The Kyoto Protocol and Sustainable Cities
Potential Use of Clean-Development Mechanism in Structuring Cities for Carbon-Efficient Transportation

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This paper assesses the possibility for changing urban development patterns to reduce transportation greenhouse gas (GHG) emissions. The analysis was carried out as part of a larger project exploring the possibility of using the clean development mechanism (CDM) to reduce transportation GHG emissions in Santiago, Chile. The paper provides an overview of the analytical approach, which includes an integrated travel demand model with sensitivity to mesolevel land use variations, a method to generate optimal land use scenarios that relate to emission reductions, and a process to estimate the level of subsidies needed to produce those land use scenarios. Limitations to the approach and suggestions for future research are discussed. The paper concludes with an assessment of the results in the face of the fairly strict requirements for project development and implementation implied by the CDM.

Interest in modifying urban development patterns to influence transportation energy consumption dates back to at least the first global oil crisis of the 1970s (1). Today, energy security risks continue while the risk of global climate change adds further pressures to reduce transportation energy consumption. While the climate change mitigation burden clearly falls to the world’s industrialized nations, which account for the overwhelming share of anthropogenic greenhouse gas (GHG) emissions, the rapidly industrializing countries constitute a large and growing share of global emissions [almost 50%, including the countries of Eastern Europe and the former Soviet Union (2)].

In February 2005, the Kyoto Protocol to the United Nations Framework Convention on Climate Change entered into force for signatory countries. The protocol contains several market-based mechanisms, including the clean development mechanism (CDM), which allows industrialized-country governments or private entities to invest in developing-country emission reductions. The industrialized-country project proponent earns emission reductions—known as certified emission reduction units (CERs)—toward domestic targets, while the developing country advances its development goals. Indeed, the Kyoto Protocol specifies that CDM projects must help host countries achieve “sustainable development,” although it does not specify a definition of that concept. The market value of a CER varies in relation to the prevailing carbon price and can be influenced by factors such as country and project risk. In Europe, the price per tonne of carbon recently exceeded $20.

The majority of CDM projects to date have focused on renewable energy, energy efficiency, and landfill gas projects. As of early 2005, of roughly 1,200 CDM projects under development, just over 200 had reached the project design document (PDD) stage. The PDD represents the first step in the CDM process, formally defining the project, estimating emissions reductions, and describing the monitoring plan. Of those 200 projects, just four were transportation projects (3).

Transportation remains an important and challenging GHG emissions sector to address: it accounts for approximately 30% of anthropogenic GHG emissions, is growing rapidly, and has highly dispersed emissions sources (e.g., individual vehicles) with few readily available, less-carbon-intensive energy substitutes. More broadly, transportation clearly plays an important role in sustainable development. In the case of passenger transportation, for example, transportation provides access to jobs, education, social opportunities, and the like—all fundamental to human development. At the same time, however, transportation often imposes impacts, in the form of air pollution, accident risk, and the like that pose serious threats to sustainability.

While details of the numerous CDM project requirements extend beyond the scope of this paper and are provided elsewhere (3), three critical CDM-specific aspects bear mention here, due to their importance to this analysis:

1. The project baseline, which must represent a defensible vision of future emissions relative to business as usual;
2. Additionality, which refers to the requirement that emissions reductions be additional to what would have taken place in absence of the project; and
3. Monitoring and verification, which refers to the need for external monitoring and verification of emission reductions.

This paper presents results of an effort to assess the potential of the CDM to reduce GHG emissions from the transportation sector in Santiago, Chile. The paper analyzes a decidedly behaviorally based intervention: the possibilities for modifying urban development patterns to reduce GHGs via changes in passenger travel demand. Location Efficiency and Transit-Oriented Development (LABTUS) (4) presents a more detailed exposition of the theoretical and technical underpinnings of the analysis.
TRANSPORTATION AND CDM: WHY LAND USE?

