

# Energy Sufficiency Kaizen Achieving Zero Energy Cost and Variance with Sufficiency-inclusive Private Energy Portfolios

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## ABSTRACT

Mid-sized industrial and commercial firms consume between 300 to 30,000 MWh of electrical and thermal energy per month. Energy managers in these firms seek to minimize costs, both in terms of absolute expense and the indirect costs of variances from expected quality.

While many business managers negotiate direct utility costs, few firms have a continuous improvement process that structure cost control, efficiency improvement, and risk reduction. A complete management process requires planning, quantifying and exercising options, and variance analysis of efficiency and risk measures. The methods to accomplish this are not well understood.

We describe how an Energy Index is used in the context of the Deming cycle with sufficiency-inclusive private energy portfolios, usually implemented as a microgrid. We discuss valuation, planning techniques, and show how business can institute a process that can be used to drive both energy cost and variance to zero over time.

**Keywords:** Energy Index, Energy Portfolio, Efficiency, Deming Cycle, Discounted Cash Flow, Distributed Generation, Kaizen, PDCA, Real Options, Reliability, Sufficiency, Variance Analysis, Zero Cost, Zero Variance

## Nomenclature

$c^d$  —Demand Rate [\$/kW]

$\gamma^d$  —Demand Charges [\$]

$\Gamma_r$  —Risk adjusted real cost of energy

$d$ —energy consumption [kWh]

$D$ —Total Energy consumed to produce  $O$  [kWh]

- e—emissions cost [\$/kWh]  
L( $\tau$ )—Instantaneous Load in [kW]  
MTTF—mean time to failure [hours]  
MTTM—mean time to maintain [hours]  
MTTR—mean time to repair [hours]  
O—economic output per year [\$]  
R—reliability impact cost factor  
T—Billing Period typically a month [days \* 24 hours]  
 $\Delta t$ —Sampling period typically 15 minutes [0.25 hours]  
 $\Lambda$ —economic loss per year due to energy variances  
 $\tau$ —Time variable [hours]  
 $\Phi$ —Private energy portfolio  
 $\Psi$ —Total Energy produced by sufficiency resources [kWh]

## INTRODUCTION

The emergence of distributed generation (DG) presents a challenge to established energy management methods. While private control over a microgrid lowers energy costs, it can also increase management burden. To offset this extra effort, energy sufficiency, the degree to which one controls one's own energy supply, must be a forward-looking energy management process that follows *zero cost* and *zero variance* principles.

Our experience shows that energy managers are subject to a largely reactive management process. For businesses that consume medium to large quantities of energy, paying \$-\$10 million per year, an energy oriented continuous improvement process is largely incomplete or absent.

We list here a few of the many improvement opportunities in the typical energy management process:

- Valuation of efficiency or sufficiency investments is usually based on a discounted cash flow (DCF) assessment. Managers typically hesitate to invest in fuel driven sufficiency, in spite of a positive NPV, because of their intuitive perception of fuel risk.
- Not all energy managers consider distribution and transmission fees as variables. Energy contracts often compete on generation cost alone, which ignores the remaining cost components that can vary from 10% to 25% of the total.

- Monolithic contract structures do not allow cost curves that follow demand curves. Most business managers desire their costs to follow the demand, preserving profits as much as possible in a downturn. Energy contracts are negotiated on a current price equilibrium basis, but this may not represent the interests of the buyer over time.
- Ambient energy systems, such as solar, often deliver a small share of energy needed, and are often dismissed as inadequate even with a favorable unit price. Managers lack the tools to plan and benefit from an iterative improvement scheme.
- Energy efficiency improvement measures are rarely in an integral interplay with demand/response, load, storage, or sufficiency contract options, so that business managers may actively exploit the economic advantages of microgrid resources.

The Deming (Plan-Do-Study-Act, Figure 2) cycle [1] is a well-established framework of continuous improvement (Kaizen), and of orienting a business process' compliance with its customer requirements. The purpose of this cycle is to make sure that a business is executing according to a plan, which, presumably, reflects a manager's interpretation of customers' wishes.

We demonstrate the use of an energy index that comprises both efficiency and sufficiency factors, derived through constructive manipulation of a sufficiency-inclusive private energy portfolio. Zero cost and zero variance is attained over time by placing this index dynamic into the Deming Cycle context.

