hypothetical case example of bidding for concrete structure repair and renewal for transportation infrastructure at the scale of a municipality, with an emphasis on demolition waste management, resource consumption control, and embodied carbon saving. To promote a CE, it is assumed that (i) the municipality seeks a long-term (25-year) collaborative contract, rather than a project-based proposal. Furthermore, (ii) the request for proposals (RFP) combines the removal of existing concrete with the supply of fresh concrete, as one tender. The scope of the work includes supplying 135,000 metric tons of concrete per year, as well as the removal of about the same amount of installed concrete, for repairing existing structures of the transport infrastructure, including bridges, tunnels, and curbsides, among others. For simplicity, it is assumed to be a unit price bid, asking for a single price per ton of supplied concrete, to cover all expenses, including material, manufacturing, demolishing, transportation, and disposal. While the case example is hypothetical, all assumptions for modeling the business case are taken from an actual major concrete supplier in Ontario, Canada. In this case example, the province government is assumed to have taken two main initiatives to support CEBMs.

As elaborated earlier, the goal of this study is to quantitatively understand the impact of upper-level government incentives on the CEBM. The objectives include: (i) *investigating the possibility of a profitable CEBM* by offering the unit price, at which enough financial incentives will be created for various players of the supply chain, namely the DOT, supplier, recycling unit, and deconstruction company, to adopt a CEBM; and then (ii) *sensitivity analysis* to prioritize the impact of three government financial intervention policies; i.e., price on carbon, landfill tipping fees, and direct financial incentives, on the CEBM unit price. The method includes the use of system dynamics for a material flow analysis (MFA), firstly in a traditional linear model, and then deviating to a circular process. The MFA is then transferred to cashflows for an economic analysis to identify the optimal price of RCA. Lastly, one parameter at a time (OAT) sensitivity analysis will be performed to compare the significance of each intervention tool.

2. CONTEXTUALIZATION OF THE CEBM

Figure 1 illustrates simplified block diagrams to compare the linear and circular processes to address the problem. On the one hand, in the linear supply chain (Figure 1-a), virgin aggregates are extracted from natural resources and are mixed with Portland cement and water, to produce concrete, and add to the existing stock of concrete structures, through construction practices. At the same time, the old concrete removed from existing structures is shipped to the landfill and disposed of, together with the production and construction wastage and residuals. In the circular alternative, depicted in Figure 1 (b), on the other hand, replacing demolition with deconstruction helps to recover and extract RCA from the old concrete, and loop it back to the production line. Based on these simplified diagrams, as well as a set of assumptions explained in the following, the processes are modeled, and cashflows are formed to compare the profitability of the two alternative processes.



(a) Linear flow (b) Circular flow

Figure 1: Conceptual models of material flow for the Linear and Circular production plans

2.1 Model Assumptions

In order to develop a profitable business case under the circular economy, we use System Dynamics (SD) to model the operation, and then we relate the material flow to cashflows. Firstly, the production is modeled as a "linear" process and the cashflow diagram is created over 25 years, to identify the unit price that can provide the expected profit margin. From there, the option of adding a recycling unit is studied to extract RCA from deconstructed concrete. The model is then optimized so that both recycling and the manufacturing units remain net worth positive and have a balanced profit margin. The SD models were created in Vensim® PLE software (Ventana Systems Inc., 2025), and Net Present Value (NPV) economic analyses were conducted in Microsoft Excel. Assumptions of the model include:

- While the case is hypothetical and no specific jurisdiction is scoped; it is developed based on the Canadian market, and industry partners (including a major concrete supplier, RCA supplier, and demolition company) all active in Canadian construction were engaged to verify our assumptions.
- The operation is studied under the steady state condition.
- The decision horizon is 25 years, ending at the end of the contract term.
- Two alternative RCA process lines were studied: (i) "*partial recycling*" through a small-scale plant with an average capacity of 25,000 tons/year; and (ii) "*full recycling*" through a medium-scale unit with an average annual capacity of 150,000 tons.
- The useful lives of both RCA plants and the concrete manufacturing line are considered to be 25 years.
- The use of cement, water, and concrete additives is invariant under the use of virgin aggregates and RCA; hence, are excluded from the alternative comparison process.
- Aggregates, by virtue of their volume, make up approximately 60% to 70% of the total volume in a typical concrete mix. This translates into roughly 75% by weight for normal weight aggregates. Therefore, this coefficient (0.75) is used to convert the concrete production quantities to the quantity of virgin aggregate and vice versa. This factor is hard-coded in the "Virgin Aggregate" flow and "Concrete Manufacturer" stocks of the SD model.
- The concrete mix is assumed to follow a 4:2:1 mix of gravel, sand, and Portland cement, respectively. The water content is assumed to have a proportion of 0.5 in this formula.
- The discount rate (annual interest rate) is assumed to be 10%, inclusive of inflation (i.e., real interest rate).
- Given the size of the project, a minimum profit margin of 7% is assumed (and was confirmed by the industry partner of the study) to be attractive for the bidder company.