This CDM analysis rests on the basic premise that influencing land use patterns produces changes in individual travel behavior, thereby influencing transportation GHG emissions. In contrast to typical CDM projects, this initiative differs in a fundamental way by aiming to change individual behavior. In this sense, the approach faces methodological and implementation hurdles relative to technology-oriented CDM projects, for which estimated GHG emission impacts are (relatively) straightforward to calculate and verify. In the land use case, changes in land use are expected to influence the distances people travel, as well as the relative attractiveness and the occupancy of different modes. Because these effects are behavioral and, in some cases, depend on second-order influences, estimation of their impacts requires modeling techniques that introduce uncertainties.

Despite the challenges, behavioral change may have to play an important role. For example, the recent assessment by Heywood et al. (5) of transportation energy consumption under plausible vehicle technological improvements in the U.S. market leads to the “sobering overall conclusion” that technology improvements and reductions in travel growth are critical. For developing countries, rapid growth in vehicle ownership and use is expected, as are growth rates in per-capita light-duty vehicle kilometers traveled (VKT) on the order of four to 30 times as great as Organisation for Economic Co-operation and Development countries (6). These rapid growth rates signify an important amount of catching up: in 2050, per-capita VKT in North America will still be three as great as in Latin America (6). While it is not reasonable to expect the developing countries to simply curtail transportation demand, absent a technological silver bullet, some reduction of VKT growth may well be necessary in both the industrialized and the developing world.

This reality leads to an examination of the role of urban structure in reducing VKT growth. Beyond promising the potential global benefits, efforts to change urban development patterns offer other potentially important long-term co-benefits, such as open space preservation, improved air quality and public health, reduced needs for transportation infrastructure investments, and the like. In the face of continuing urbanization prospects, interventions in urban structure could bring quality-of-life improvements for nearly 2 billion additional developing-country urban dwellers by 2030 (7).

Analytical Precedents

Land use interventions have long been of interest as a way to influence travel demand, with multiple reviews of relevant analyses carried out over the years (e.g., 1, 8, 9). The multiple studies reveal somewhat wide-ranging estimates of effects, which can be partly attributed to differences in approach (e.g., spatial scale of analysis, analytic technique), the types of built environment measures used, and the effects (e.g., mode choice, trip rate) analyzed. Recent years have seen a push to base the relevant research within more rigorous behavioral theories (e.g., 10) that closely align with traditional transportation systems analysis (e.g., 11). Most recently, analysts have made the explicit turn to random utility theory–based discrete-choice models (e.g., 12).

In the late 1960s, several precedents emerged in the form of simulations, looking specifically at the potential for alternative city structure to influence transportation patterns, primarily in the form of experimental analyses of hypothetical cities (e.g., 13). Continuing advances in computational power and the 1970s energy crises spurred many analyses of how altering spatial structure could reduce transportation energy consumption (e.g., 14). These efforts, in most cases, used techniques similar to the traditional travel forecasting models (or Lowry-based integrated models), but with the goal of identifying generic, energy efficient, urban forms. The typical result was the heavily CBD-focused city, or the polynucleated form (e.g., 15). Relevant energy use–focused simulations (e.g., 16) as well as empirical analyses (e.g., 17) continued into the 1980s.

In more recent years, forecasting models have been applied to real cities to gauge the potential for land use strategies to influence travel demand. In the United States, the pioneering effort was the LUTRAQ project, in the Portland, Oregon, metropolitan area. LUTRAQ employed integrated land use and travel demand models to assess other urban forms as possible alternatives to developing a new highway (18). Other studies have followed somewhat in the LUTRAQ tradition in the United States (e.g., 19, 20).

Policy Implications

Even if it is possible to confidently predict the influence of land use on travel behaviors, the ability to influence relevant outcomes hinges critically on institutional and policy settings. The U.S. experience with local air pollution offers an interesting precedent, in particular the need to ensure state conformity with air quality regulations. U.S. Environmental Protection Agency (21) guidelines suggest that land use can be included as a strategy in the control of transportation air quality if the effects are quantifiable, surplus (i.e., additional), enforceable, permanent, and adequately supported. Such requirements suggest a direct precedent for the relatively stringent project-based requirements of the CDM. At least one project, the proposed redevelopment of a 138-ac former steel mill site in central Atlanta, Georgia, offers a promising precedent: modeling techniques were used to predict both meso- and microlevel influences (estimated to achieve reductions on the order of 15% to 67% and 4% to 6%, respectively) (20); and the project developer agreed to several monitoring, verification, and contingency measures (22). Still in early development stages, the project’s effects on transportation air quality cannot yet be evaluated.

