Assessment of the Potential Cumulative Benefits of Applying Utility-based Cogeneration in Ontario

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Significant reductions in annual and cumulative energy use and associated environmental emissions are predicted in Ontario, during the period 1989 to 2010, through utility-based cogeneration using the facilities of the provincial electrical utility. Six scenarios are considered, where utility-based cogeneration satisfies minor or major portions of the heat demands of the residential-commercial and/or industrial sectors. It is concluded that more extensive utility-based cogeneration in Ontario would likely be beneficial, and that further study of the province's options for utility-based cogeneration, and the appropriate implementation of the most beneficial option, appears to be justified.

Des réductions potentielles importantes dans l'utilisation annuelle et cumulative de l'énergie et des émissions dans l'environnement qui y sont associées ont été identifiées pour l'Ontario pour la période 1989-2010 grâce à la cogénération produite par les services publics utilisant les installations de production d'électricité de la province. Six scénarios sont envisagés, dans lesquels la cogénération basée sur les services publics comble une partie majeure ou mineure des besoins déterminés par la demande en chauffage des secteurs résidentiel-commercial et\ou industriel. L'étude parvient à la conclusion que la cogénération basée de manière plus extensive sur les services publics serait vraisemblablement bénéfique et que des études supplémentaires sur les options de la province en matière de cogénération basée sur les services publics semblent être justifiées.

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The authors are grateful for the support provided by Natural Resources Canada, Energy Research Laboratories/ Canada Centre for Mineral and Energy Technology, the Canadian Federal Green Plan, the Natural Sciences and Engineering Research Council of Canada, and the South Bruce Economic Development Corporation.

1. Introduction

This paper investigates the potential long-term benefits of the simultaneous production of thermal and electrical energy (cogeneration) using the facilities of Ontario Hydro, which provides almost all of Ontario's electricity supply. In previous studies (Rosen, 1994; Rosen and Dimitriu, 1993), the authors investigated the annual effects of utility-based cogeneration in Ontario in six scenarios. Reductions in energy usage and environmental emissions were determined for each scenario. The base-case year considered was 1989. It was shown that the implementation of utility-based cogeneration in Ontario offers significant opportunities to reduce annual energy use and related environmental emissions. This study extends the previous one in that annual effects of utility-based cogeneration in Ontario are predicted for each year until the year 2010, and the cumulative effects (i.e., the cumulative reductions in energy use and environmental emissions) through to 2010 are projected.

The six scenarios (see Figure 1) involve the use of heat from basic or advanced utility-based cogeneration networks to supply some of the heat demands of the residential-commercial and/or industrial sectors of the province (Rosen, 1994; Rosen and Dimitriu, 1993). Specifically, a basic utility-based cogeneration network supplies a minor portion (9%) of the annual heat demand of the residential-commercial sector (in scenario A), a minor portion (6%) of the annual heat