- The concrete company is assumed to provide demolished concrete to the RCA plant for free. This (as will be further discussed) is still considered profitable for the company, as they will save the cost of disposal at landfills.
- The RCA company must pay the landfill cost for any non-recycled concrete that they dispose of.
- The base attainable recovery rate (for extracting concrete from the existing concrete structure) through deconstruction is assumed to be 70%. We will investigate the effectiveness of higher recovery rates as well.
- The cost parameters, along with the rates related to production, recovery from deconstruction, and recycling, are summarized in Table 1.

Table 1: parameters considered in SD model

Item	**unit**	**Amount***	**Reference**
Landfill Tipping Fee	$/ton	110	(Ottawa Valley Waste Recovery Centre, 2025)
Recycling cost	$/ton	10	
Virgin Aggregate	$/ton	30	Transportation cost from (RSMeans, 2024)
Cement	$/ton	183	
Production rate	Fraction	0.9	
Rho (Recovery Rate)	Fraction	0.7	
Omega (Recycling Rate)	Fraction	0.75×0.6֍	
Unit cost of transportation - RCA unit	$/ton	2	
Unit Cost of demolition	$/ton	100	
Unit cost of Deconstruction	$/ton	120	
Carbon tax rate	\$/kgco^{2}	0.08	(Government of Canada- Environment and Climate Change Canada, 2023)

** Values of the items without a reference are taken from (or verified by) the industry partners*
֍ 0.75 is the aggregate coefficient

