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# Vermont City Electric Optimization Modelling

**MGMT 573 – Case 3 – Group 6**

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## Introduction

Vermont City Electric (VCE) is a municipal utility established in 1905 to provide affordable electricity to Vermont City residents while pioneering sustainable energy practices. Facing budget constraints and climate commitments, VCE employs demand-side management (DSM) strategies to reduce energy consumption and shift demand away from peak periods. Daniela Shazar, is brought in to as a member of VCE's Citizen's Oversight Board, to leverage optimization modeling to prioritize DSM programs that maximize cost savings and carbon reductions under a strict $800,000 budget. Her analysis balances immediate financial limitations with long-term environmental goals, ensuring VCE meets its dual mandate of affordability and sustainability.

VCE's strategy integrates cost-effective DSM programs, such as energy-efficient retrofits, smart lighting, and renewable energy incentives, with an optimized power supply mix. By segmenting annual demand into load blocks, VCE allocates low-carbon sources (e.g., wood-powered McNeil, hydro Contracts, and future Wind) to high-demand blocks, minimizing reliance on expensive, carbon-intensive options like oil-fired VCE GT and the Market. A mixed-integer optimization model selects DSM programs that deliver the greatest MW savings per dollar, prioritizing initiatives with lasting impacts across six years. This approach reduces emissions by curbing peak demand and strategically aligning supply costs with environmental priorities, ensuring compliance with budget constraints while advancing Vermont City's climate goals.

**Problem Statement**: Find the DSM programs that VCE should retain or eliminate given the current budgetary environment and objective to minimize cost. What is the total carbon impact of this strategy?

## Question 1

**Assumptions/Predictions :** 1. Cost growth rate per year of 3% for McNeil 4% for all other power sources. 2. Population growth rate 0.52% per year and per capita use growth of 0.02% per year.

Without DSM activities, the trend was to get power from the cheaper sources for the various power blocks as illustrated in Table 1. The cost of power peaks at block 3 and drops to the lowest at block 5 as expected. VCE relies mainly on its in-house power generation from McNeil and VCE GT for blocks one, two and three. This solution makes good intuitive sense because the cheapest sources of power are chosen first in the first 3 blocks and then market is used during peak demand.

*Table 1- MW of power in 2009*

| | | Block 1 | Block 2 | Block 3 | Block 4 | Block 5 |
|---|---|---|---|---|---|---|

| | | | | | | |
|---|---|---|---|---|---|---|
| McNeil | | 26.5 | 26.5 | 26.5 | 0 | 0 |
| Contracts | | 14.9 | 14.9 | 14.9 | 0 | 0 |
| VCE GT | | 18 | 7.356 | 0 | 0 | 0 |
| Market | | 0.068 | 0 | 0.021 | 32.27 | 26.509 |
| | | 59.468 | 48.756 | 41.421 | 32.27 | 26.509 |

The wholesale market is the only source considered for blocks four and five to reduce costs even though the $CO_2$ emissions was considerable higher. The carbon impact of this decision as shown in table 2 is the higher $CO_2$ emissions in block 4 and 5 but it is needed to make this decision to satisfy demand in block 4,5.

*Table 2*

| | Block 1 | Block 2 | Block 3 | Block 4 | Block 5 |
|---|---|---|---|---|---|
| Carbon Impact | 5,113.35 | 5,265.56 | 4,455.46 | 46,899.93 | 6,247.64 |
| TON CO2 Emissions in 2009 | 67,981.94 | | | | |

The adjusted cost of the DSM activities is a reduction in the cost of power from 2009 to 2014 t*able 3*. DSM strategies reduce total costs and

*Table 3*

| | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|---|
| Cost | $18,144,551.03 | $18,783,060.83 | $19,653,730.33 | $20,180,980.19 | $21,170,007.20 | $22,545,062.37 |
| Adjusted Cost | $18,144,551.03 | $17,468,246.57 | $17,098,745.38 | $16,548,403.76 | $16,089,205.47 | $16,006,994.28 |
| Total Cost | **$101,356,146.49** | | | | | |

All of the DSM programs except "Business: New Construction" are selected. Considering that the total cost of selected programs should be under $800,000, it was excluded from the program.