EMPIRICAL CASE: SANTIAGO, CHILE

Background

In Chile, roughly 85% of the nation’s population lives in urban areas. Still, even moderate future urban growth has important implications. For example, a 1.25% annual population growth rate in the Santiago metropolitan area would imply an additional one million new households locating in the city over the next 30 years. Given current urban growth trends—from 1985 to 1995, the urban area expanded 70% more rapidly than population growth (23)—the distribution of future population growth and related land uses will greatly influence underlying urban travel behavior for generations of Santiaguinos. Today, the contiguous urban area of Greater Santiago’s 38 municipalities covers approximately 80,000 to 90,000 ha (800 to 900 km²). The gross population density is roughly 65 persons per hectare, while the net (of, e.g., roadways, open space) population density is on the order of 85 persons per hectare.
Multiple, often interrelated factors have contributed to Santiago’s urban growth patterns in recent years (23), including income growth, motorization, space demands, and subsequent suburbanization pressures. These factors are mutually reinforced by real estate company growth and land speculation. Development of transportation infrastructure plays a clear role, expanding access to the urban edge. Another expansionary pressure comes from continuous demand for lower-income housing, typically located on the urban fringe. Public policy initiatives have produced somewhat countervailing effects. For example, a program of urban renovation subsidies has created incentives for the development of some 22,000 new apartments in the central city since 1992. At the same time, a 1997 modification to the metropolitan land use regulatory plan opened up almost 20,000 ha for urban development in the rapidly suburbanizing north. Recently, the World Bank–supported Sustainable Transport and Air Quality Project included a location efficiency component, a concept still in initial stages of development.

Data

The primary data underlying the analysis come from the 2001 origin–destination (O-D) survey and the land use census, carried out and compiled under the auspices of national transportation planning authorities (SECTRA) described elsewhere (e.g., 24). Estimation of the model required approximated transportation costs for all O-D pairs for all mode types; these were derived from a previous (2001) transportation model run (that used SECTRA’s travel forecasting model, ESTRAUS). Vehicle occupancy factors, vehicle types, distances traveled, and average speeds were derived from ESTRAUS, the household O-D survey, and related surveys (e.g., traffic counts) carried out complementarily to the O-D survey. Emissions factors come from a locally developed vehicle emissions model (MODEM).

Methodology

The preliminary empirical analysis of the 2001 O-D survey suggested three basic strategies for intervention: (a) increase nonmotorized transportation (NMT) for nonwork trips by locating shopping and services closer to residential areas (Figure 1 shows the NMT dominance for trips under 1.2 km); (b) increase NMT for school trips by allocating schools closer to residential areas; and (c) increase public transportation usage for medium- to long-distance trips.

Transportation Demand and Emissions Model

The transportation demand model consists of a set of discrete choice models (multinomial logit models) of trip generation, distribution, and mode choice. The model was specified for and estimated on morning peak period workday travel because information on the level of service was available only for that period. Figure 2 presents the basic framework for the transport demand model, with trip generation (production and attraction) at the upper (root) level, trip distribution conditional on trip generation, and mode choice conditional on trip distribution. The inclusive values from the lower-level nest serve as indexes of relative utility in the higher-level nests. In this framework, certain parameters (represented by θ) are users’ fixed-taste parameters, while α and β vary to represent different land use conditions. The variables are defined as follows.