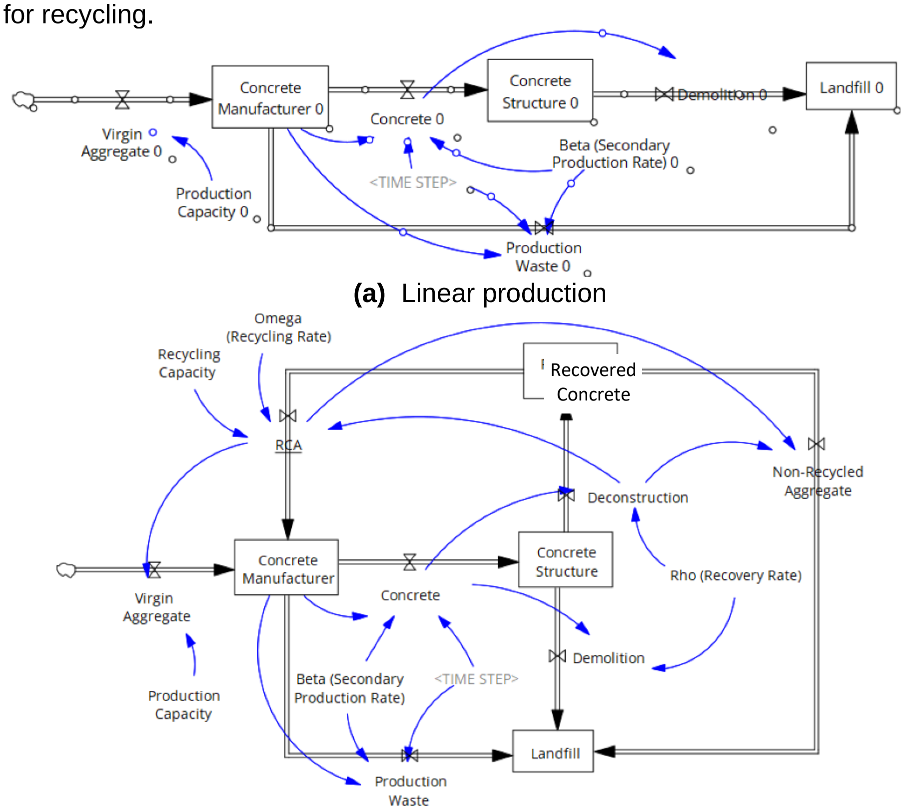
2.2 Linear Production Model

In the first step, a “take, make, use, and dispose” model is followed, aiming to identify the unit price to achieve the expected profit. The model is shown in Figure 2 (a). Since the quantity of demolished concrete is the same as the supplied concrete (less about 3% wastage), it was assumed that the same amount of material flows in and out of the concrete structure. A Production Rate of $\beta = 0.9$ sets the amount of waste from the production at 10%, and the plant’s production capacity is controlled by another parameter, i.e., Production Capacity = 150,000 tons). As mentioned earlier, since the aggregate is assumed to comprise 75% of the concrete weight, the virgin aggregate extracted from the mine is estimated at 0.75 of the production capacities. After running the model, the material flow is recorded for an NPV (Net Present Value) analysis. The cash-in and cash-outflows, covering the OpEx (Operating Expenditures), CapEx (Capital Expenditures), and revenue were calculated for each year, based on the unit costs and the amount of material flow. All CapEx calculations were based on historical data of similar plants, through the cost-capacity factor method, as will be explained in the next section. The revenue was calculated based on the amount of concrete supplied to the concrete structures, and the unit cost of the work (Uc) applied per ton of concrete supplied. After applying the actual market price for virgin aggregate (as shown in Table 1), the minimum price per ton of concrete required to achieve a 7% profit margin, was estimated at CAD \$364.61/ton.

2.3 Circular Production Model

In the second step and given the comparatively large expenses associated with the raw material and disposal of demolished concrete (22% and 36% of the OpEx, respectively, as per our calculations), the idea of creating a secondary plant for recycling demolished concrete to extract RCA can be economically feasible. To begin with, a partial recycling scenario with a small RCA plant of an annual capacity of recycling 25,000 tons aggregate per year (at the CapEx of \$350,000) was added, with a recycling rate of $\omega = 0.6$. It is assumed that the demolished concrete will be shipped and delivered to this plant at no charge to the

RCA unit, and the plant will sell back the recycled aggregate to the concrete processing unit. In practice, no major price differences are reported for virgin and recycled aggregates (as long as having the same mechanical properties). It is only mentioned in the literature that in some cases the unit weight differences between the two types of aggregate may result in better volumetric prices for the RCA than virgin aggregate. For example, recycled CA6 is 15% lighter than virgin CA6, so one may receive up to15% more volume per ton (or pay 15% less per ton) (Ozinga, 2025) (Anon, n.d.)Nevertheless, in this study, creating additional economic incentives for the concrete plant is one of the criteria; otherwise, it may be hard to justify the business plan for recycling.



(a) Linear production

(b) Circular production

Figure 2: Stock-flow Diagram of the process

Following the cost-capacity estimating technique, the cost of processing units can be related to their capacity (Class 5 or 4 based on AACEI (Prasad *et al.*, 2011)), through an operation factor:

$$\mathbf{C_B = C_A\ (\ Q_B\ /\ Q_A\ )^{\alpha}}$$

where C_A and C_B are the costs of two similar plants, with the production capacities of Q_A and Q_B respectively, and α is the exponent, or proration factor. The value of the exponent typically lies between 0.5 and 0.85, (Prasad *et al.*, 2011) of plant (Prasad *et al.*, 2011). Based on the information of two plants with capacities of 50,000 ton and 200,000 ton and capital costs of $850K and $2.5M respectively, we first calculated the value of exponent α as 0.78. From there, the capital cost of a concrete production line with an annual capacity of 150,000 ton was estimated as:

$$\text{Cost}\_{\text{Concrete plant}} = \$\ 2{,}500{,}000\ (150{,}000/200{,}000)^{0.78} = \$\ 1{,}997{,}505 \approx \$\ 2{,}000{,}000$$