- VCE should retain the following 8 programs:  Business: Existing Facilities
- Residential: New Construction
- Residential: Existing Homes
- Retail Products
- Commercial Smartlight
- Commercial Heating and A/C
- Commercial Outdoor Lighting
- LED Streetlight Program

This solution is logically sound because the excluded DSM program, "Business New Construction," saves approximately the same amount of power as "Business: Existing Facilities," the program with the highest power savings. Therefore, it makes sense to select only one of the two most expensive and highest power-saving programs and then allocate the remaining budget to include as many other DSM programs as possible while staying within budget. The total direct cost of the selected programs is **$794,547**, which stays within the $800,000 budget. Business: New Construction ($240,480) exceeds the remaining budget if added, so it is excluded. The selected programs optimize cost savings in meeting the electricity demand.

DSM programs within the stated budget reduce the demand in each block, leading to lower energy production from higher carbon sources like VCE GT and Market, thus reducing total $CO_2$. However, if the budget were increased, Business: New Construction could be included, which has a higher MW saved, especially in Block 1 (peak), leading to more savings. Therefore, the budget restriction does impact the choice because without it, all programs could be selected. The current selection leaves some budget unused, but adding the more expensive program would exceed the limit. Hence, increasing the budget would allow including more programs, which may increase costs but provide lower carbon emissions.

## Question 2

The total carbon impact of the DSM strategy is an output of **340,283.53** from 2009 to 2014. The breakdown is provided in t*able 4*.

*Table 4*

| Carbon Impact | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | Total |
|---|---|---|---|---|---|---|---|
| TON CO2 Emissions | 67,981.94 | 67,580.9 | 68,349.39 | 67,419.95 | 69,167.22 | 68,951.86 | 340,283.53 |

The total carbon emissions over 2009–2014 are due to the selected DSM programs which focus on cost savings. The model minimizes reliance on high-carbon sources (e.g., VCE GT and Market). In 2009, for instance, the "Market" usage in Block 1 is reduced to 0.068 MW (vs. 50 MW capacity), lowering emissions. We see here that DSM strategies reduce the carbon impact till the year 2012 and then the carbon impacts increase in 2013 and 2014. This is because the demand of power increases in 2013 and 2014 by a greater margin which increases costs, supply and carbon impact. The population growth rate and the per capita use growth rate significantly affects the demand in 2013 and 2014. This happens after the installation of wind power source in 2012.

→ 3.Budget Restriction Impact:

The $800,000 budget restricts including Business: New Construction.  Case for Increasing the Budget:

Including Business: New Construction would save **0.246 MW in Block 1** (peak demand), reducing reliance on expensive, high-carbon Market power during peak hours. This could lower long-term costs and emissions, justifying a budget increase. The current budget leaves **$5,453** unused, indicating room for strategic reallocation or expansion.

Limitations of the model

Some limitations identified include:

- DSM programs are modeled as binary, preventing partial implementation. Phased or scaled adoption might offer better cost-efficiency in reality.
- DSM energy savings are assumed constant over all six years, neglecting possible efficiency decay or changes in user behavior.
- The model assumes constant annual population growth (0.52%) and per capita electricity use growth (0.22%), ignoring potential economic, technological, or behavioral shifts.

**Memo to the Citizen's Oversight Board**

Subject: DSM Program Recommendations for 2009

**Key Findings:**

- Optimal Programs: 8 programs selected, costing **$794,547** (under budget).
- Carbon Reduction: DSM reduces peak demand, cutting emissions from oil (VCE GT) and Market sources.
- Budget Impact: Current limit excludes Business: New Construction. A higher budget could enhance savings.