Energy Studies Review Vol. 6, No. 2, 1994 Printed in Canada

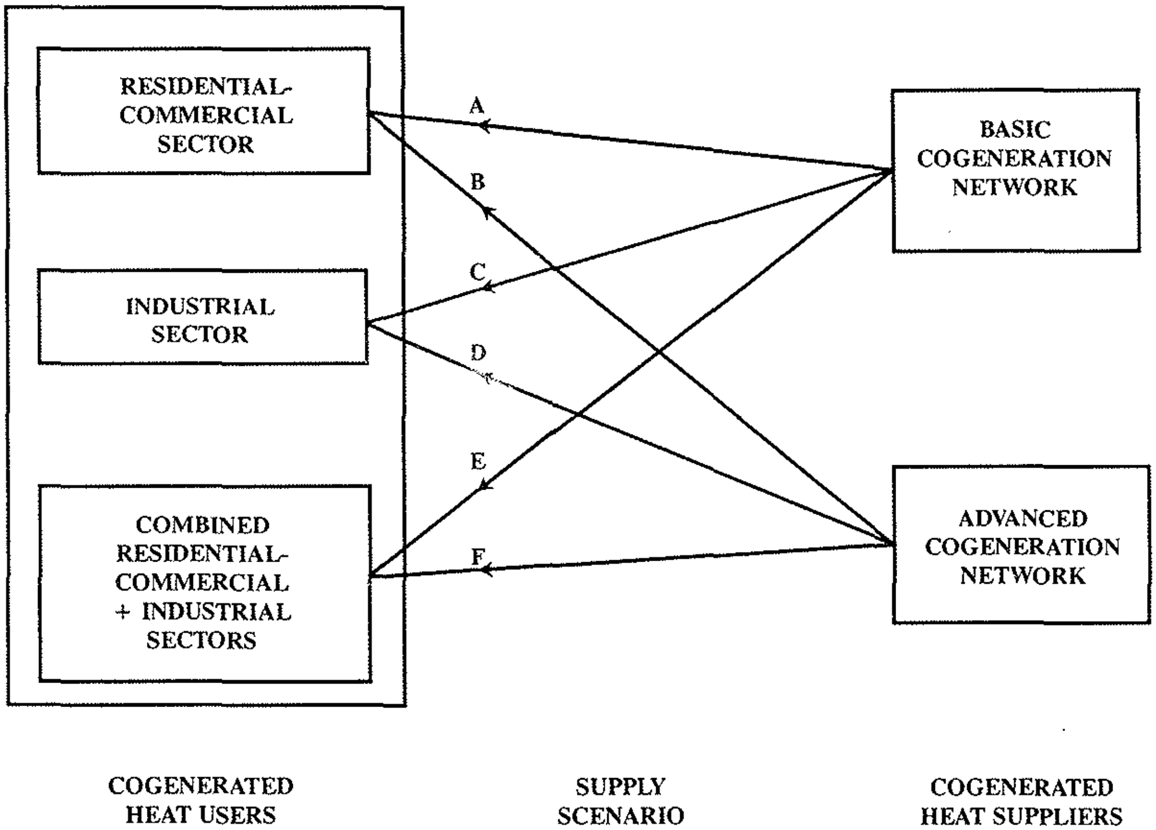

Figure 1: The six cogeneration scenarios considered.

demand of the industrial sector (in scenario C), and both of the above heat demands (in scenario E). Similarly, an advanced utility-based cogeneration network supplies an increased portion (40%) of the annual heat demand of the residential-commercial sector (in scenario B), an increased portion (12%) of the annual heat demand of the industrial sector (in scenario D), and both of the above heat demands (in scenario F).

The present paper focuses on the supply of cogenerated heat from electrical generating stations in the utility sector of the province. The demand for this heat is estimated for each scenario by making assumptions about the factors affecting demand. This paper is based on a report (Rosen *et al.*, 1993a), and relates to other studies for Ontario by the present authors of the advantages of utility-based district cooling (Rosen *et al.*, 1993b, 1994). Furthermore, this and the above related reports form part of a broader investigation into the benefits of electrical-utility-based cogeneration in Ontario, including economic aspects (Rogner, 1993a, 1993b) and environmental and health (Hart, 1993) aspects. Note as well that the reports cited above relate to a separate study of the opportunities for cogeneration and district heating and cooling at several sites in Canada (FVB/Eltec, 1993).

2. Background

Thermal power plants (such as fossil-fuel and nuclear plants) form the basis of most cogeneration systems. In thermal power plants, an energy resource (normally a fossil or nuclear fuel) is converted to heat (in the form of steam or hot gases); a portion (normally 20 to 45%) of the heat is converted to electricity, and the remainder is rejected to the environment as a waste. In cogeneration systems, some of the generated heat is delivered as a product (normally as steam or hot water), and the production of electricity and waste heat is reduced. Overall cogeneration efficiencies (based on both the electrical and thermal energy products) of over 80% are achievable (Rosen, 1994; Rosen and Dimitriu, 1993). The main advantage of cogenerating thermal and electrical energy is that less input energy is consumed than would be required to produce the same products in separate processes. Additional benefits often include reduced environmental emissions (due to reduced energy consumption and the use of modern technologies in large, central installations), and more economic, safe and reliable operation (FVB/Eltec, 1993).

Two main categories of heat demands can normally be satisfied through cogeneration: (i) residential-commercial processes, which require large quantities of heat at relatively low temperatures (e.g., for heating air and water); and (ii) industrial processes which require heat at a wide range of temperatures (e.g., for drying, heating and boiling in, for instance, chemical processing, manufacturing, metal processing, mining and agriculture). The use of a central heat supply to meet the heat demands of the residential-commercial sector (which is taken here to include the institutional sector) is often referred to as district heating, and has been applied and studied extensively (FVB/Eltec, 1993; Ontario Ministry of Energy, 1977; MacRae, 1992). It is noted that the use of cogenerated heat to drive chillers for cooling, which are presently electrically driven, is not considered here, but is addressed in related reports (Rosen *et al.*, 1993b, 1994).

Many general descriptions and studies of cogeneration systems have been reported (MacLaren Engineers Inc., 1988; Acres International Limited, 1987; Association of Energy Engineers, 1991; Henneforth and Todd, 1988), some of which have focussed on Ontario (MacLaren Engineers Inc., 1988; Acres International Limited, 1987; Diener and Cain, 1993). Cogeneration systems are in use throughout the world (e.g., over 4000 are listed by the Association of Energy Engineers (1991)). The size and type of a cogeneration system are normally selected to match thermal and electrical demands as optimally as possible (MacLaren Engineers Inc., 1988).