Establishing an aggregates recycling business requires a capital investment between $4.40 and $8.80 per metric ton of annual capacity(U S Department of Interior and U S Geological Survey, 2000). In this study, by taking the average of these values, the CapEx for the large RCA processing unit (with an annual capacity of 150,000 tons) is estimated to be $1,000,000. Therefore, by assuming an operation factor of α= 0.6 (which cording to AACEI, is recommended for processing units with unknown operation factor), the cost of a small unit (with an annual capacity of 25,000 tons) will be calculated as:

$$\text{Cost}\_{\text{SmallRCA Plang}} = \$\ 1{,}000{,}000\ (25{,}000/150{,}000)^{0.6} \approx \$\ 350{,}000$$

The useful life of both RCA and concrete plants is assumed to be 25 years. As seen in Figure 2 (b), in the proposed circular model, concrete removal is performed through deconstruction rather than demolition, achieving a 70% recovery rate ($\rho = 0.7$), with the remaining 30% sent to landfills. Since landfill fees account for approximately 36% of operational expenses, transporting extracted concrete to the RCA unit—even at no cost—is financially beneficial. For the circular model to be competitive, RCA must be priced lower than virgin aggregate while maintaining positive net present values (NPV) for both the RCA and concrete production units. While savings from landfill fees, input aggregates, and carbon taxes help offset deconstruction costs, the limited capacity of a small-scale RCA unit (25,000 tons/year) makes partial recycling financially unviable. Achieving a 7% profit margin for both the concrete manufacturer and the RCA plant would require a concrete price of $366.64 per ton, which is higher than the linear model. Additionally, the RCA plant would need to sell at $380.70 per ton, over 12 times the cost of virgin aggregate, rendering partial recycling economically infeasible. The capacity limitation also means that 69,500 tons per year of recovered concrete would still require landfilling, increasing tipping fee burdens for the RCA plant.

The full recovery scenario with the large RCA plant, with an annual capacity of 150,000 tons and a CapEx of $1,000,000, was further evaluated. The results showed that, despite a better performance than partial recycling; investment in the large plant for full recycling remains financially unviable. The minimum concrete price for a 7% profit margin was calculated to be $346.20 per ton, and the minimum RCA price would need to be $176 per ton – still more than 5 times the cost of virgin aggregate. One effective solution to improve the profitability of the circular model can be increasing the recovery and recycling rates. Our industry partners have verified that these rates can exceed 95%, reaching up to 99%. However, even by applying a recovery and recycling rate of as high as 95% – 99%, the price of RCA required to achieve a 7% profit margin will be $66.32/ton, which is still higher than virgin aggregate. It is worth mentioning that considering the coefficient of 0.75 for the weight of aggregates in concrete, even with a 100% recovery rate from deconstruction and a 100% recycling rate, the maximum possible amount of extractable RCA will be 0.75(135,000) = 101,250 tons. Hence, under these assumptions, the RCA available for use will not exceed 101,250 tons per year. However, to achieve full production capacity and eliminate the need for virgin aggregates, an additional inflow of old concrete from external sources shall be incorporated into the model.

3. GOVERNMENT INTERVENTION POLICIES

As seen, under the current financial infrastructure of the construction industry, it is hard, if ever possible, to create profitable CEBMs that can compete with the traditional linear model of take-make-dispose. To balance the case, direct financial help from the government, in the form of incentives or punishments, appears to be necessary. in this study, we focus on three main mechanisms typically available to governments to support the CE; i.e., carbon tax; landfill prices; and financial incentives. Assuming a 95% recovery and recycling rate, along with the associated costs and benefits, achieving a 7% profit margin for both the concrete manufacturer and the RCA plant would require a concrete price of $298.84 per ton, approximately 20% lower than the price of concrete made from virgin materials. This cost reduction primarily stems from savings in landfill costs and carbon tax. Furthermore, for the RCA plant to maintain a 7% profit margin, the minimum price of RCA would need to be $66.32 per ton, which is more than twice the cost of virgin aggregates. The lower concrete price required to achieve a linear 7% profit margin makes the investment in recycled aggregates economically justifiable. However, paying twice the cost of virgin aggregates for RCA, especially when considering the challenges associated with handling and processing recycled materials, seems neither reasonable nor practical.

