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From equipment to infrastructure: community energy management and greenhouse gas emission reduction

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Community energy management (CEM) (also called community energy planning) combines planning concepts – neo-traditional design, complete communities, green cities – with energy management concepts – energy cascading, demand-side management, integrated resource planning. It can be applied at the level of neighborhoods, cities and even small regions in order to exploit the synergies between urban design objectives for livable cities and energy management objectives of minimizing energy use and its associated environmental effects for a given standard of living. CEM encompasses (i) land use planning, (ii) transportation management, (iii) site design, and (iv) local energy supply and delivery planning. While traditional energy management focuses on energy using equipment and buildings, CEM also considers the urban land use and infrastructure level. This study applies CEM to four representative communities in British Columbia, Canada, over the period 1995 to 2010, and compares the results to a business-as-usual (BAU) scenario. The aggregate effect is a decrease in energy service costs and energy consumption of 15–30%, and in air emissions (CO_2 and NOx) of 30–45%. The methodology and results, with respect to one aspect of CEM – land use planning – are extrapolated to the provincial level in order to estimate total CO_2 emission reduction potential. CO_2 emissions are reduced by 17% from BAU. Additional approximate calculations (restricted to land use planning) suggest that on a global scale CEM can be an important element in the greenhouse gas emission reduction strategy, especially given the dramatic urban growth anticipated in developing countries in the coming decades. Implementation of CEM requires an array of policy initiatives from governments at all levels, as the following examples illustrate. National and provincial (state) governments can (i) change the legislation governing regional and municipal land use planning, (ii) tie infrastructure grants to CEM type municipal investments, and (iii) provide information support and fiscal incentives for developers. Regional and municipal governments can (i) change zoning objectives, (ii) encourage specific types of developments through development charges and tax incentives to developers, and (iii) work with energy and other utilities to encourage particular energy forms and delivery systems.

Background

The current throughput of energy required to drive our economic system creates challenges for society, particularly with respect to the use of resources and the production of waste. In industrialized countries, there has been a trend toward de-materializing and de-energizing the economy largely as a result of technology evolution and structural change. The potential for continued de-coupling of economic performance from energy and material throughputs is the subject of considerable discussion. Much of the debate has centered on technological substitution at the level of buildings, equipment and processes, and on structural change to the economy. However, there is growing awareness that the overall design of human settlements, be these neighborhoods, communities or entire regions, is also a critical determinant of energy and material throughput for a given economic system. Redesigning the urban form,[1] notably in terms of infrastructure and land use patterns, can

[1]The term urban is used in a very broad sense here to refer to the broad range of human settlements.

significantly affect the energy throughput – and associated wastes – of our economic systems, both by influencing the demand for energy services and by supporting new technologies for delivering those services (Owens, 1986).

This perspective is supported by three important trends. First, energy analysts are beginning to direct greater attention to the critical role of urban infrastructure and urban land use patterns in determining energy consumption levels. While this had always been understood in the past, energy policy efforts have generally been more focused on buildings and equipment rather than on the overall structure within which these are used. Second, there is a growing understanding of the environmental impacts associated with energy use in urban areas. Early awareness of the relationship of automobile use to smog has evolved to an understanding of critical relationships between specific energy-related emissions and different human and environmental impacts. Even global climate change, which is otherwise not a strictly urban issue, is seen as closely linked to the use of energy in urban centres in developed and, increasingly in future, developing countries. Third, there is a growing recognition of the improving cost-effectiveness of technologies for small-scale, decentralized cogeneration of heat and electricity, especially if heat requirements are concentrated, and growing potential for specific applications of other more environmentally benign energy technologies in urban settings.

Recognition of the collective importance of these factors has led to the development of new concepts and new methods of analysis. A critical concept is *community energy management* (CEM).[2] CEM is a planning and management process that focuses on energy strategies that can be implemented at the neighborhood, municipal or regional level. On one hand, CEM is consistent with and in many ways a synthesis of a variety of planning initiatives such as *neo-traditional urban design*, *complete communities* and *green cities*. These planning initiatives are driven more by public concern about air quality, congestion, noise, accessibility to services, preservation of green space and overall urban livability than about energy *per se*. On the other hand, CEM is also a logical extension of various energy-focused management and planning initiatives including *energy cascading*, *industrial ecology, demand-side management* and *integrated resource planning*. These initiatives focus on meeting society's energy service needs in ways that minimize energy throughput, with potential economic and environmental benefits. Whereas integrated resource planning has been applied by electric and natural gas utilities in North America to assess choices about buildings and equipment from the perspective of the utility and its customers, CEM is more directed at choices about urban design and infrastructure from the perspective of the local community.

CEM typically encompasses measures which emerge at the level of communities, notably:

- land use planning (eg zoning for specific land uses, land use densities, and land use patterns);

[2]Also referred to as community energy planning (CEP).