\[ T_{nipm} = \text{number of trips in transport mode } m, \text{ with trip purpose } p, \text{ generated at zone } i, \text{ with destination in zone } j, \text{ made by a trip-maker from household type } n; \]

\[ c_{nipm} = \text{calibrated trip cost parameter from zone } i \text{ to zone } j, \text{ for trip purpose } p, \text{ by mode } m, \text{ made by a trip-maker from household type } n; \]

\[ \theta_{np} = \text{Lagrange multiplier, derived from an entropy maximizing-based travel demand model, for the constraint matching observed to modeled total trip costs, by persons in household type } n; \]

\[ \beta_{np} = \text{Lagrange multiplier, derived from an entropy maximizing-based travel demand model, for the constraint matching observed trips and modeled trips, with purpose } p, \text{ at zone } j, \text{ by persons in household type } n; \]

where

\[ T_{nipm} \]

- The number of trips in transport mode \( m \) with trip purpose \( p \), generated at zone \( i \), with destination in zone \( j \), made by a trip-maker from household type \( n \);

\[ c_{nipm} \]

- The calibrated trip cost parameter from zone \( i \) to zone \( j \), for trip purpose \( p \), by mode \( m \), made by a trip-maker from household type \( n \);

\[ \theta_{np} \]

- The Lagrange multiplier, derived from an entropy maximizing-based travel demand model, for the constraint matching observed to modeled total trip costs, by persons in household type \( n \); for trip purpose \( p \);

\[ \beta_{np} \]

- The Lagrange multiplier, derived from an entropy maximizing-based travel demand model, for the constraint matching observed trips and modeled trips, with purpose \( p \), attracted to destination zone \( j \), by persons in household type \( n \).

**Figure 1** Mode share by trip distance (first 5 km).
The model does not consider route assignment due to limitations in available resources and time. But the modeling framework allows for expansion to include route assignment as well as to analyze relevant transportation management measures, such as parking pricing and availability, changes in levels of service, and the like. The lack of route assignment in the current application implies that the levels of service of the transportation modes are invariant when land uses change; the only exception to this is the case of walking, for which an empirically derived trip distance effect was included (walking accounts for 37% of all weekday trips and 23% of morning peak trips). This simplification also implies that average speeds—derived from observed data and independent of route, zone, or time of day—were used to calculate GHG emissions.

Despite these simplifications, the model performed fairly well. Modeled emissions exceeded actual (observed) by 21%, due primarily to overestimates of private transportation emissions, which accounted for nearly 80% of total emissions (buses accounted for 15%). The model had a tendency to overestimate the number of longer distance trips (Figure 3).

**Optimization and Land Development Subsidy Models**

The travel demand model simulates system equilibrium, building from the relationships observed in the travel survey and the land use census to predict how future travel patterns will evolve under different land use scenarios. A second-stage model uses an optimization procedure, with the goal of minimizing emissions [details on the specification and procedure can be found elsewhere (4)]. This process relocates activities (households and firms), so that the associated expected transportation demand (aggregated across modes, purposes, and periods) minimizes the expected emission totals (when observed emission rates for 30 vehicle types are considered). The location patterns of different activities influence trip demand by affecting trip generation and trip attractions.

From the optimum location pattern, a third model calculates the subsidies required to make households and firms locate according to the optimized city. This model is based on the urban equilibrium theory used in MUSSA [the Santiago land use model, discussed elsewhere (25, 26)], simulating a process of real estate auctions with stochastically behaving bidders. The method to calculate the subsidies consists of inverting the location model on prices and replacing, in the resulting formula, the optimal allocation pattern—the inverse of the allocation model’s normal process. Thus, the estimated optimal subsidies reconcile the auction equilibrium with the optimum location pattern. The equilibrium approach makes the interactions of all agents explicit—as represented in their bid functions, including location externalities (e.g., neighborhood quality represented by the average income of residents and zonal building density) and firms’ agglomeration economies (including reduced production costs from firm concentration and increases in clients’ travel costs). These interactions take on particular relevance for computation of optimal subsidies; they are economic forces that induce differential prices across space, directly affecting the required subsidies. The modeling framework enables the consideration of a range of relevant land planning interventions, such as changes in zoning codes, density allowances, and the like. Altogether, the approach (e.g., the inverse process, the consideration of externalities, and planning regulations) involves the solving of a set of nonlinear simultaneous fixed-point equations and requires an ad hoc converging algorithm developed in the study.