This analysis demonstrates that applying RCA in concrete production presents a financial paradox. On the one hand, from the perspective of the RCA plant, the significantly higher cost of RCA compared to virgin aggregate raises concerns about its economic feasibility. On the other hand, from the perspective of the concrete manufacturer, even when paying twice the price of virgin aggregate for RCA, savings from the carbon tax reduction and reduced landfill costs can offset the higher material cost. This paradox underscores the need for this study to examine the impact of different policies on the economic viability of RCA adoption. Given that the higher cost of RCA challenges its competitiveness, concrete manufacturers can still benefit from savings through carbon tax and landfill cost reductions. Hence, the intervention policies could play a crucial role in balancing these economic gaps. In the rest of this section, we provide a brief overview of the Canadian policies regarding the three interventions focused on by this paper. Then in the next section, results of a sensitivity analysis will be provided to shed some light on the effectiveness of each, in supporting CEBMs.

3.1 Price on Carbon

Canada's carbon pricing framework plays a crucial role in influencing emissions-intensive industries, including concrete aggregate mining, through a combination of federal and provincial mechanisms. The Greenhouse Gas Pollution Pricing Act established a national carbon price, which started at $10 per tonne of CO_2 equivalent in 2018 and is set to increase to $170 per tonne by 2030 (Benjamin *et al.*, 2022). This pricing structure applies to fossil fuels used across industries, including mining and construction. For large industrial emitters such as mining facilities, the Output-Based Pricing System (OBPS) provides an alternative to direct carbon taxation by setting sector-specific performance standards. Facilities that exceed their allocated emissions limits must pay a charge or submit credits, while those below the threshold can earn tradable credits, effectively incentivizing emissions reductions while maintaining industry competitiveness (Withey *et al.*, 2022). Canada's carbon pricing approach is dynamic and subject to periodic review. The annual carbon price increases, along with ongoing regulatory adjustments, ensure the system remains aligned with evolving climate commitments. Recent adjustments to the OBPS Regulations have sought to enhance industry compliance while mitigating competitiveness risks in sectors such as aggregate mining, construction, and heavy industry (Benjamin *et al.*, 2022).

At a provincial level, carbon pricing strategies vary from one province to another. For example, British Columbia has maintained a carbon tax since 2008, which applies broadly to industries including mining and follows the federal benchmark, progressively increasing to $170 per tonne by 2030. Other provinces, such as Ontario and Québec, have adopted cap-and-trade systems that set industry-specific emission limits and trading mechanisms to mitigate financial impacts on carbon-intensive sectors (Mascher, 2018). By integrating performance-based standards and credit-trading mechanisms, the OBPS structure balances economic feasibility with emission reduction goals, ensuring that mining and construction industries remain competitive while progressively reducing carbon footprints (Withey *et al.*, 2022).

Table 2: An overview of some landfill policies across Canada (as of January 2025)

Jurisdiction	Costs and regulations
British Columbia, Vancouver	Garbage, up to 1 ton: $175/tonne • Minimum and maximum fees applicable • Transaction fee: $5/load (included in minimum and maximum fees) 1 ~ 7.99 ton • $153/ton Maximum fee: $1,021 (6640 kg and above) • Transaction fee: $5/load (included in maximum fee) more than 8 ton • $127/ton • Transaction fee: $5/load (included in maximum fee)
Kelowna	The Glenmore Landfill in Kelowna charges $50 per tonne for clean concrete (uncontaminated material under 2 feet, such as sidewalks and tiles). Dirty concrete with minor contaminants like soil or rebar costs $70 per tonne, while heavily contaminated materials are classified as garbage and charged at higher rates.
Alberta, Calgary	In 2025, Calgary's residential landfill rates include a $25 flat fee for loads under 250 kg, while heavier loads (250 kg and over) are charged $113 per tonne. Specific materials, such as yard waste, have a reduced rate of $50 per tonne.
Ontario, Sudbury	The standard tipping fee for garbage is $106 per tonne. Loads weighing 100 kg or less are subject to a flat rate of $3.50. Additionally, a gate fee of $5 applies to all entries, alongside the applicable tipping fees
Brantford	The Mohawk Street Landfill charges $25 per tonne for non-reinforced concrete, asphalt, and brick rubble. A minimum load fee of $10 applies to all loads weighing 150 kg or less.
Ottawa Valley Waste Recovery	For sorted construction and demolition waste, including concrete, the fee is $110 per tonne, with a minimum fee of $20 for loads under 175 kg.
Province of Québec	As of January 1, 2025, the Quebec government has set the charge for the disposal of residual materials at $32.00 per metric ton. This fee is subject to an annual increase of $2.00 per metric ton, aligning with the government's initiative to encourage waste diversion from landfills through recycling and recovery efforts