## ENDX – THE ENERGY INDEX

An energy portfolio is a set of contracts for the purchase of some number of units of energy at an agreed-upon price. There is little new or exotic about this: energy utilities manage extensive energy portfolios with frequently shifting positions. Portfolios offer a number of risk management options, insulating the portfolio owner from supply, but not systemic risk.

Few such portfolios, if they are private, are energy sufficient, i.e.,

they do not include controlled DG resources<sup>1</sup>. We suggest that managed energy portfolios should be extended to include sufficiency resources as a matter of course, i.e., onsite generation of thermal and electrical energy, as required. We will show that this inclusion enables a continuous improvement in energy productivity and a lowering in cost beyond that attainable by traditional market-only means. In fact, portfolios with certain types of sufficiency are the only way to attenuate systemic risk.

### Definitions

We introduced an energy index (Endx or Ex(t)) based on a factor of efficiency and sufficiency ratios [2], which is expressed as

$$\text{Ex}(\Phi, t) = O(t) \cdot [\Psi(\Phi, t) / \Gamma(\Phi, t) D(\Phi, t)]$$

where the comprising functions are

O—Enterprise output value [\$]<sup>2</sup>

$\Gamma$ — Cost of Energy [\$]

$\Psi$ —Energy produced by sufficiency resources [kWh]

D—Total Energy consumed to produce O [kWh]<sup>3</sup>

And some stochastically evolving energy portfolio  $\Phi$ :

$$\Phi = \{M \cup S \mid M = (M_1, m_2, \dots, m_n), S = (s_1, s_2, \dots, s_k)\}$$

Where M are market contracts and S are sufficiency contracts. We redefine the aggregate energy portfolio cost C for some point in time t as  $\Gamma$  to avoid later confusion.

We assume that O is a random stochastic variable, and  $\Gamma$ ,  $\Psi$  and D are stochastic functions on an energy portfolio  $\Phi$ .

### The Challenge of Planning

To develop a plan one must quantify desired future value, as shown in Figure 1 for Endx:

A planned Ex(t) value provides the regression value for variance analysis. The purpose of planning is not only to improve energy productivity, but also align cyclical output (O) with load (D). What process might business managers, such as logistics or financial officers, use to plan Ex, and, more importantly, what value does this have?

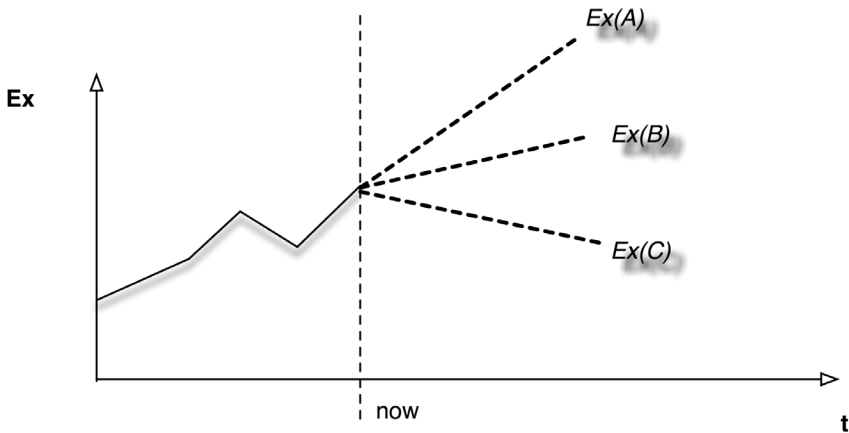


Figure 1. Finding a desirable future Endx value

### The Sufficiency Kaizen Process

Nobody knows what the price of energy will be next quarter or next year. Forecasts are by definition erroneous, and the decision of what kind of energy purchasing instrument to structure is not much different from placing a bet in a casino.

Yet, energy managers are expected to position their companies for minimal energy risk, and we believe that much can be done. While most continuous improvement specialists concentrate on continuous efficiency improvement, much of the risk, cost, and control issues are related to energy supply.

Kaizen, Japanese for “change for the better,” is one of the core ideas behind the Toyota Production System, a school of thought of industrial productivity that grew out of the teachings of W. Edwards Deming. The idea behind Kaizen is that everything should continuously improve towards the changing wishes of the customer. The implementation of this idea is necessarily complex for complex enterprises, and Sufficiency Kaizen is no different.