Travel distances and the spatial distribution of activities are modeled in an integrated fashion, with relevant factors that influence residential and nonresidential location decisions considered. Except for route assignment, the model considers the full set of relevant choices: residential and firm location and passenger travel demand. The model produces, for given time periods, a land use–transportation equilibrium—a nontrivial accomplishment given the multidimensionality of the problem and the nonlinearity associated with the interdependency between location choices and between the location pattern and trip choices, including the effects of land rents.

\[ \alpha_{np} = \text{Lagrange multiplier, derived from an entropy maximizing-based travel demand model, for the constraint matching observed trips and modeled trips, with purpose } p, \text{ generated at destination zone } i, \text{ by persons in household type } n. \]
Application

The model considers 409 ESTRAUS zones, 13 household categories (stratified by income and auto ownership), three trip purposes (work, education, and other), and 11 modes (including combinations with subway). The model was employed (a) to establish the baseline, which assumed trend growth in travel demand as a function of household growth (estimated at 1.47% annually) and concurrent growth in residential and nonresidential land uses and (b) to estimate reductions in travel emissions that resulted from several scenarios of mesoscale changes in household, educational, and other land uses. Emission reductions derive directly from reduced VKT due to a shift from motorized to nonmotorized travel and changes in trip destination choices.

The emissions effects of several alternative land use scenarios were analyzed:

- Scenario A. The preoptimal scenario, represented city performance under an optimal land use relocation—providing something of an upper limit of potential emission reductions without regulations on future land use patterns;
- Scenario B. The education-oriented scenario, relocated educational facilities in direct proportion to residential location patterns;
- Scenario C. The nonresidential-oriented scenario, redistributed nonresidential land uses in proportion to residential location patterns; and
- Scenario D. The subcenter scenario, concentrated a high share of residential and nonresidential land uses into defined subcenters on the urban edge.

Scenario A was built through use of the optimal model, and the others were defined in accordance with the criteria described earlier. The subsidies estimated were demand-side subsidies (i.e., those required to induce changes in households’ and nonresidential land users’ locational decisions); in this sense, the subsidies worked in a way similar to the urban revitalization subsidies mentioned earlier.

The modeling assumed that the various land use scenarios could be realized within a 5-year period, possibly an unrealistic pace of change given the magnitude of the restructuring implied and the inertia of current trends (and existing land uses). In the case of slower implementation, the total present value of benefits to a project proponent would be reduced. This could be troublesome for a project with a proposed short (e.g., 7-year) time frame. Under the CDM, projects may be undertaken for a fixed period of 10 years or in three renewable periods of 7 years each (to a total of 21 years).

Each of the first five years was modeled, and the difference between the project and the baseline emissions were calculated. After the 5th year, the differential emission reductions (achieved at Year 5) were assumed to perpetuate. The ultimate impacts of the land use changes would certainly extend well beyond Year 5, as the built environment and related transportation behavior would endure for at least a generation. These extended effects were included in the results presented below.

Two important points arise about the application. First, the 409 zones from a previous version of ESTRAUS were used because, at the time, data on interzonal levels of service (for model calibration) were available only for those zones. The size of many of those zones may mask local-level influences on travel behavior. Recent analysis has shown some influences of, for example, dwelling unit density and land use mix on the choice of pedestrian and public transportation mode in Santiago, after control for interzonal levels of service; these effects vary, however, according to trip purpose, as noted elsewhere (27). Second, in this application, only the use of subsidies to achieve the four land use scenarios was examined (other mechanisms like zoning could be used to achieve the same results). The modeling framework allows the consideration of a range of planning alternatives.