**Recommendation:**

Approve the 8 programs and consider a budget increase to include Business: New Construction for greater long-term efficiency.

**Attachments:**

- Total DSM Cost: **$794,547**
- Carbon Savings: Estimated reduction in $CO_2$ emissions across all blocks (detailed in model).

Optional Thought Question (Carbon Tax):

A 2014 carbon tax would incentivize VCE to prioritize low-carbon sources (McNeil, Contracts, Wind) over Market and VCE GT. This would reduce emissions but increase costs if high-carbon taxes apply. The model would reallocate energy supply to minimize tax liabilities, potentially accelerating investments in renewables.

**Appendix**

Budget constraint

$$Y_1 \times 240480 + Y_2(353622) \ldots\ldots Y_9(46240) \leq 800{,}000.$$

$Y_n$ = binary $\Rightarrow \in (0,1)$

$X_{ijk}$ = Non negative ; $\geq 0$

Carbon Emission Calculation

$$\sum_{j=1}^{5}\sum_{k=0}^{5}\left(X_{1,j,k}(0.028) + X_{2,j,k}(0.022) \ldots X_{4,j,k}(0.491)\right)$$

# Solution Structure.

Variables $X_{ijk}$ , $Y_n$

$X_{ijk}$ :- MW of power from vendor (i) in block (j) during year (k)

$Y_n$ :- = 1 if DSM (n) is selected ; 0 otherwise.

Objective Function

- Minimize Sum of Total Cost : $\sum_{k=0}^{5}$ Total Cost

Total Cost in 2009 = (k=0)
= No. of hours in all Blocks × MW of power used in 2009 × Cost per MWh × discount factor in 2009

Total Cost in 2010 (cost growth rate for each vendor applied)
= No. of hours in all blocks × MW of power used in 2010 × Increased Cost/MWh in 2010 × discount factor in 2010.

Same calculation for all years till 2014

- Increased Cost Calculation :

$\sum_{i=1}^{4} \sum_{j=1}^{5} \sum_{k=0}^{5}$ cost per MWh ( 1 + percentage increase in cost).

For eg. • For 2010, for McNeil in Block 1,
= 50.9 (1+0.03) = \$ 52.42
• For 2011, for McNeil in Block 1,
= 52.42 (1+0.03) = \$ 53.9 ...... till 2014.
Follow same for all years

Constraints.

→ Demand Constraint

For 2009. $\sum_{j=1}^{5} \sum_{i=1}^{4} X_{ij} \geqslant$ Average load in block(j) − Total Savings from DSM (n) in block j.

$$X_{11} + X_{21} + X_{31} + X_{41} + X_{51} \geqslant 60.1 - 0.632.$$

$$\cdots\cdots X_{41} + X_{42} + X_{43} + X_{44} \geqslant 27.1 - 0.644.$$

For 2010-2014 $\sum_{j=1}^{5} \sum_{i=1}^{4} X_{ij} \geqslant$ Average load (1+ Population growth rate)$^{year(t)}$ × (1+ Per capita use growth rate) − Total Savings from DSM (n) in block j.

$$\sum_{i=1}^{4} X_i \geqslant 60.1(1+0.0052)^1(1+0.0022)^1 - 0.632 \cdots$$

$$\cdots\cdots \sum_{i=1}^{4} X_i \geqslant 27.1(1+0.0052)^5(1+0.0022)^5 - 0.591$$

↑This includes all blocks (j) in years 2010-2014.

→ Capacity Constraint:

$i=1$ $\sum_{k=0}^{5} X_{1,k} \leq 26.5$ (For each block (j)).

$i=2$. $\sum_{k=0}^{5} X_{2,k} \leq 14.9$ (For each block j)

$i=3$. $\sum_{k=0} X_{3,k} \leq 18$ (For each block j)

$i=4$. $\sum_{k=0} X_{4,k} \leq 50$ (For each block j).