INFRASTRUCTURE AND LAND USE PATTERNS

- Density
- Mix of land uses
- Energy supply infrastructure
- Transportation network

MAJOR PRODUCTION PROCESSES, TRANSPORTATION MODES AND BUILDINGS

- Choice of industrial process
- Choice of transportation mode
- Building and site design

ENERGY USING EQUIPMENT

- Transit vehicles
- Motors
- Appliances
- HVAC systems

Figure 1 Hierarchy of energy-related choices

- transportation management (eg developing modes of transportation, transportation networks, and the supporting infrastructure and services);
- influencing site design (eg encouraging site designs that improve the economics of energy efficiency measures and alternative energy supply technologies, and that provide specific energy use benefits by, for example, accounting for micro-climate considerations[3]); and
- fostering efficient and environmentally benign energy supply and delivery systems (eg supporting distributed generation, district heat and power, waste heat recovery, heat pumps, etc).

The relevance of urban land use patterns and urban infrastructure to energy policy can be shown by representing the determinants of energy demand in a hierarchy of energy-related choices, as depicted in Figure 1. Urban land use and infrastructure is the top level. Urban form has a determining influence on the full cycle of energy use because density and land-use patterns affect the level of energy service requirements (eg commuter distances), the design of intra-urban transportation systems, the character of energy transmission systems, the potential for waste heat utilization, and even the possibilities for alternative energy supply systems. Building design, major industrial processes, and transportation mode options are at the next level of the hierarchy. Choices at this level also determine the opportunities and constraints for the specific energy using equipment that will function inside buildings (motors, appliances, space and water heaters, lights, etc), operate on the transportation network (vehicles, trains, etc) and be called upon by industrial processes (grinders, refiners, motors, thermal

[3]Using building design and vegetation/landscaping to provide wind shielding, solar, gain, summer cooling through shade trees, etc.

reducers, etc). This energy using equipment is at the bottom of the hierarchy.

The hierarchy of Figure 1 is illustrated by a look at personal mobility. At the urban land use and infrastructure level, urban density and land use patterns (eg siting of residential, commercial, institutional and industrial land uses) determine to some degree the amount of personal mobility required and even the choice of transportation modes (eg higher densities along with mixing of residential, commercial and some industrial uses increase the opportunity to walk or cycle; higher density in concentrated nodes improves the economics of mass transit). At the next level, decisions on the investment mix between mass transit of various forms, roadway development for buses and cars, and safe right-of-ways for cyclists and pedestrians play an important role in the acquisition and use of each of these technologies. At the equipment level, both individual vehicles and mass transit technologies can vary by efficiency and fuel type.

As the example illustrates, the energy policy hierarchy can be viewed from several perspectives. The hierarchy has a spatial dimension in that the scope widens as one moves up from individual units of equipment to the overall urban land use pattern and infrastructure. The hierarchy has a time dimension in that the turnover rate of the stock of energy using equipment is counted in years and perhaps one or two decades while the time to fully transform the urban landscape, including infrastructure, is counted in many decades and, in some respects, centuries. Finally, the hierarchy has a decision making dimension in that urban land use patterns and infrastructure are more generally determined by government and public agency decisions while equipment level decisions are generally made by individual firms and households. Thus, market forces frequently predominate in resource allocation decisions at the equipment level while public sector planning and management decisions, albeit often in response to market forces, tend to predominate at the infrastructure level.

Objective and methodology

In this study we explore two questions. The first question is to assess *why* policy-makers should be interested in CEM. Answering this question requires evaluating economic and other benefits and costs of CEM. The second question is to assess *how* policy-makers might implement CEM. Answering this question involves an analysis of institutional design, the relationships between levels of government, and various market and non-market policy instruments.

For consideration as a legitimate policy option, the why of CEM must be answered at two levels: the community level in order to evaluate possible local actions, and a more aggregate level in order to evaluate how CEM might contribute to regional or national goals, such as an environmental target. In this study, CEM measures are evaluated through four case studies which compare two alternative scenarios of development over a 15-year time frame (1995–2010): a business-as-usual (BAU) scenario and a CEM scenario. Then, the effects of some CEM measures are aggregated to the level of the province of British Columbia, Canada in order to assess their effect on regional or national goals. At this level, the study focuses on the objective of reducing provincial emissions. This second step is based on a subset of the CEM measures applied in the four community case studies, that being the urban land use planning measures.

The why of any policy option should not be examined in isolation from the question of how that option might be implemented. Otherwise, there is a risk that policy analysts will understate the full costs associated with implementation, and hence overstate the benefits. An example is the occasionally observed discrepancy between the economic gains expected from energy demand-side management measures and the realized net benefits of such measures when calculated in hindsight.[4] To minimize the risk of such a discrepancy, we probe in some detail how CEM measures can be implemented and what the associated costs are likely to be. We also have inflated upward the estimated costs of CEM measures by 5–15% in order to account for unforeseen and intangible costs. Nonetheless, the proposed measures involve changes in the character and density of urban neighborhoods, in the selection of modes of urban transportation and even in the design of individual sites and buildings. Such changes may provide some unaccounted for benefits, but are also likely to represent additional unaccounted-for costs.[5] Where such costs are not adequately accounted for by the 5–15% upward cost adjustment to CEM measures, the study implicitly assumes that some changes in societal values and expectations about urban lifestyles are possible without substantial losses of consumer surplus. This assumption needs to be tested further in future research.