In Ontario, many cogeneration systems are possible based on current coal and nuclear electrical stations (e.g., steam can be extracted from one or more points on the turbines and exported to nearby heat users, and steam can pass through part of the steam turbines and then be diverted for use in heating). In the early 1980s, Ontario Hydro (1984) claimed that large supplies of heat in the form of steam or hot water are available at several of its stations around the province (at as high as 230°C for nuclear and 510°C for coal-fired stations). Nevertheless, cogeneration is used only very minimally in the current electrical generation system (e.g., cogenerated steam from the Bruce Nuclear Power Station is used for heating in such other facilities as the on-site heavy-water production plant and the Bruce Energy Centre, a nearby industrial park).

3. Approach and Methodology

3.1 Previous Studies

This section describes the approach and methodology used in the previous studies (Rosen, 1994; Rosen and Dimitriu, 1993), including a discussion of the scenarios in which the effects and benefits of implementing utility-based cogeneration are examined for the province. The scenarios are assessed by evaluating the change in quantities such as energy consumption and environmental emissions when cogeneration is implemented, relative to a base-case year. The scenarios consider the effects of cogeneration implementation on the electrical-utility sector, the remainder of Ontario, and the overall province. The number of scenarios considered is intended to be sufficient to illustrate the potential benefits of utility-based cogeneration over the range of viable implementation possibilities, but limited enough to avoid confusion. The base-case year is a typical recent year, formed using 1990 energy data and 1988 environmental emission data.

The six cogeneration scenarios, described earlier and illustrated in Figure 1, are all based on Ontario Hydro's existing facilities. The scenarios likely span the possible ranges of market penetration for utility-based cogeneration in Ontario, with Scenarios A and C assuming the least penetration and Scenario F assuming the most. Other potential heat demands in these sectors that are serviceable by utility-based cogeneration are not considered here (e.g., absorption-chillers can cool using utility-cogenerated heat).

The scenarios consider two hypothetical utility-based cogeneration networks: basic and advanced. The basic network consists of the current network of Ontario Hydro thermal stations, with only minor cogeneration modifications implemented in some nuclear and coal stations. The advanced network consists of a modified network, where some multi-unit stations are separated and located near heat demands, and where advanced cogeneration technologies are used along with current-technology thermal stations modified for cogeneration. For the advanced network, government intervention through legislation and incentives to promote cogeneration is assumed to be sufficiently great to result in significant market penetration for cogeneration and the perception that cogeneration can be used as a conventional heating technology. Hot-water storages are used in both networks, especially for coal stations, which operate much more intermittently than nuclear stations.

The scenarios consider two potential cogenerated-heat users: the residential-commercial and industrial sectors. The annual heat demand in Ontario in 1990 for the residential-commercial sector was 514.5 PJ and for the industrial sector 414 PJ. The residential-commercial demands are almost exclusively for low-temperature heat for space and water heating, while the industrial heat demand is for various tasks and, based on a breakdown determined elsewhere, is approximately made up of 59.5 PJ at low temperatures (<125°C), 147.0 PJ at medium temperatures (125-400°C) and 208.5 PJ at high temperatures (>400°C).

In all scenarios, half of the cogenerated heat is used to offset electricity provided by Ontario Hydro to users for heating. The other half of the cogenerated heat is used to offset the non-Ontario Hydro energy resources (e.g., natural gas and oil) used by others for heating. Also, the cogenerated heat is assumed to be produced from coal and nuclear energy, in the same proportions as electricity is generated from them currently (i.e., 33% from coal and 67% from nuclear energy). To supplement the cogenerated electricity, non-cogenerating coal and nuclear generating stations based on current technology are used, again in the same proportions as cited above.

Potential markets in Ontario for utility-cogenerated thermal energy are a portion of the total thermal-energy demands in the residential, commercial, institutional and industrial sectors. These markets depend on many factors:
(i) the quantity, supply rate and temperature of supplied heat must satisfy all demand requirements;
(ii) users and suppliers of thermal energy must be located within a suitable distance of each other;
(iii) heat must be available when it is in demand, either by cogenerating when heat is demanded or storing the heat during periods between its generation and utilization;
(iv) overall infrastructure and all relevant technologies must exist for all cogeneration steps, including heat supply, distribution, storage and utilization;
(v) the system must be able to accommodate actual variations in heat-demand parameters (quantity, temperature, etc.);
(vi) the attitude towards the idea must be positive for all parties involved (suppliers, distributors, users, etc.); and
(vii) given a traditional economic approach, the economics for cogeneration options should be at least competitive with, and preferably superior to, the economics for other non-cogeneration options.

Note that the inclusion of externalities such as environmental costs can substantially increase the economic competitiveness of cogeneration and that environmental policy objectives may lead to cogeneration options being considered even in cases where they are not competitive when environmental impacts are omitted from the cost and benefit calculations.