3.2 Tipping Fees

Landfill tipping fees for concrete waste in Canada vary significantly across municipalities, influenced by local policies, disposal capacities, and sustainability initiatives. Research indicates that concrete waste comprises approximately 10-16% of construction, renovation, and demolition waste streams in Canada. The diverted rate for concrete waste is estimated at 72.4%, primarily through recycling into aggregate for road base or new concrete production. However, the cost of processing recycled aggregate is often comparable to or higher than virgin aggregate due to contamination removal, processing, and storage costs, making disposal in landfills a more attractive option for some companies (Earle *et al.*, 2014). Across different provinces, landfill fees for construction and demolition waste are structured to encourage recycling. For instance, Québec levies an additional $22 per tonne on landfill tipping fees to fund waste diversion programs, while Manitoba imposes a $10 per tonne surcharge, with 80% allocated to municipal recycling initiatives. Despite these policies, disposal remains an attractive alternative in some regions where landfill costs do not fully reflect the long-term environmental and social costs (Canada's Ecofiscal Commission, 2018).

A major barrier to concrete recycling in Canada is the perceived lower quality of recycled aggregate. Although it has been incorporated into Canadian construction standards such as CSA Standard A23.1-00, which acknowledges concrete as a fully reusable material, industry concerns remain regarding issues, such as durability and contamination. Additionally, transportation costs significantly impact the feasibility of recycling, as landfills are typically located closer to construction sites than specialized recycling facilities (Earle *et al.*, 2014). These findings underscore the need for stronger policy measures, such as higher landfill tipping fees for concrete waste or subsidies for recycling infrastructure, to enhance the economic viability of recycled concrete while reducing the reliance on virgin aggregate sources. Table 2 shows some of the landfill costs across Canada.

Table 3: Some key targeted financing options across Canada

(a) *Federal Government*	
Canada Small Business Financing Program (CSBFP)	This program offers loans up to $1 million to help small businesses purchase or improve land, buildings, and equipment. Interest rates are capped to ensure affordability, with a maximum of prime +3% for term loans and prime +5% for lines of credit.
Canada Growth Fund (CGF)	Established with a $15 billion investment, the CGF initiative designed to attract private capital for clean economy projects. By leveraging financial tools such as contracts for difference, it mitigates investment risks and incentivizes low-carbon technologies, businesses, and supply chains.
Clean Economy Investment Tax Credits (ITCs)	Federal government provides refundable tax credits to encourage capital investment in clean energy, hydrogen, and carbon capture technologies. These incentives aim to accelerate Canada's transition to a net-zero emissions economy by 2050.
(b) *Provincial Governments*	
Ontario	The Ontario's Clean Technology Loan Program supports clean energy start-ups and sustainable businesses through government-backed loans, venture capital funds, and private lenders, fostering the province's green economy.
Québec	Québec's Compétivert Program provides targeted financial assistance to businesses integrating clean technologies and eco-friendly practices, reinforcing the province's commitment to sustainability and circular economy initiatives

3.3 Loan Incentives

Canada has implemented a variety of federal and provincial financial programs to support businesses that contribute to a clean economy, offering incentives such as low-interest loans, investment tax credits, and targeted funding initiatives. At the federal level, the Canada Small Business Financing Program (CSBFP) provides loans of up to $1 million to assist small businesses in financing sustainable projects, including clean technology adoption (Rana *et al.*, 2021). Additionally, the Canada Growth Fund (CGF), with an allocation of $15 billion, leverages financial tools such as carbon contracts for difference and concessional capital to attract private investment in low-carbon projects. The Clean Economy Investment Tax Credit further incentivizes businesses by reducing costs associated with renewable energy and carbon capture investments (Martin and Riordan, 2020). At the provincial level, Ontario offers tailored loan programs to support clean technology and sustainable start-ups, while Québec's Compétivert Program provides financial assistance to businesses integrating sustainable practices into their operations (Rana *et al.*, 2021). Other financial instruments, such as green bonds and sustainability-linked loans, have also gained traction in Canada, enabling businesses to access lower-cost capital for environmentally friendly initiatives (Martin and Riordan, 2020). These targeted financial measures help overcome capital constraints, foster job creation in green industries, and accelerate Canada's transition towards a more sustainable economy. Table 3 shows some of the available targeted financing options across Canada.