CEM measures will vary according to the existing urban form, resource availability, demographics and commercial/industrial base of the community. Broadly, however, they fall into four categories: land use planning, transportation management, site design and alternative energy supply (Figure 2).

These four CEM categories and individual CEM measures are not independent. For example, the introduction of district heating will be far more cost-effective if zoning changes are made to establish a district heating zone (MacRae, 1992). Special standards for density, mixed use, rate of growth, thermal systems design and infrastructure connections will help to develop an acceptable thermal load profile, a balance of electrical and thermal requirements to improve the economics of cogeneration, and favorable conditions for future retrofit to district heating. Similarly, density increases without

[4]Many early evaluations of the cost-effectiveness of electricity demand-side management measures tended to overstate the benefits by overlooking some of the utility's costs of implementation and overestimating the market penetration rate.

[5]In economic terms, this type of cost is usually described as a loss in consumer surplus, where consumer surplus represents the difference between an individual's willingness to pay (ie benefits received) and the price actually paid in the market. For example, in the current context, an individual may incur no additional market costs as a result of CEM, however a loss of consumer surplus may occur if the consumer settles for a less desirable lifestyle (eg living in a higher density than is preferred; travelling in a transit vehicle instead of a private car).

Sector	Goal	Sample Strategies
Land Use Planning	• Access-by-proximity • Support waste heat utilization	• Target strategic locations for high density, mixed use, transit oriented development • Offer financial incentives to developers for preferred densities, mixes and amenities • Increase proportion of multi-family housing • Establish a strict urban boundary • Locate heat sources near heat sinks • Establish district heating zones with special standards for density, diversity, growth etc.
Transportation Management	• Shift the mode of travel • Shift to alternative fuels	• Improved transit, high-occupancy vehicle, pedestrian and cycling facilities and services • Parking pricing strategies • Employer trip reduction programs • Fleet fuel switching
Site Design	• Increase efficiency • Increase use of micro-climate	• Reduced lot size and setbacks from street • Use of vegetation for shading or wind-shielding • Building standards/performance certification • Financing and technical assistance for efficiency improvements
Energy Supply	• Exploit local resources • Increase use of "clean" resources	• Distributed generation • District heating and cooling • Heat pumps, solar technologies • Recovery of waste heat • Financing and technical assistance for homeowners, businesses and developers to invest in alternative technologies

Figure 2 Sectors, goals and sample CEM strategies

concomitant improvements in transit infrastructure may not lead to reduced energy use nor to improved community livability. Thus, CEM involves an integrated approach to planning and management in all four categories of CEM measures.

Evaluating CEM: the Why

Local level analysis: four community case studies

To evaluate CEM at the local level, four communities were selected to represent a cross-section of community types and locations. Both BAU (business-as-usual) and CEM scenarios are based on official community and utility planning documents and interviews with senior planners.

To develop a BAU scenario, utility planners provided current energy consumption patterns and projections. Urban planners identified the most likely locations and characteristics of new development. Average trip distance is estimated using the weighted average distance from population centres to the nearest mixed-use node where shopping and services are located. Housing type mix is based on recent trends and projections.

In the CEM scenario, population distribution is adjusted (within realistic limits according to growth projections) until the CEM land use plan accommodates 30% of new residential growth in nodal areas, entirely in apartments and multi-family dwellings, with the remaining 70% in contiguous development (ie eliminating vacant tracts of land between developed areas, except for designated green spaces). Overall growth is accommodated in equal proportions of single family dwellings to apartments and multi-family dwellings, and half of all new commercial development is located in mixed-use (residential/commercial) nodal areas. Various additional assumptions complete the urban form demand-side scenarios.

On the supply side, the BAU scenario assumes that energy continues to be provided primarily through the electricity grid and natural gas mains, in shares generally equal to those

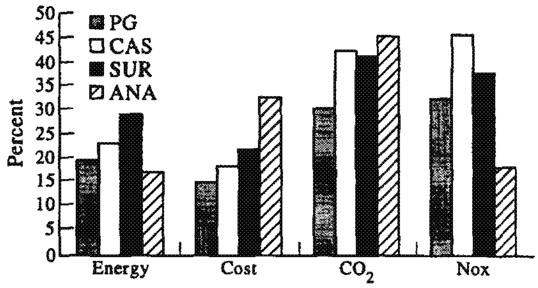

Figure 3 CEM Savings relative to BAU: four community case studies

in 1994.[6] The CEM scenario assumes that a variety of local and imported supply options are available. In particular, district heating zones are developed in three of the four communities. The economic viability of district heating depends upon re-zoning nodal areas, incrementally increasing density, and mixing uses and energy loads to gradually reach threshold economic conditions. Local wastes (eg wood, municipal waste) fuel some cogeneration plants in the under 10 MW capacity range.[7]