The portions of the heat demands to be met by utility-cogenerated heat (referred to in Section 1) are estimated by considering the factors discussed in the previous paragraph. The main factors involved here in deciding to use utility-cogenerated heat are taken to be distance, infrastructure, attitude, economics and temperature. It is assumed

for the residential-commercial sector that
(i) for all scenarios, utility-cogenerated heat temperatures permit 100% of heat demands to be satisfied, as they are all at low temperatures;
(ii) 35% of heat demands are within a serviceable distance of the cogeneration plant for scenario A, and 60% for scenario B; and
(iii) 25% of potential users find the infrastructure/attitude/economic conditions favourable enough to use cogenerated heat for scenario A, and 65% for scenario B.

For the industrial sector, it is assumed that
(i) utility-cogenerated heat temperatures permit 100% of low- and medium-temperature industrial heat demands to be satisfied for scenarios C and D, 30% of high-temperature demands for scenario C and 40% for scenario D;
(ii) 30% of low, 23% of medium and 15% of high temperature demands are located within a serviceable distance of the cogeneration plant for scenario C, while the corresponding values are 60, 45 and 30% for scenario D; and
(iii) 40% of potential users find infrastructure/attitude/economic conditions to be favourable enough to use cogenerated heat for scenarios C and D.

A computer code, developed by Ryerson graduate P. Gharghoury, following the method outlined in this section, was used in the analyses. The code is a simple and straightforward tool for calculating and accounting for all energy quantities in the system.

3.2 Present Study

The methodology used in the previous studies (Rosen, 1994; Rosen and Dimitriu, 1993) to assess the annual effects of utility-based cogeneration in Ontario is used here. The characteristics of the six scenarios are unchanged. However, data for the base-case year (1989 in the previous study) are modified for future years through to 2010. The computer program used in the scenario assessments in the previous studies (Rosen, 1994; Rosen and Dimitriu, 1993) is applied to each new base year so as to determine the annual reductions in energy use and emissions for that year.

Energy use for the initial base-case year (1989) is shown in Table 1. To modify the base-case year, predictions are utilized of annual energy use and environmental emissions to 2010, by the National Energy Board of Canada (1991) and Statistics Canada (1990; 1991). The resulting base-case energy usage, for each year from 1989 to 2010, is presented in Table 1 of another report (Rosen *et al.*, 1993a).

Table 1: Annual Energy Use (in PJ) in Ontario for the Initial Base-Case Year (1989)

	Utility	Non-Utility	Total
Electricity	-	448	448
Gas & NGL	-	886	886
Oil & Petroleum	17	837	854
Coal	441	21	462
Other	-	168	168
Uranium	783	-	783

The predictions for the base-case year are based on data in the report *Canadian Energy Supply and Demand, 1990-2010* (National Energy Board of Canada, 1991) and are modified to match values of Statistics Canada (1990; 1991) in the past years (i.e., 1989, 1990) by noting that there is no wood energy use in residential sector and by assuming the following:
(i) utility-sector oil use is constant from 1990 to 2010 at 14 PJ/yr;
(ii) provincial coal use (excluding the utility-sector) is constant at 21 PJ/yr;
(iii) agriculture-sector energy use is constant at 43 PJ/yr;
(iv) the fuel breakdown for space and hot water heating in previous reports (Rosen, 1994; Rosen and Dimitriu, 1993) applies here; and
(v) reductions in environmental emissions are proportional to reductions in the use of the fuels from which the emissions are produced.

Annual emissions to the environment of SO_2, NO_X and CO_2 from the utility sector, broken down by fuel, for the initial base-case year (1989) are presented in Table 2. The modified base-case emissions, again based on projections by the National Energy Board of Canada (1991), are presented for each year between 1989 and 2010 in Table 3(a) of another report (Rosen *et al.*, 1993a).

The base year data used here for 1989 and 1990 differ slightly from the data for those years

Table 2: Annual Utility-Sector Emissions of SO_2, NO_X and CO_2 in Ontario, Broken Down by Fuel Source, for the Initial Base-Case Year (1989)

	Material Emissions (kt)		
	SO_2	NO_X	CO_2
Coal	294.8	60.2	26,991
Oil	2.8	8.3	1,194
Natural Gas	0.0	0.0	0
Total	297.6	68.5	28,185

used previously (Rosen, 1994; Rosen and Dimitriu, 1993) because a different categorization is used for some data and because some different data sources were utilized.

4. Results and Discussion

The scenario-assessment results, as discussed in the next two subsections, indicate that the annual and cumulative reductions from 1989 to 2010 in energy use and related environmental emissions, due to implementation of a utility-based cogeneration program, would be significant.