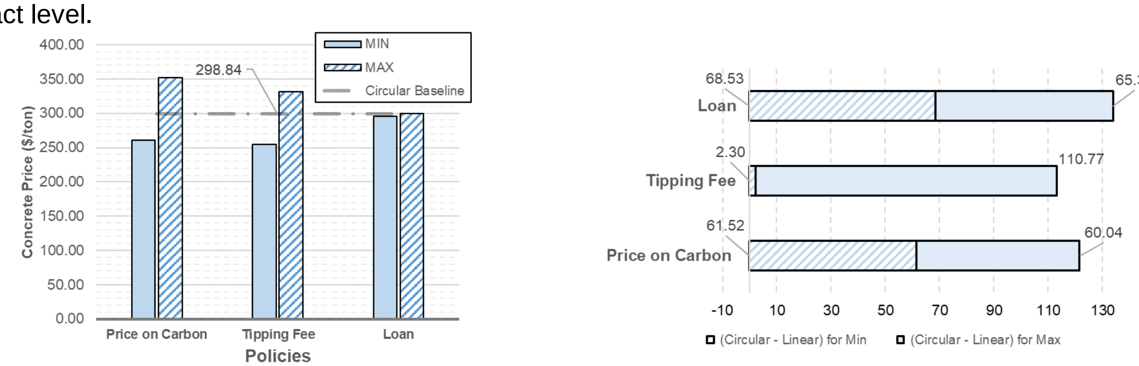
4. SENSITIVITY OF CEBM TO GOVERNMENT INTERVENTION POLICIES

To study the effectiveness of these financial support policies in addressing the economic challenges and bridging the profitability gap of the CEBM, a One at a Time (OAT) sensitivity analysis was performed on carbon pricing, raising tipping fees, and direct loans. Table 4 shows the input values to the sensitivity analysis. We deviated tipping fees (for landfills) and price on carbon, between the minimum and maximum records in various Canadian jurisdictions. Also, to consider the impact of loans (supporting the CapEx), we applied the price of capital for a typical commercial loan (CSBFP) and one of the less expensive incentives for sustainable business models, i.e., Green Municipal Fund, as the worst- and best-case scenarios, respectively.

Table 4: Variables of the sensitivity analysis (all prices and fees in CAD/ton)

	Landfilling Fee	Price on Carbon	Direct Loan
Baseline	110	80	–
Min	20	0	Typical commercial loan (CSBFP)
Max	175	170	Green Municipal Fund

Figure 3 illustrates the results of sensitivity analysis for concrete unit price (as the most important contributing factor to the competitiveness of the CEBM) and compares them against the linear model. As seen in Figure 3 (a), the concrete price is sensitive to all three studied policies: with direct loans being the least impactful parameter. To provide a clearer view, we calculated the concrete price in a linear model (using virgin aggregates) in each of the baseline; min (worst case); and max (best case) scenarios and from there, we evaluated the difference between the concrete price in circular and linear models (shown on Figure 3-b). As seen, the circular model always results in lower unit prices for concrete (subtracting unit prices of linear from circular model universally results in a positive number). The prices are shown to be sensitive to government incentives, with tipping fees at the maximum and direct loans at the minimum impact level.



(a) Recycled concrete price

(b) Difference in concrete price *(Circular case – Linear Case)*

Figure 3: Sensitivity analysis of the concrete unit price to three government incentives

4.1 Discussion

The results indicate that a CEBM could be achieved in our problem, even without extreme carbon tax or tipping fees. Landfilling costs for non-recycled aggregate are the most influential factor in the economic feasibility of RCA production. Given the high recovery and recycling rate of 95%, most waste materials are diverted from disposal. However, for the remaining RCA waste that has no viable alternative but landfilling, government subsidies, policies, and incentives aimed at reducing landfill costs could further enhance RCA's competitiveness. Lowering landfill costs for unrecoverable RCA waste would help mitigate financial burdens and improve the overall sustainability of the recycling process. Given the significant impact of landfill costs, adjusting other factors, such as carbon tax, would have a minimal influence on the economic feasibility of RCA production. Under the baseline configuration for which landfill cost is $110 per ton, changes in carbon tax do not substantially affect the required RCA price (as seen in Table 5 and discussed in the following).