A spreadsheet model is used to evaluate the impacts of the CEM measures in the year 2010. The model is a simple static representation of three states: the present, the BAU scenario in 2010 and the CEM scenario in 2010. The inputs to the model are variables that affect energy consumption and energy supply resources, and that can be manipulated by policy instruments (eg density, diversity, housing splits, location of new development, average vehicle occupancy, new energy supply resources). The model relates these inputs with simple linear functions and sums the resulting outputs, these being energy consumption, various emissions, total energy system costs, and employment indicators. All costs are in constant dollars, calculated using life-cycle cost analysis at a real social discount rate of 7%.[8]

Figure 3 presents a summary of some of the incremental energy, cost and emission reductions associated with a shift from BAU to a concerted CEM effort by the four communities. In the figure, ANA is a small settlement not integrated to the natural gas and electricity grids, SUR is a large, high growth suburb of Vancouver, PG and CAS are integrated natural resource-based communities of 70,000 and 7000 inhabitants respectively.[9]

The results suggest that CEM could lead to energy savings of 15–30% and air emission (CO_2 and NOx) savings of 30–45%. At the same time, the model calculates that the life-cycle costs of the various energy services would be reduced by CEM relative to BAU by 15–30%. In other words, the reduction in CO_2 emissions from CEM measures fit what has generally been defined as *no regrets* in that these measures are desirable from an economic perspective alone.[10]

Because the CEM measures were tested as packages, Figure 3 shows average values for a given set of measures. It is not possible from this research to determine the shape of a marginal cost curve of individual CEM measures in order to find out if some of these lead to net cost increases rather than financial savings.[11] Indeed, the interdependence of CEM measures may frustrate efforts to assess CEM at this level of disaggregation, requiring instead a portfolio approach to assessing additions or deletions of specific measures.

However, when costs and CO_2 emission reduction potentials are categorized into transportation and building measures, it is possible to explore in greater detail the relative attractiveness of alternative CEM strategies in terms of the economics of CO_2 reduction. The most beneficial no regrets measures relate to transportation. CO_2 abatement in the transportation sector is achieved at significant cost savings to society, largely due to the decreased need for travel.[12] Savings per tonne of CO_2 abated ranged from $140 to $230. CO_2 abatement in the buildings sector is less beneficial, but still satisfies the no regrets definition. Savings per tonne of CO_2 abated ranged from $28 to $78.

The study also probed the local employment effects of the CEM strategy.[13] Energy supply related investments in the CEM scenario tend to produce two to three times more jobs in the local economy than in the BAU scenario.[14] These local benefits resulting from the four categories of CEM measures are calculated from the community perspective, meaning that the costs reported are those incurred by the community rather than by society as a whole.

[6]There are some adjustments. For example, British Columbia produces most of its electricity from hydropower, but a greater share of electricity is expected to come from natural gas-fired technologies under BAU.
[7]For technical details (pricing, efficiencies, density ratios, technologies, etc) see Failing (1995).
[8]Thus, the model is like the spreadsheet models used to estimate demand-side management potential. While the use of a social discount rate is problematic when evaluating costs and benefits of private demand-side management expenditures by firms and households, it is less so when evaluating decisions that have a substantial public sector predominance. Nonetheless, future tests of the model should include higher discount rates or some other mechanism to reflect the risks associated with alternative investments and the potential role that private firms may play in such investments.

[9]ANA=Anaheim Lake, SUR=Surrey, PG=Prince George and CAS=Castlegar.
[10]The highest cost and CO_2 savings are found with the non-integrated community, ANA. Here, the switch from diesel electricity generation in the BAU scenario to cleaner fuels under CEM creates particularly significant environmental and economic benefits.
[11]Always, of course, with the caveat that significant differences in consumer surplus are possibly being ignored.
[12]Our estimates of the decreased need for travel are consistent with the results of studies conducted by independent researchers in Toronto, New York, Chicago and a selection of cities in the United Kingdom. Holtzclaw (1993) reports that a doubling of density is associated with reductions in distances travelled of roughly 30%.
[13]Focusing on employment can be misleading because politicians and the public may mistakenly equate job creation with wealth creation. Nonetheless, at the local level there can be legitimate interest in the potential local employment effects of CEM measures and other management and planning decisions.
[14]Estimated employment increases are primarily due to two factors: investments in efficiency, which tend to create more jobs than investments in energy supply; and savings associated with lower energy bills, which result in a re-spending effect as people re-spend these savings on other consumer goods and services, including energy.