4.1 Reductions in Energy Utilization

For scenarios A to F, Figure 2 presents annual

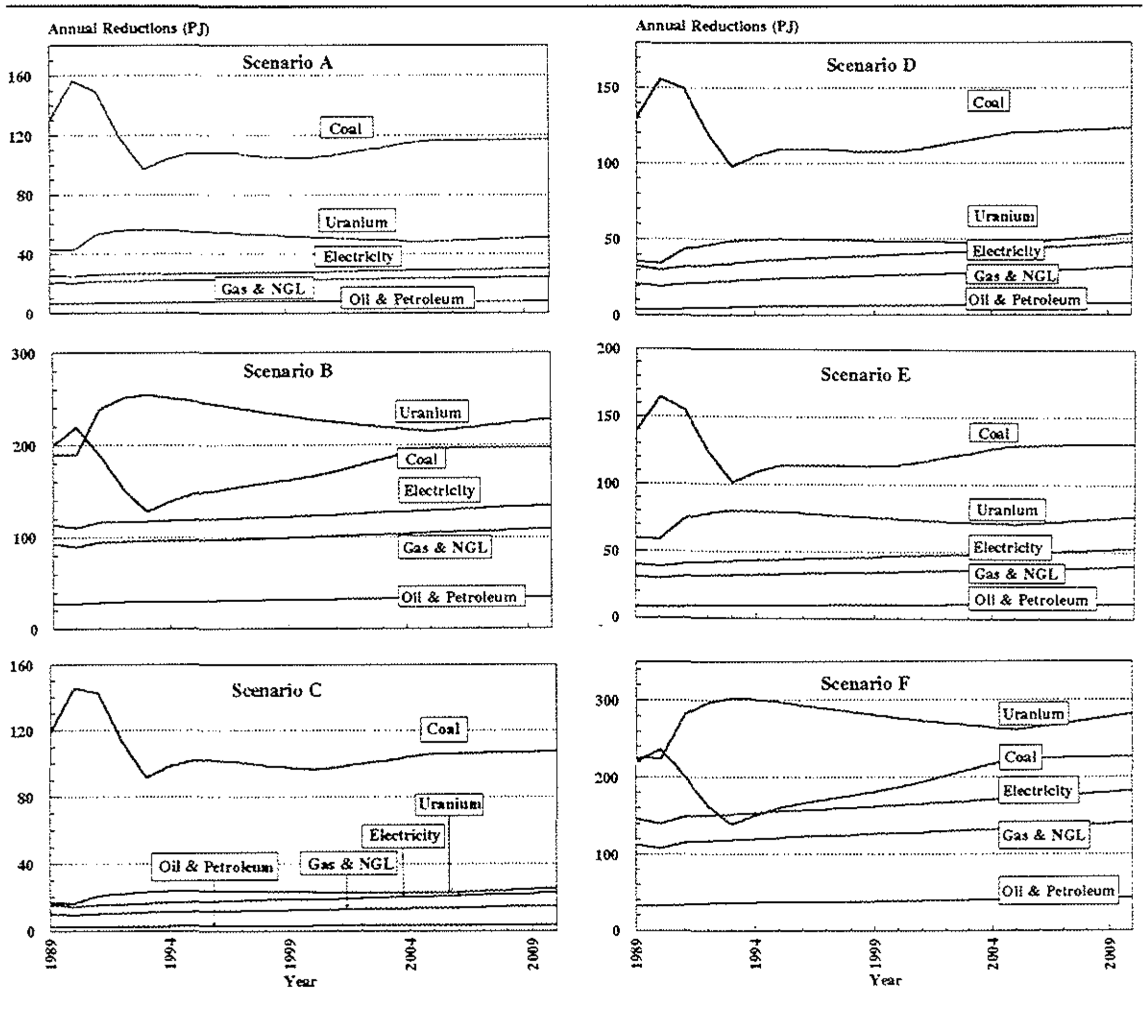

Figure 2: Annual reductions in Ontario energy use, for several energy forms, from 1989 to 2010, projected for six utility-based cogeneration scenarios.