Much as the concept of zero inventory production under wide variety demand conditions was once considered implausible<sup>4</sup>, today zero energy variance and cost may seem equally so.

However, we know of no laws of nature, or economics, that contradict this path for energy management. For some firms zero energy cost is already a reality, albeit on a smaller scale. Sufficiency Kaizen seeks to harness this dynamic on an industrial scale.

We subsequently describe a six-step process that describes Sufficiency Kaizen, depicted in overall sequence in Figure 2. Then the six steps are discussed in detail.

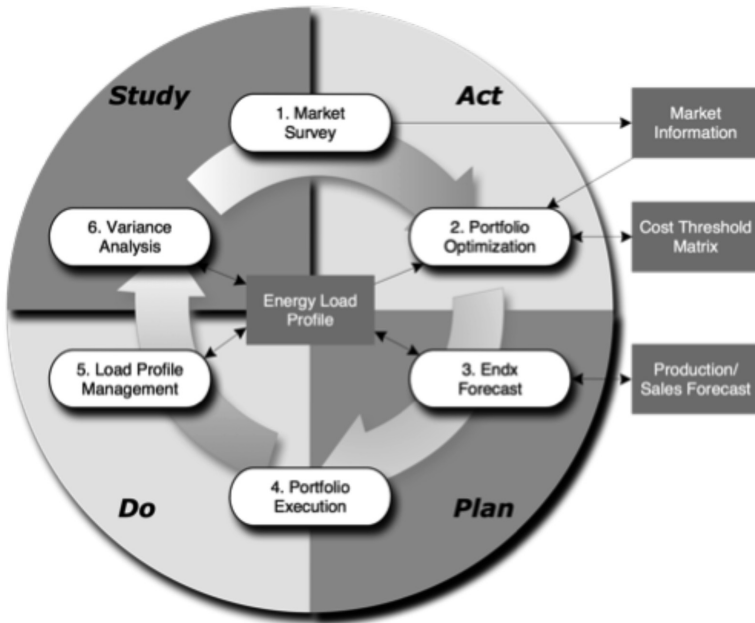


Figure 2. Sufficiency Kaizen process diagram

### SURVEYING THE MARKET

To create options, energy managers must continually be aware of marketplace development in terms of available market contracts, regulatory constraints, and technological innovation. A structured and continuous market survey gathers information about the net present value (NPV), performance characteristics, and investment costs of proven (or even experimental) energy technologies—these either reduce the load profile (D) or generate (convert) required energy.

### OPTIMIZING THE PRIVATE ENERGY PORTFOLIO

The objective of this step is to determine the lowest cost energy sources for the next working period. The result is a cost threshold matrix

(example shown in Figure 5), which lists the energy unit cost thresholds for each portfolio contract option, and the amount of energy supply offered by that option.

Consider a private energy portfolio that evolves over some time interval 0 to  $z$ , as shown in the following diagram (Figure 3).

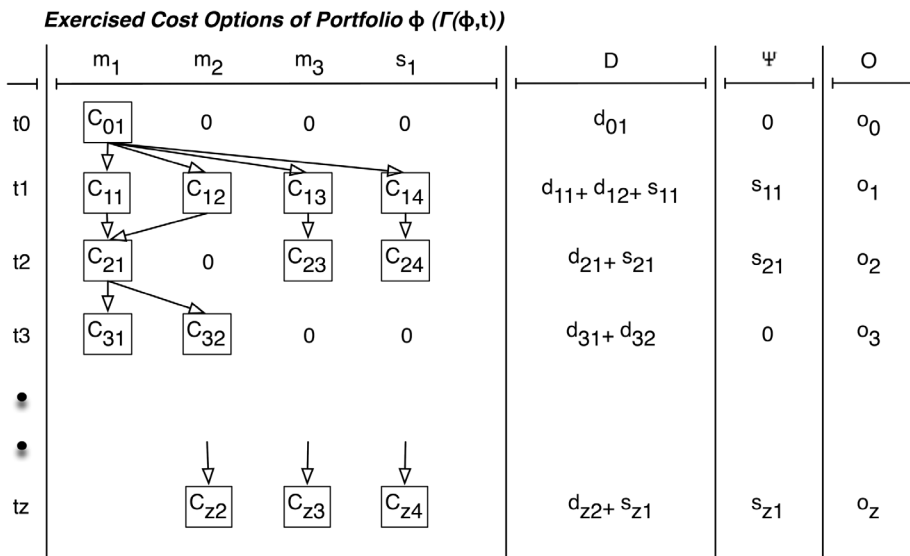


Figure 3. Example evolution of a private energy portfolio with sufficiency resources and Endx parameters<sup>5</sup>