Extrapolating the results: the provincial level

To evaluate the possible contribution of CEM measures to provincial (state) or national policy objectives, the results of the four case studies are extrapolated to the province as a whole. However, this exercise is limited to the set of land use planning measures applied in the four case studies and does not include any effects of the other three CEM measures: transportation, site design and energy supply. Thus, only CEM measures influenced by land use planning are considered here. These include, among others, choice of housing type, availability of waste heat, district heating market share, and transportation modal shares, but not transportation-specific measures such as vehicle efficiency improvements. The results of the study focus on estimating the costs of CO_2 emission reduction, this being an emerging energy policy objective for higher levels of government.

For extrapolating the CEM land use planning measures, three classes of urban development are identified:

- nodal – high density, mixed use, pedestrian-oriented;
- compact – moderate density, transit-oriented; and
- sprawl – low density, single use auto-oriented.

Three energy end-uses are considered: space heating, specific electricity use, and transportation. Per capita energy consumption and energy-related emissions vary by urban development class and energy end-use. Also, the unit costs of available energy supply technologies vary according to urban development class. For example, combined heat and power and waste heat recovery generally decrease in unit cost with higher densities and greater mixed land use.

The study identifies those technologies that are affected by land use considerations, estimates their penetration rates in each urban development class, and quantifies the extent to which per capita emissions and costs are affected by land use patterns. It also estimates per capita consumption by end-use in each class. By altering the percentage of the BC population forecast to live in each class by 2010 (ie a BAU growth projection vs a higher density/mixed use CEM scenario), the long-term energy, cost and emission implications of alternative urban land use patterns can be estimated. This shift, for the BAU and CEM scenarios, is achieved by allocating communities in British Columbia into one of three archetypes of high, moderate or low overall density (Figure 4) and then simulating the incremental effects of CEM land use measures on the shares of node, compact and sprawl development within each of the three community types.

The following equation is used for calculating total CO_2 emissions in the extrapolation exercise. Total provincial CO_2 emissions are equal to the sum of the CO_2 emissions per unit of energy used for energy end-use i by energy system j, multiplied by the market share of energy system j in development class k, multiplied by the consumption of energy for end-use i in development class k.

$$TCO_2 = \sum_{ijk} E_{ij} * M_{jk} * C_{ik}$$

TCO_2=total provincial energy-related CO_2 emissions.
E_{ij}=CO_2 emissions per unit of energy (CO_2/GJ) used for energy end-use i by energy system j.
M_{jk}=market share (%) of energy system j in development class k.
C_{ik}=total consumption of energy (GJ) for end-use i in development class k.

The energy system (j) is a combination of fuel type and conversion system and includes energy technologies (for space heat and electricity end-uses) and transportation modes (for transportation end-uses). Consumption of energy by end-use and development class depends on the per capita values derived from the case studies, as well as additional assumptions from recent research on space heat, electricity and transportation end-use requirements for each of these types of urban forms (California Energy Commission, 1993). These

Nodal	**Relatively high density cities which already have a significant nodal area(s) and which have already begun a trend toward moderate increases in density and mixed use. Gross population density and net residential greater than 20 per hectare.**
Compact	**Moderate density cities characterized by relatively large portions of non-contiguous development, but containing some mixed use nodes. Gross population density and net residential density of 5 to 20 per hectare.**
Sprawl	**Low density cities with a large proportion of non-contiguous development and exurban land; usually with no significant mixed use area. Gross population density and net residential density less than 5 per hectare.**

Figure 4 Classes of urban development

Table 1 Scenarios: BAU and CEM

Population by Development Class in 2010

	BAU				CEM	
	%	Initial Population	%	2010 Population	%	2010 Population
Node	4%	116,000	4%	217,000	16%	867,000
Compact	17%	544,000	17%	922,000	38%	2,060,000
Sprawl	79%	2,466,000	79%	4,283,000	46%	2,494,000

Summary of Costs and Emissions in 2010

	$/cap	t/cap	BAU $/year (Millions)	tonnes/year	CEM $/year (Millions)	tones/year	Abatement Cost $/tonne
Node	$2,144	4.28	$474	946,577	$ 1,865	3,725,512	
Compact	$3,554	6.81	$ 3,382	6,477,063	$ 7,413	14,197,645	
Sprawl	$5,940	10.30	$ 25,241	43,780,464	$ 14,648	25,408,129	
Total			$ 29,096	51,204,104	$ 23,926	43,331,286	
Savings					$ 5,170	7,872,819	$ (657)

consumption intensities (with energy and CO_2 values) are then multiplied by the total provincial population allocated to each development class.