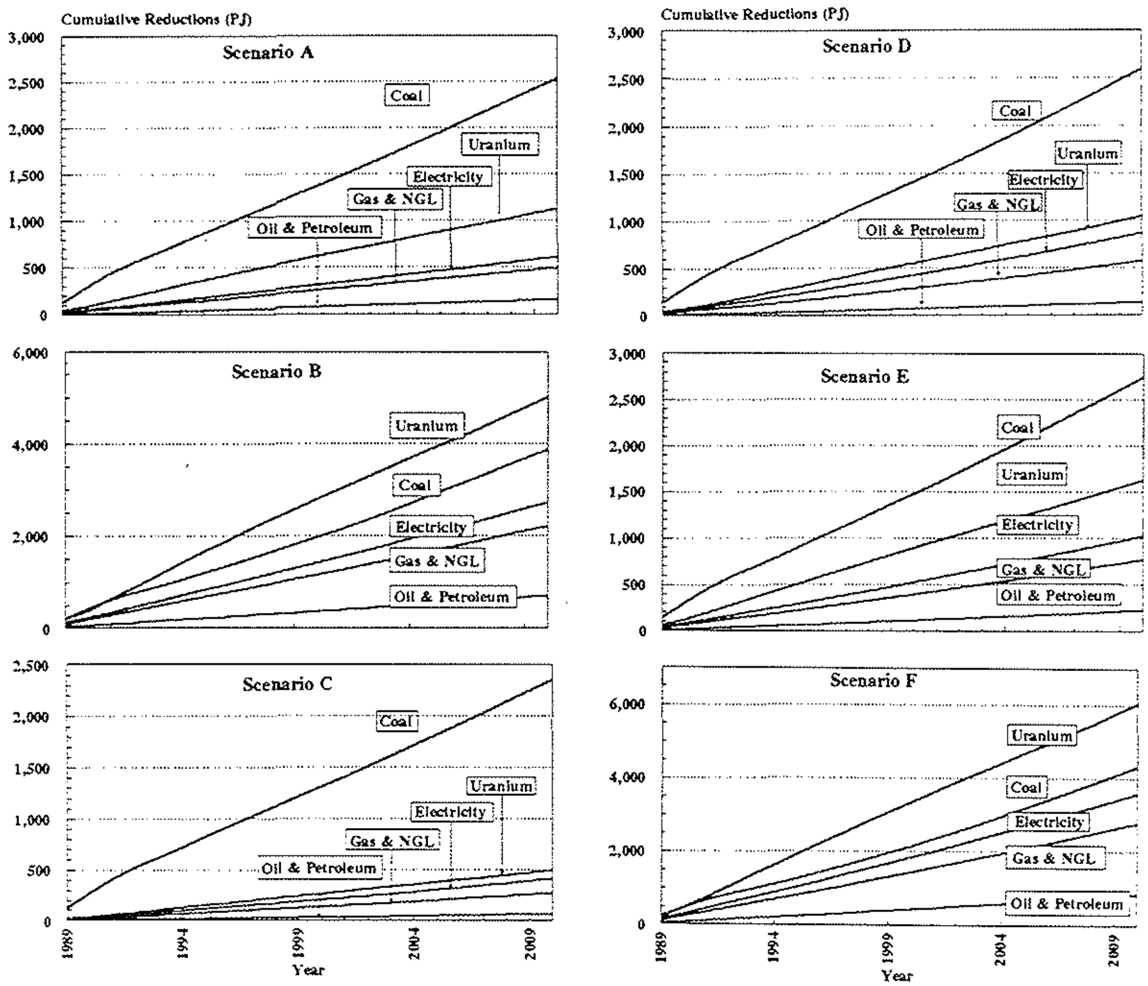

Figure 3: Cumulative reductions in Ontario energy use, for several energy forms, from 1989 to 2010, projected for six utility-based cogeneration scenarios.

reductions in provincial energy use between 1989 and 2010, while Figure 3 presents cumulative reductions through to 2010. These figures are based on the following data:

(i) annual reductions in energy use in Ontario for each year between 1989 and 2010, for each of the six cogeneration scenarios, as presented in Table 1 of another report (Rosen *et al.*, 1993a); and

(ii) the same data, but with the reductions given as percentages from the base-case values, as presented in Table 2 of the same report.

In these tables, annual reductions in energy use for the utility sector, non-utility sector and the total province are presented.

In Figures 2 and 3, five energy forms are considered: electricity, natural gas and natural-gas liquids (NGLs), oil and petroleum, coal, and uranium. The annual and cumulative reductions in Figures 2 and 3 for electricity, natural gas and NGLs, and oil and petroleum occur entirely within the non-electrical-utility sectors of the province, while reductions for coal and uranium occur entirely within the utility sector (except that a small portion of the coal reduction occurs within the industrial portion of the non-utility sector for scenarios C, D, E and F). It is noted that the reductions in utilization of the primary