Even if the carbon tax were completely eliminated, the minimum required price of RCA would still remain $64.98 per ton. This highlights that landfilling costs are the dominant financial factor, and without target policies to reduce these costs, other economic adjustments would have limited effectiveness in improving RCA's competitiveness.

Table 5: Price of RCA and concrete (in CAD/ton) for various scenarios (ρ = ω = 0.95)

	RCA Price		**Concrete Price**	
	Min	***Max***	***Min***	***Max***
Tipping Fee	*27.27*	*94.52*	*254.80*	*331.50*
Price on Carbon	*64.98*	*67.82*	*260.63*	*352.35*
Direct Loan	*62.53*	*66.84*	*296.08*	*299.22*

In the end, let us further focus on the price of RCA in CEBM under various scenarios. As seen in Table 5, the RCA price to maintain the expected 7% profit margin is in most scenarios considerably (between two to three times) higher than virgin aggregates (around $30/ton). The only case resulting in a lower RCA price is when the tipping fees are reduced to their minimum amount nationwide. This is because higher landfilling costs will negatively affect the recycling unit when disposing of the wastage after extracting RCA. While this is a critical point and must be further investigated in future studies; one should bear in mind that in the proposed CEBM, the RCA price is an internal agreement between cooperative actors of the supply chain, i.e., the recycling unit, concrete plant and demolition entity. Hence, this may not be considered a negative parameter for the competitiveness of the business model. Nevertheless, in practice, forcing the concrete plant to purchase RCA at almost twice (and more, based on Table 5) the price of the free market is neither feasible nor logical. Future studies must focus on mechanisms to overcome this barrier and make the CEBM practical and feasible.

5. CONCLUDING REMARKS

This study examined the financial challenges and policy-driven opportunities in transitioning to Circular Economy Business Models (CEBMs) in the construction industry. The findings demonstrated that, while under prevailing market conditions, CEBMs may not be cost-competitive with a linear supply chain; non-financial support mechanisms, such as bundling demolition with construction in long-term cooperative contracts can result in competitive circular alternatives. While such structural adjustments significantly improved feasibility, financial incentives remained necessary to ensure competitiveness and long-term adoption. Crucially, our findings underscored that these incentives must be designed in a highly targeted and case-specific manner, as broad financial support without strategic alignment with market conditions would yield limited impact. The study assessed both financial and structural interventions in enabling a profitable CEBM, with a focus on RCA as a circular material. The proposed CEBM could offer concrete at a competitive price compared to virgin concrete, despite the additional costs associated with deconstruction and material recovery. However, the competitiveness of RCA remained a challenge, as its price (to balance the supply chain) was significantly higher than virgin aggregate. Among the financial levers analyzed – carbon pricing, landfill tipping fees, and direct incentives – landfill tipping fees had the strongest influence on reducing RCA costs to competitive levels. While direct financial incentives played a role in reducing capital expenditures, their effect on the final cost of RCA was limited. Similarly, carbon pricing, despite its broader environmental impact, did not substantially shift economic feasibility in favor of RCA.

The results further revealed an economic paradox: while RCA suppliers required significantly higher prices to remain profitable, concrete manufacturers still benefited from RCA adoption due to savings on landfill fees and carbon taxes. This underscored the need for a balanced policy approach that aligned incentives across stakeholders. Market-structural interventions, such as bundling deconstruction and construction contracts and extending contract durations, were identified as potential complements to financial measures in improving CEBM feasibility. Ultimately, while circular models offered a viable path for reducing construction waste and embodied carbon, their widespread adoption depended on strategic government policies. Future research should explore optimizing deconstruction and recovery rates/capacities, integrating emerging recycling technologies, and assessing long-term policy impacts on CEBM adoption. Without targeted interventions, linear models would likely continue to dominate, limiting progress toward a sustainable, resource-efficient construction sector.