Results

The analysis produces the following emissions reductions relative to the baseline: Scenario B (education), 12%; Scenario C (nonresidential), 21%; Scenario D (subcenters), 40%; and Scenario A (preoptimal), 67%. At Year 10, estimates of cumulative emission reductions ranged from 4.4 million tonnes to 21.1 million tonnes; at Year 21, the estimates ranged from 11 million tonnes to nearly 57 million tonnes (Table 1). The relatively high total reductions apparently obtainable under both Scenario A and Scenario D represented extreme upper bounds: the significant city restructuring implied in these scenarios made their implementation unlikely to impossible. The estimated
subsidies that would be required to achieve these scenarios reflect this: $5 billion over 5 years for Scenario D and $15 billion for Scenario A.

In contrast, the estimates suggested that the relatively more moderate emission reductions in Scenario B and Scenario C could be more viable. In fact, the Scenario B appeared feasible, with the required subsidies implying a cost under $10/tonne over a 7-year time frame. The subsidies restructure the city, a situation that implies permanent travel demand changes. Extension of the project lifetime tended to reduce estimated total costs per tonne (Table 1). If implemented under a single 10-year accreditation period, Scenario B would be an attractive CDM investment at current CER market values.

**Strengths and Limitations**

One must view the above results as preliminary for any CDM application, given the analytical and data limitations. In relation to the data, the major problems arose from the lack of necessary information (i.e., changes in travel costs) about impacts of future proposed transportation interventions, hampering “true” baseline estimation.

It must be recognized that any practical effort to model the complex urban system must simplify in at least some relevant dimensions, which naturally produces uncertainty in predictions. In this case, lack of data and time required that the model focus on home-based trips made during the morning peak period of a normal workweek. By means of expansion factors, this period was extrapolated to represent the entire year. While roughly consistent with current travel forecasting practices in Santiago, this extrapolation may have been a source of inaccuracy (worth removing in a more detailed study). For example, the majority of household shopping, recreation, and social trips occur during off-peak periods, on weekends, or both, and such trips may have different travel patterns from those modeled during the morning peak. The trip-based focus also made it impossible to account for potentially important influencing factors, such as trip-chaining. Furthermore, as mentioned above, potential local level effects (i.e., beyond those captured by interzonal levels of service) on, for example, mode choice, were not taken into account in this application.

The modeling did not include actual network performance (route assignment), and thereby did not account for such things as changes in vehicle speeds, which not only influence emissions but also potentially influence mode choice, trip generation, or both. In relation to the influences of land use on mode choice, the modeling approach ultimately captured only the effect of trip distance changes on walk trips (and subsequent substitution for motorized mode trips). This approach ignored potentially important effects, such as the variation in vehicle occupancy rates brought about by land use changes. A related simplification stemmed from the complexity in estimating the emissions effects from changes in demand for different modes, such as bus or taxi. In the model application, it was assumed that bus fleets and frequencies adjusted quickly to demand, thereby producing emissions reductions. Furthermore, the impacts on commercial and freight traffic were excluded. Finally, and importantly, the impacts of the scenarios on so-called cobenefits (such as travel time reduction, air pollution improvement, open space conservation, etc.) were not taken into account.

The above-mentioned limitations to the modeling must be viewed in light of the accomplishments. An attempt was made at a “complete” model of the city, one that could account for the interactions within the land market and between the land market and the transportation system. In this way, consistent choice patterns arose from actual prices and costs within the system and the calculated subsidies reflected the summary of a number of complex pecuniary and technological forces. The optimization procedure that searched for the land use pattern that generated transport demand with the lowest possible GHG emissions considered all choices (except route assignment), including: modes, trip destination, location, and building supply.

**Possible Extensions and Refinements**

If the researchers had additional time and resources, several useful extensions to this work could be undertaken, such as

- Including multimodal transportation network assignment and link-by-link performance;
- Extending the analysis to off-peak travel, weekend travel, and trip chaining;
- Incorporating commercial traffic;
- Including potential evolution in vehicle technologies;
- Assessing more thoroughly the influence of microlevel urban design on travel behavior;
- Improving the evaluation methodology to fully include all social benefits and costs (i.e., the cobenefits);
- Developing a vehicle ownership model sensitive to land use variations discussed elsewhere (27);
- Expanding the model’s spatial context, to account for current rural and semirural areas; and
- Generating a set of feasibility and policy constraints to produce more realistic land use patterns and rates of change.