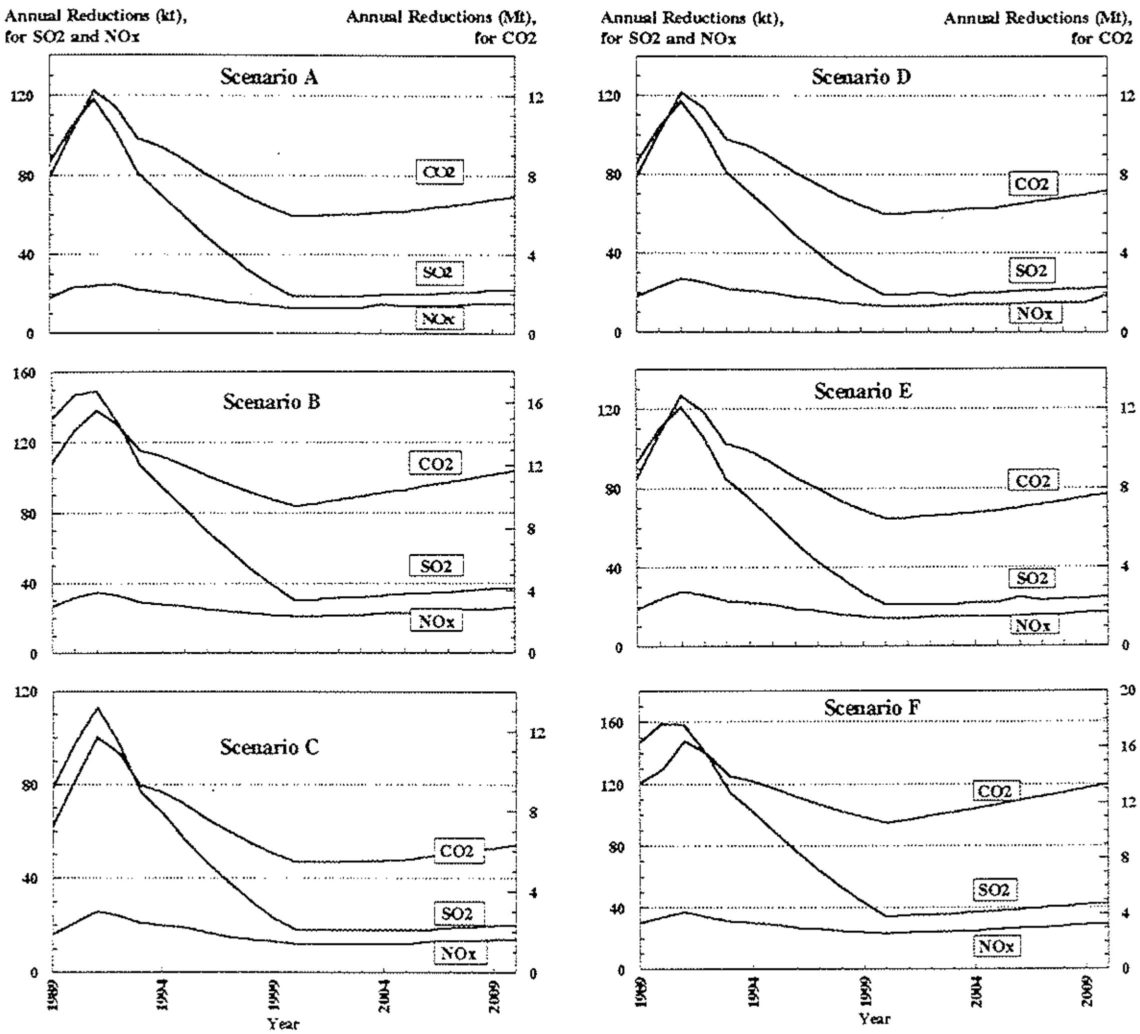

Figure 4: Annual reductions in utility-sector environmental emissions of SO_2, NO_X and CO_2 in Ontario from 1989 to 2010, projected for six utility-based cogeneration scenarios.

energy forms coal and uranium are not independent of the reduction in the utilization of the secondary energy form electricity. Rather, the reduction in electricity use for heating, achieved through the use of cogenerated heat in its place, leads to reduced requirements for the coal and uranium used to generate the electricity.

It is shown in Figures 2 and 3 that, for the six cogeneration scenarios during the period 1989 to 2010, the cumulative reductions in usage for electricity, coal and uranium, respectively, range from as low as 414 PJ, 2358 PJ and 500 PJ (for scenario C) to as high as 3587 PJ, 4328 PJ and 6057 PJ (for scenario F). The corresponding average annual reductions for these three energy forms, respectively, range from as low as 19 PJ, 107 PJ and 23 PJ (for scenario C) to as high as 163 PJ, 197 PJ and 275 PJ (for scenario F).

4.2 Reductions in Environmental Emissions

For scenarios A to F, Figure 4 illustrates annual reductions in emissions of SO_2, NO_X and CO_2 by the utility-sector between 1989 and 2010, while Figure 5 illustrates cumulative reductions through to 2010. These figures are based on the reductions