In time period t<sub>0</sub> all energy is purchased from market contract m<sub>1</sub>. The unit cost of m<sub>1</sub> is c<sub>01</sub> (\$/kWh) and d<sub>01</sub> units (kWh) are purchased, so that C<sub>01</sub> = c<sub>01</sub> \* d<sub>01</sub>. No sufficiency systems are operating<sup>6</sup>.

In period t<sub>1</sub> we find that the Endx optimization tells us to diversify to m<sub>1</sub>, m<sub>2</sub>, m<sub>3</sub> market contracts. A sufficiency system is put into operation, which uses contract m<sub>3</sub> as a fuel, consuming d<sub>13</sub> units at a unit cost of c<sub>13</sub>, comprising a total cost of C<sub>13</sub>. The non-fuel operating cost of the sufficiency system is c<sub>14</sub>, and it produces s<sub>11</sub> kWh of energy, costing C<sub>14</sub> dollars.

In period t<sub>2</sub> we find that m<sub>2</sub> has become too expensive, so the share of D is moved to both s<sub>1</sub> and m<sub>1</sub>.

In t<sub>3</sub> the market drops below the cost of s<sub>1</sub>, and so on, until some

final state  $t_z$  where we use  $m_2$  and  $s_1$ .

This is a hypothetical retrospective of an optimal Endx progression over  $z$  periods. In other words, we are at time  $t_z$  looking back over decisions made to illustrate the dynamic of Endx parameters.

To examine the decision-making process in detail, we now suppose we are at time  $t_0$ , planning for an optimized portfolio for time  $t_1$ . See Figure 4.

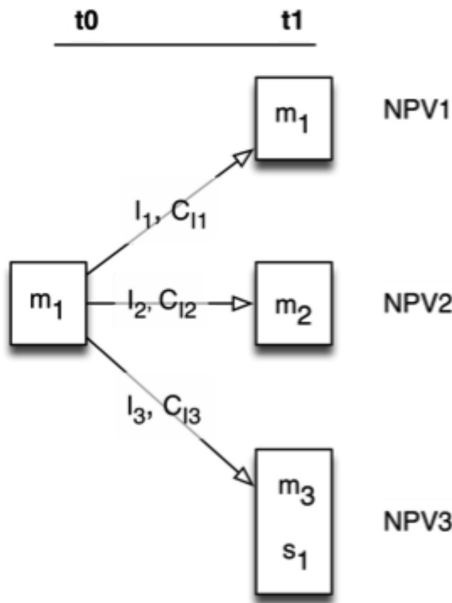


Figure 4. Decision matrix at time  $t_0$

**Methods of Optimized Portfolio Valuation**

As described above we supply the entire energy demand today ( $t_0$ ) with one single contract  $m_1$ . See Figure 4. The market survey has offered us three options: continue in full or in part using  $m_1$ , meet some of the load in combination with  $m_2$ , or combine  $m_1$ ,  $m_2$ , and some amount of  $m_3/s_1$ .  $m_3$  is a market contract for fuel that supplies  $s_1$ .

Each option bears an investment cost  $I$  and results in some cost  $C_1$ . The net present value of each potential contract is  $NPV_x$ . The goal is to find  $C_1$  for one or more portfolio options that meet  $D$  for period  $t_1$ , such that  $C_1 < C$ , or at least  $\min(C_1)$ .

Each portfolio option comes with its own historical average cost

rate of increase ( $\alpha$ ) and historical volatility ( $\sigma$ ), representing the risk of each option.

There are at least two methods for determining which option to take: future Discounted Cashflow (DCF), or Real Options. First, we have to understand the real unit cost of energy for each portfolio entry.

### Energy Real Cost Model

The basic energy cost equality is  $c \cdot d$ , or unit cost times volume. This cost accounting does not consider additional or subsequent costs of energy, of which there are several. We briefly discuss three influencing cost factors: emissions ( $e_s$ ), load ( $\gamma$ ), and reliability (R) costs.