The results of the extrapolation exercise are presented in Table 1, which shows the total effect of the province-wide application of the slate of CEM land use planning measures.[15] Under the CEM scenario, only 46% of the population is in the sprawl category by 2010 compared to the 78% projected for BAU. More than half of the population is in the node and compact development classes, compared to only 21% under BAU. The CEM scenario reduces CO_2 emissions by 7.9 million tonnes compared to BAU among a population projected to be 5.4 million people. This emission reduction of 17% would be accompanied by life-cycle cost savings of 20%. While there are a number of uncertainties associated with the underlying data, the results are relatively insensitive to changes in the key assumptions.[16]

Implementing CEM: the How

While CEM may appear to offer several benefits to policy-makers at all levels of government, its widespread implementation faces several challenges. To the extent that there are similarities between demand-side management efforts over the past decades and CEM initiatives, there may be barriers to CEM implementation.[17] Some of the perceived benefits of CEM are based on an engineering/economic life-cycle cost analysis for providing energy services. As with demand-side management analysis, there may be differences in the values society perceives from alternative urban forms and infrastructure under CEM which otherwise appear to provide the same energy service. An example is the different value consumers seem to put on mobility alternatives such as individual vehicles and mass transit. A personal vehicle is generally seen as providing greater value per person-kilometre travelled than a mass transit vehicle. Another example is the different value consumers seem to put on high density residential development relative to low density development.[18] Nonetheless, the results of this research suggest that even if the full costs of CEM are significantly higher than the upward adjusted engineering/economic costs used in this study, CEM appears likely to offer various benefits to individuals and society as a whole. This suggests its desirability as a policy objective of government. The associated challenge, then, is to devise effective, low cost implementation strategies.

Implementation is expected to require changes to public policy and planning processes in both energy and urban planning, with particular emphasis on partnerships between community planners, energy utilities and regional transportation planning authorities.[19] At a minimum, implementation will require the following at the municipal or regional level.

- Establishing regional standards for new development (eg site, building, street and lot design, efficiency standards, etc) and development cost charges (ie sliding charges levied

[15]In contrast to the results from the case studies, the results of the extrapolation exercise are calculated from the perspective of the region (province) and thus are corrected for various subsidies to road and transit infrastructure as per Litman (1995).

[16]A sensitivity analysis involved: (1) decreasing the achievable market share of CEM building measures and CEM transportation modes by 10%; (2) increasing the model share of alternative modes in sprawl by 10%; and (3) halving the multipliers used to estimate the relationship between cost and density. CO_2 reductions changed by 1.1%, 1.0% and 4.2% for space heating, electricity generation and transportation respectively. Cost savings increased by 5.3%, 4.0% and 9.2% for each of space heating, electricity generation and transportation.

[17]As noted earlier, CEM and demand-side management differ in that the latter is especially focused on influencing consumer decisions about equipment and buildings while the former is more focused on influencing decisions of various levels of government. This may make CEM easier to implement than demand-side management, but this has not yet been demonstrated.

[18]However, there is some evidence that consumers will value high density but complete communities, more than low density incomplete ones.

[19]Even though the evolution of natural gas and electricity markets may diminish or eliminate the commodity production role of utilities, the distribution function will remain important for the foreseeable future. Utilities delivering services for natural gas, electricity, district heat, water, sewage and perhaps others will continue to play a critical role in the development of urban infrastructure.

against developers at the time of construction) to encourage preferred densities, use mixes, energy efficient construction, on-site generation, etc.

- Developing special zoning standards in consideration of energy objectives (eg district heating/cogeneration zones with special standards for density, diversity, growth rate, infrastructure connections, etc). These may include standards for immediate energy considerations, or for the preservation of future options (eg setting standards for roof pitches and lot orientation in anticipation of the development of cost-effective solar technologies; prohibiting electric baseboard heat in anticipation of future conversion to district heat; requiring site connections in preparation for a future district heating system, etc).
- Introducing explicit energy objectives into developer negotiations for re-zoning, building permits, environmental review processes or other regulatory processes, as well as ensuring that developers are well informed about relevant new technologies and the emerging business opportunities for the private sector in independent power production.
- Involving energy utilities as direct stakeholders in developer negotiations and as strategic partners in official community planning processes.

Energy policy implications for provincial, state or federal governments include the following.

- Introducing legislative changes that make energy planning an explicit function of municipal and/or regional government.
- Providing technical and financial support for the integration of energy considerations into traditional community planning processes.
- Encouraging utilities to form planning partnerships with municipalities for consideration of community-based service options (eg development standards, development cost charges, district heating zones, location of heat sinks relative to heat sources, etc).
- Using fiscal policies and information policies to encourage developers to act as, or assist the operation of, energy service companies; in other words, help to develop better links between building developers and building managers.
- Supporting market and regulatory changes that improve access to technical assistance from the private sector (eg energy service companies) and access to energy markets (eg open access to spot markets for independent power producers of any size).
- Making the transfer of matching funds for infrastructural investments conditional on the adoption of CEM principles and strategies.
- Involving urban planners in regional, national and international policy development processes for greenhouse gas emission reduction strategies.

Broader greenhouse gas policy implications of CEM

Further research

These results at the local and regional levels suggest that CEM measures represent a potentially significant and low cost policy option for CO_2 emission reduction. CEM has no regrets characteristics in that it may provide economic benefits even without consideration of its reduction of CO_2 emissions. CEM strategies are simultaneously supportive of other community objectives including improved local air quality, accessibility of services, housing affordability, preservation of options for productive land and general improvements to urban livability, many of which are seen to have intangible non-monetized benefits.