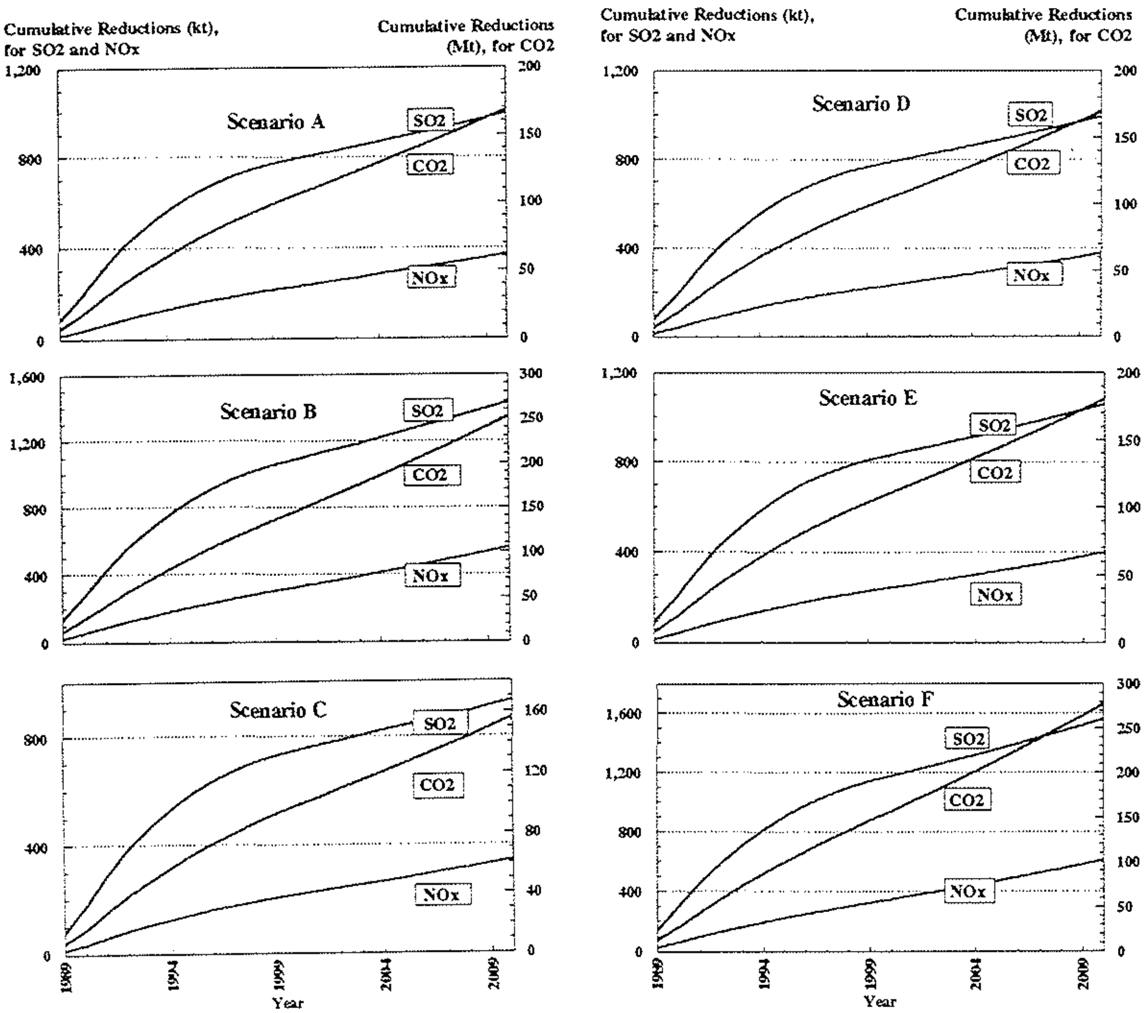

Figure 5: Cumulative reductions in utility-sector environmental emissions of SO_2, NO_x and CO_2 in Ontario from 1989 to 2010, projected for six utility-based cogeneration scenarios.

in annual emissions to the environment of SO_2, NO_X and CO_2 from the utility sector in Ontario, for each of the six cogeneration scenarios, and for each year between 1989 and 2010, listed in Table 3(b) of another report (Rosen *et al.*, 1993a).

The reduction in utility-sector emissions of CO_2 due to implementation of the cogeneration scenarios is particularly significant. It is shown in Figure 5 that the cumulative reduction in utility-sector CO_2 emissions between 1989 and 2010 ranges from as low as 156,200 kt (for scenario C) to as high as 277,600 kt (for scenario F). Similarly, cumulative reductions in SO_2 and NO_X emissions, respectively, range from as low as 932 kt and 345 kt (for scenario C) to as high as 1565 kt and 614 kt (for scenario F).

4.3 Other Issues

The benefits of implementing a utility-based cogeneration program in Ontario, as discussed in this paper, may be further enhanced if a cogeneration-based system for providing chilled water for space cooling is also implemented. This idea is investigated in related reports by the present authors (Rosen *et al.*, 1993b, 1994).

5. Conclusions

The annual and cumulative reductions in energy use and related environmental emissions between 1989 and 2010, theoretically possible due to the implementation of a utility-based cogeneration program, are likely to be significant. These conclusions are consistent with and reinforce many of those from previous studies by the authors into the opportunities for utility-based cogeneration in Ontario (Rosen, 1994; Rosen and Dimitriu, 1993). Consequently, it would appear to be worthwhile for Ontario to consider the development and implementation of a utility-based cogeneration program designed for optimal provincial benefits.

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