### Emissions Pricing

Sustainability accounting requires that no further cost is incurred to anyone after process use, i.e., an indefinitely intact resource balance sheet.

Emitting combustion byproducts into the air is largely free. To see how this might change, consider that today most western city dwellers pay for their water supply twice: once for the water, and once for subsequent waste treatment. This cost burden was inconceivable fifty years ago, but when the rivers started burning<sup>7</sup> in the 1970's, attitudes, and prices changed.

Analogous to water pricing, the offset environmental costs of energy purchases can be modeled as a simple multiplier sensitive to volume, called  $e_x$ . Unless this value is reflected consistently in the balance of payments, its inclusion is voluntary. Further, if offset market receipts are to have any meaning in portfolio considerations, the corresponding expense must be captured at this level.

### Demand Charges

Grid-derived electrical energy does not follow a linear cost curve. Management of transmission and distribution network capacity requires peak load considerations. Utility companies transfer their capacity maintenance costs through so-called demand charges, which can be modeled as

$$\gamma^d = c^d \cdot \left( \max_{\tau=0 \rightarrow (T-\Delta t)} \frac{1}{\Delta t} \int_{\tau}^{\tau+\Delta t} L(\tau) d\tau \right) \quad (1)$$

and must be included for most large electrical grid contracts. Therefore, the actual price for grid contract  $m$  must use anticipated load profile data. Some utilities may apply so called “ratchet demand charges” where the demand charge in a given billing period cannot be less than certain percentage of a past peak demand charge.

### Reliability Costs

The non-availability of energy resources can result in loss of economic output. This variance, an instance of the energy cost of non-quality, occurs if the instantaneous portfolio supply is less than the instantaneous demand.

Availability can be defined as:

$$\text{Availability} = \frac{\text{MTTF}}{\text{MTTF} + \text{MTTR} + \text{MTTM}} \quad (2)$$

Down time (non-availability) in hours per standard year is calculated as:

$$\text{Down time} = (1 - \text{Availability}) \cdot 8760 \quad (3)$$

The relationship between the down time of energy resources and economic output of the enterprise is a complex interplay of energy resources and sufficiency assets. For example, some assets may be grid-connected and their operational availability is gated by it. In the interest of brevity it will suffice it to say that loss of economic output can be expressed as:

$$R = \frac{O - A}{O} \quad (4)$$

where  $O$  represents full potential economic output without down time and  $A$  is the historical average economic variance due to actual or expected down time. For anticipated portfolio configurations the expected value of  $A$  follows a complex trajectory. It is a function of the system configuration and portfolio, defined by interactions modeled by microgrid network topologies. We leave this specific derivation to a future effort.

Using these three considerations (the reader may have more), we derive a suggested portfolio cost equality at time  $t_0$  of

$$C_{0x} = [(e_{0x} + c_{0x}) \cdot d_{0x} + \gamma_{0x}^d] / R \quad (5)$$

Where  $x$  corresponds to a specific energy contract representing different energy sources, thus providing a risk adjusted gross cost value per energy contract.

We note that for some market contracts  $e_{0x}$ ,  $\gamma_{0x}^d$  is equal to zero. Likewise, without loss of generality, other charges such as basic service charge for grid connection are not included in the equation. These could be included as a simple additive term just as the demonstrated inclusion of the demand charge component  $\gamma_{0x}^d$ .

Taking into account the full portfolio of energy contracts results in the following expression for the cost at time  $t_x$  of

$$\Gamma_r(\Phi, x) = \frac{1}{R} \sum_{j=1}^{n+k} [(e_{xj} + c_{xj}) \cdot d_{xj} + \gamma_{xj}^d] \quad (6)$$

providing a risk adjusted real cost value with sustainability features. We assume that a forecast model for  $c$  itself is based on geometric brownian motion, expressed as

$$c_{t+1} = \alpha c_t + \sigma c_t z \quad (7)$$

where  $z$  is a normally distributed random variable with mean of zero and standard deviation of 1<sup>8</sup>.