However, while the research reported here provides evidence of CEM's potential, there is still considerable uncertainty about the impacts of an explicit CEM strategy, both in terms of the true costs and what is achievable. Two avenues for further research are particularly noteworthy.

First, CEM analysis would ideally be based on geographically-specific quantitative indicators (Holtzclaw, 1993). The research in this study was limited by the frequent lack of availability of reliable high resolution data (eg population, employment, transportation patterns at the neighborhood scale). More rigorous case study applications and aggregation/extrapolation techniques are required to refine quantitative estimates of reduction potential and costs.

Second, conventional energy demand models simulate the demand for energy at the lower levels of the energy hierarchy: equipment, vehicles and buildings. The importance of CEM as a greenhouse gas abatement strategy implies a need to integrate CEM into the more conventional framework of energy policy models. For example, CEM modelling should link to both the interaction of energy supply and demand models (for district heating, local production of electricity, etc), but also to the interaction between macro-economic scenarios or models and the general level of demand for energy services which normally drive energy demand models.

In spite of these shortcomings, these preliminary results from CEM analysis can contribute to the broader policy objectives and even to more specific policy questions. Two pertinent greenhouse gas policy questions provide an example of this. One question is the relative importance of CEM strategies in both developed and developing countries, given the rapid urbanization occurring in much of the developing world. A second question concerns which measures governments should pursue immediately and which measures warrant delay.

Global urbanization trends, CEM and CO_2 emissions

Population growth combined with rapid urbanization will result in dramatic growth in urban structures in developing countries over the next decades. This urban development will not be identical to that experienced by developed countries in the past, but under current trends it may be considerably

Table 2 CEM and global urban CO_2 emmissions

	World	Developed	Developing		
1995 Urban Population (1000s)	2,500,000	1,000,000	1,500,000		
2025 Urban Population (1000s)	5,000,000	1,000,000	4,000,000		**t/capita/yr**
				Node	4.28
				Compact	6.81
Energy and CO_2 Intensity Multiplier 1995		0.5	0.1	Sprawl	10.30
Energy and CO_2 Intensity Multiplier 2025		0.5	0.3		

1995 Developed			**BAU 2025 Developed**			**CEM 2025 Developed**			**CO_2 Reduction**
% pop	**Pop**	**1000s t/yr**	**% Pop**	**Pop**	**1000s t/yr**	**% Pop**	**Pop**	**1000s t/yr**	**Due to CEM**
4%	40,000	85,600	4%	40,000	85,600	16%	160,000	342,400	
17%	170,000	578,850	17%	170,000	578,850	38%	380,000	1,293,900	
79%	790,000	4,068,500	79%	790,000	4,068,500	46%	460,000	2,369,000	
TOTAL		4,732,950	TOTAL		4,732,950	TOTAL		4,005,300	727,650

(The three rows In each cell are node, compact and sprawl).

1995 Developing			**BAU 2025 Developing**			**CEM 2025 Developing**			
% Pop	**Pop**	**1000s t/yr**	**% Pop**	**Pop**	**1000s t/yr**	**% Pop**	**Pop**	**1000s t/yr**	
4%	60,000	25,680	4%	160,000	205,440	16%	640,000	821,760	
17%	255,000	173,655	17%	680,000	1,389,240	38%	1,520,000	3,105,360	
79%	1,185,000	1,220,550	79%	3,160,000	9,764,400	46%	1,840,000	5,685,600	
TOTAL		1,419,885	TOTAL		11,359,080	TOTAL		9,612,720	1,746,360
WORLD TOTAL URBAN CO_2 EMISSIONS		6,152,835		BAU	16,092,030		CEM	13,618,020	2,474,010

more energy and CO_2 intensive than under a scenario in which a CEM strategy is pursued. Table 2 presents a rough analysis to illustrate the potential emission reduction impacts of the simultaneous pursuit of CEM strategies in developed and developing countries over the 30-year period from 1995 to 2025. Data is from:

- this study, for the incremental effects of CEM relative to BAU;
- the United Nations Population Division, for urban population estimates;
- the report of Working Group III of the Intergovernmental Panel on Climate Change (IPCC) (Bruce, Lee and Haites, 1996), for estimates of per capita carbon intensities.

According to definitions developed by the United Nations Population Division, the current world urban population is roughly 2.5 billion, of which 1.5 billion is in developing countries. By the year 2025 the world's urban population is projected to double to about 5 billion, with almost all of this growth occurring in developing countries. An increase in the urban population in developing countries from 1.5 to 4 billion will entail a dramatic growth in urban structures over the next 30 years. There are multiple options for how this urbanization will occur, but it is possible to explore a rough contrast between BAU and CEM.