**IMPLICATIONS AND LESSONS**

If effective intervention in city structure by means of an instrument such as the CDM (with its stringent requirements regarding baselines, etc.) is wanted, then it is necessary to confront challenges associated with the time and resources required to develop adequate analytical tools and collect the needed data. Furthermore, the importance of institutional capabilities (i.e., a fully responsible, empowered, and accountable agency) to implement such an initiative cannot be ignored. Nevertheless, this analysis has shown how urban policies can be analyzed with the goal of development from a do-nothing city to a more sustainable urban future.

The preliminary results showed some promise. In the case of Scenario B (education), the estimated subsidies required to achieve the changes in land uses indicated potential CDM feasibility. A major uncertainty in this case stemmed from the degree to which consumer demand (for educational opportunities) would comply with the model predictions, a situation requiring more detailed modeling on school quality choice. In the case of the Scenario C (nonresidential), the costs per tonne escalated, in the range of $91 to $150 (Table 1). However, in both these scenarios, the value of additional and possibly significant cobenefits could reduce the costs per tonne.

The results underscore a challenge: people and companies would apparently demand significant compensation (measured by subsidies) to change their location behavior to induce more GHG-efficient travel patterns. This result should not be surprising; travel behavior figures only moderately in most households’ residential location choices and, quite often, in choices about where to shop or send children to school [see, for example, Weisbrod et al. (28)]. Our modeling suggested that inducing transportation change through land use interventions required fairly strong incentives. These estimates derived from preferences as revealed through the 2001 travel survey and related information on land uses and prices. These preferences might change in time, thereby changing the value of the required subsidies; the role of changing people’s attitudes and their impacts on behavior should not be ignored (e.g., 29).

Despite certain technological improvements, gains in vehicle fuel efficiency will not likely be capable of solving, on their own, the GHG challenge in the face of continuing VKT growth (e.g., 5). Some reduction in motorized transportation demand may well remain necessary; even if a silver bullet to transportation’s emissions problems could be found, cities would still face the problem of ever-increasing amounts of land dedicated to transportation infrastructure rather than to, for example, public spaces. Rapidly growing cities face, arguably, a more acute urgency: inattention now to land use as a measure of travel demand management locks cities into systems with fewer options; a car-dependent city cannot easily break its car dependency—physically, functionally, or culturally.

**CDM AND BEYOND**

The current CDM modalities and procedures imply very detailed analytical capability to understand the multiple interactions, second-order effects, and unanticipated consequences that may arise from attempting to influence land uses for achieving measurable transportation GHG reductions. In practice, the CDM requires accurate quantification of GHG savings, imposing an extremely high bar when management of urban form for transportation CDM credits is being considered. It is known that hanging land use patterns will change travel behavior; but these effects are quite difficult to quantify and make permanent. The approach detailed here has taken a citywide perspective under the assumption that one must aim to capture the complete effects, including location externalities and agglomeration economies.

Nonetheless, a citywide modeling approach still poses challenges, including those related to modeling complexities and data and resource requirements. Larger questions, about system boundaries, also exist. For example, the case modeled here did not include areas of potential future urban expansion; the locations of all future residential and nonresidential activities were spatially constrained to the existing urban area. In this case, the project results depended critically on future authorities and their willingness and ability to enforce current regulations related to areas for urban expansion. This raises questions about the reliability of foreseeable future urban planning regulations—critical questions because the estimated subsidies are conditional on the assumed planning scenario. Broader boundary issues could also be raised. For example, promotion of certain development patterns in Santiago may induce relevant demands in other urban markets in the country, with implications for transport GHG emissions. While not unique to this type of project, the question of where to draw the boundaries needs to be recognized explicitly because it is a global contaminant that is being examined.