Per capita intensities of energy and CO_2 in developing countries are substantially below that of developed countries, and Canada is at the high end of this latter group. Research summarized by the IPCC (Bruce *et al*, 1996) estimates that global emissions of carbon are 1.1 t C $capita^{-1}$, an average of 2.8 t C $capita^{-1}$ for developed countries and 0.5 t C $capita^{-1}$ for developing countries.[20] The estimate for Canada is 5 t C $capita^{-1}$. If it is assumed that these country ratios are relatively representative of the ratios for urban areas in developed and developing countries, it is possible to extend the results from this study to a global scale. Thus, one might assume that the average carbon emission intensity for urban areas in developed countries is about half, and in developing countries about a tenth, that of Canada. This gives the energy/CO_2 intensity multipliers for 1995 in Table 2 of 0.5 and 0.1 for developed and developing countries respectively, which are used to convert the results of this study for a crude global analysis of urban areas in developed and developing countries.[21]

The emission levels in Table 2 are taken from this study's results (Table 1). The three classes of urban development were estimated to have emissions of: node – 4.28, compact – 6.81 and sprawl – 10.3 t CO_2 $capita^{-1}$ (or 1.17, 1.86 and 2.8 t C $capita^{-1}$ if expressed in carbon equivalents). These emissions totals are for the activities classified as urban in this study, and therefore are much less than national totals. The national totals include all industry, inter-urban transportation, and all other non-urban activity. Thus, multiplying the CO_2 intensities for each urban class by the percentage share of that class, and summing these, results in an urban per capita CO_2 emission intensity from this study of

[20]The IPCC estimates here are expressed as tonnes of carbon, not tonnes of CO_2. To convert to tonnes of CO_2, they must be multiplied by 3.67.

[21]For many reasons, the values for urban areas could differ significantly from the country averages. Further research is needed to probe this issue.

9.47 t CO_2 capita^{-1}, (or 2.58 t C capita^{-1} expressed in carbon equivalents, roughly half the estimated total Canadian emissions of 5 t C capita^{-1}).[22]

The ratios described above are then combined with projected changes in urban population, per capita energy/CO_2 intensities, and alternative BAU and CEM scenarios. The 1995 world urban CO_2 emissions are currently estimated at about 6 billion tonnes. Under the BAU scenario, these are projected to increase to 16 billion, under the assumption that the relative shares of node, compact and sprawl remain constant and that per capita CO_2 intensity climbs in developing countries from one tenth to three tenths that of Canada today, but stays at the same level for developed countries (Bruce *et al*, 1996). Under the CEM scenario, the shift in the relative shares of node, compact and sprawl results in lower emissions by about 2.5 billion tonnes of CO_2, 15% from the BAU scenario. This is equivalent to about 674 million tonnes of carbon emissions, or 9% of current world carbon emissions.

This crude exercise suggests that a strategy of CEM can have a significant effect on global CO_2 emissions when one considers the rapid urban growth slated to occur in developing countries. Moreover, the results are likely to understate considerably the full potential because (i) only the land use component of CEM measures is explored and (ii) the effects realized by 2010 in the Canadian case studies are projected to the year 2025 without including any further benefits from CEM efforts. Further research is necessary to increase confidence in the estimates of CEM's impacts on CO_2 emissions.

Timing strategies for CO_2 reduction efforts

There is currently a debate among modellers and policy advisors about the best advice to give policy-makers for achieving long run targets for atmospheric CO_2 concentrations. Some recent research has suggested that there are potential economic benefits to an emissions reduction strategy that does less reduction in the near term and much more well into the next century (Manne and Richels, 1996). However, much of this research is based on models that focus on the turnover rate of equipment and building stocks as opposed to urban land use patterns and infrastructure. The research reported in this study suggests that the slow turnover rate of urban infrastructure and land use patterns requires significant changes in present, not future, policies if urban land use and infrastructure are to be substantially transformed by the middle of the next century. Indeed, the costs of delaying action on CO_2 emissions, especially CEM measures, may be much higher once the focus of economic analysis shifts from buildings and equipment to urban land use and infrastructure. These latter, according to the approximate results of this research, may represent some of the lowest cost opportunities for CO_2 emissions reductions, especially if they are implemented as the urban land use and infrastructure evolves and not in a rush at a much later time. Further empirical research is needed to address this policy trade-off.

[22] $(4.28\times0.04)+(6.81\times0.17)+(10.3\times0.79)=9.47$ t CO_2 capita^{-1}. Dividing by 3.67 to convert to tonnes of carbon equivalent, equals 2.58 t C capita^{-1}

Conclusion

This study presents a preliminary look at the potential contribution of policy options which target urban land use patterns and urban infrastructure as a means of achieving energy/environment goals. While many of the components of a CEM approach may not be new, their integration into a formal approach to energy planning is. The results of this research suggest that there are opportunities for cost-effectively reducing greenhouse gas emissions while simultaneously addressing the pressing concerns of urban areas through policy options at the interface of energy and urban planning.

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