**Additionality**

Additionality in this case poses another challenge. No policy of such broad coverage as that envisioned in any of the modeled scenarios currently exists, although the Transport Plan for Santiago (PTUS) contains three relevant programs: one focusing on the location of educational facilities, another on new areas of commercial and services, and a third on changing trends on residential locations. It is not clear whether the existence of these announced programs thus constitutes a violation of the additionality concept (none of the relevant PTUS programs currently contains any details such mechanisms to be used, etc.). A related challenge stems from the potentially changing baseline, because land use regulations evolve and these modifications can be implemented by various levels of government, as discussed by Zegras and Gakenheimer (23).

**Institutional Responsibility**

This last point highlights the considerable implementation doubts arising from the institutional side, largely due to unclear formal policies and the multijurisdictional, multisectoral government structure covering the relevant sectors. The initiative envisioned here could most feasibly operate as a unilateral CDM initiative, with a citywide authority establishing concrete goals for achieving reductions in transportation emissions and for selling the resulting CERs. The relevant authority could determine which urban development projects contribute to achieving those goals and reward them appropriately. The authority would also ultimately bear responsibility if the emission reductions were not fulfilled.
Monitoring and Verification

For the project proponent and any interested investor, success hinges on accurate monitoring and verification (M&V) of emissions reduced. In this case, while the model provides an ex-ante estimate of the emission reductions, the proof rests in ex-post validation. No straight-forward M&V program likely exists; perhaps the most reasonable one would be annual surveys (household O-D surveys, intercept surveys, and land development surveys), designed specifically to gauge whether land uses and travel patterns are responding as expected. Land development could be monitored at least in part through examination of existing building permits and tax records (as a complement to authorities’ existing activities). Use of annual travel surveys for M&V may fit well with existing Chilean government plans to implement a continuous travel survey instrument for Santiago (24).

In theory, this survey instrument could be adapted to satisfy the CDM, an action that would require, nonetheless, nontrivial decisions on the part of CDM authorities about acceptable levels of confidence. Because the survey would ostensibly be financed by the CER seller, it might be an attractive benefit to local authorities. Indeed, enhanced local data collection could be a strong complement to the project baseline. Given the estimated emission reductions (in, e.g., Scenario B, education), the required resources for a survey instrument (perhaps $250,000 to $500,000/year for 5,000 households) could be accommodated within the estimated revenue stream; this situation implies, in the case of a 10-year project lifetime, an additional cost of less than $1/tonne.

Project Lifetime and Benefit Accumulation

Essentially, all the scenarios exhibited declining costs per emissions reduced in time. So any project proponent would possess the incentive to target the longest possible project lifetime. In the case of the three 7-year renewable project lifetimes, the project baseline must be updated at the time of project renewal. This updating offers an opportunity to check the effectiveness of the project and possibly even to qualify for more (or fewer) emissions credits than those initially estimated. Nevertheless, subsequent project assessment can observe only actual urban development with the project because the baseline is unobservable.

When considering the assessment of long-term benefits, one must recognize that this project involves durable goods that induce subsequent real estate and transportation investments. In other words, the project defines a specific future path for the city, departing from the baseline with no return. Thus, it has a far-from-negligible residual value: a significant share of the city’s infrastructure, plus social, economic, and environmental impacts. While difficult to assess (in magnitude and sign, i.e., benefit or cost), these impacts may exceed the value of the total GHG reduction. Direct application of standard cost–benefit analysis for such a project is probably inadequate.

Final Comments

Our analysis showed that, under the current CDM rules and global CER market, location efficiency may prove a viable CDM option but not without analytical and institutional complications. For institutions, in Chile (or elsewhere), no all-encompassing government with authority over all relevant land use or transportation changes exists. While this initiative requires citywide implementation, agency accountability remains unclear. Nonetheless, the ongoing urbanization process and the long-term patterns of travel behavior embedded in the resulting development patterns suggest the need for ways of combining the local and the global. To adhere to its dual goals of reducing GHG emissions and promoting sustainable development, a CDM focus on defining more sustainable city futures is critical: a city’s development today dictates the city of tomorrow, not only in relation to, e.g., infrastructure development but also its induced culture.

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