### Discounted Cash Flow Valuation (DCF)

Using this simple method we find the highest NPV value for each option across different load profiles. For sufficiency resources, the more complex of the options, this is calculated as

$$NPV_x - I_x = P_x / r - C_x / (r - \alpha_x) - I_x \geq 0 \quad (8)$$

where  $P$  is the price,  $C$  is the operating cost,  $r$  is the financial discount rate, and  $\alpha$  is the average historical cost increase rate (e.g., CAGR) of contract  $x$ ,  $r > \alpha$ . Whichever load profile meets the highest NPV sum becomes the portfolio choice for the next period. Setting the above equality  $\geq 0$  and solving for  $C$  yields  $C_r$ , the threshold energy cost at which  $I_x$  is feasible.

DCF is straightforward to use, but does not consider pricing uncertainty, or the cost of future portfolio options. A more conservative, risk-inclusive, but significantly more complex method for valuation is the real options method.

### Real Options Valuation

The real options method quantifies the value of an option of each choice before us, and recommends the option with the highest value.

We already know that the value of portfolio resource at time  $t_1$  is its net present value,  $NPV_1$ . However, we'd like to find the value of the option to exercise that portfolio contract now, at time  $t_0$ , so that the option value incorporates systemic risk in the form of historic appreciation, volatility and the value of time.

Say  $V$  is an option function, and the  $V_{01}(C)$  is the option value in dollars, given the current energy cost  $C$ , of executing contract  $m_1$  in the future. The option value to execute contract  $m_1$  for time  $t_1$  at threshold cost  $C_{11}$  is (see Figure 4):

$$V_{01}(C_{11}) = NPV_1 - I_1 \quad (9)$$

To calculate the value of,  $V_{01}(C)$ , the option value at current cost, we state the following equality

$$rV_{01}(C) = \varepsilon[dV_{01}(C)] \quad (10)$$

which equates the expected rate of return of the value of the option equal to its expected future appreciation value.

This sets up a stochastic model, requiring the use of stochastic calculus by symbolic or computational means to derive a solution for  $V_{01}(C)$  in terms of known values.

There are two demonstrated methods of deriving a real number for the expected value of a future energy portfolio option. The first, by deriving an ordinary differential equation, with subsequent computational derivation by dynamic programming, is demonstrated by Siddiqui et al [5], which solves for  $C_1$  for each option. This process can be automated using methods as demonstrated by DER-CAM [6].

The second uses a pure computational—monte-carlo simulation—method that derives an investment threshold for every conceivable price input of each option. The portfolio itself is modeled in the context of a

microgrid as “dynamic portfolio vectors.” This approach, demonstrated by Kienzle et al [7], yields optimized present values (daily profits) for different portfolio options, from which  $C_1$  can be derived. The simulation method allows for impact assessments of different load-shift effects afforded by storage or demand-response contract options.

Each potential future portfolio contract is defined this way for suitable future time periods, such that that the portfolio cost goal can be re-stated as a minimization function as long as Energy Load— $D$  is satisfied, or

$$\text{Min}(\Gamma_t) = \left\{ \text{Min} \sum_{i=1}^{n+k} (C_{ti}) \mid D = \sum_{j=1}^{(n-k-1)+k} d_{tj} \right\} \tag{11}$$

and the forecast  $Ex$  as

$$Ex(\Phi,t) = 0(t) \cdot \left[ \psi(\Phi,t) / \text{Min}(\Gamma_t) D(\Phi,t) \right] \tag{12}$$

It is important to note that operational flexibility, i.e., the ability to start and stop sufficiency resources without penalty, are important pre-requisites for consideration [8].

**Building a Cost Threshold Matrix**

The investment thresholds for all known portfolio options,  $C_{ix}$  comprise a cost threshold matrix.

The minimal next-period cost, with its embedded risk quantifica-

Portfolio Option for $m_x$	$C_1$	$d$ (kW)	Period	$\sigma$
$\alpha$ value 1	\$0.08	100	2	-0.01
$\alpha$ value 2	\$0.086	100	2	0.013
$\alpha$ value 3	\$0.092	100	2	0.028

Figure 5. Example Cost Threshold Matrix showing different cost threshold values for different historical sample periods

tion, is selected from the Cost Threshold Matrix. This may or many not include investments in additional sufficiency, or it may consist of the temporary disuse of onsite generation in favor of some grid-supplied market contract.

As stated above, the selected new portfolio must meet the updated and revised energy load profile D.

## FORECASTING ENDX PERFORMANCE

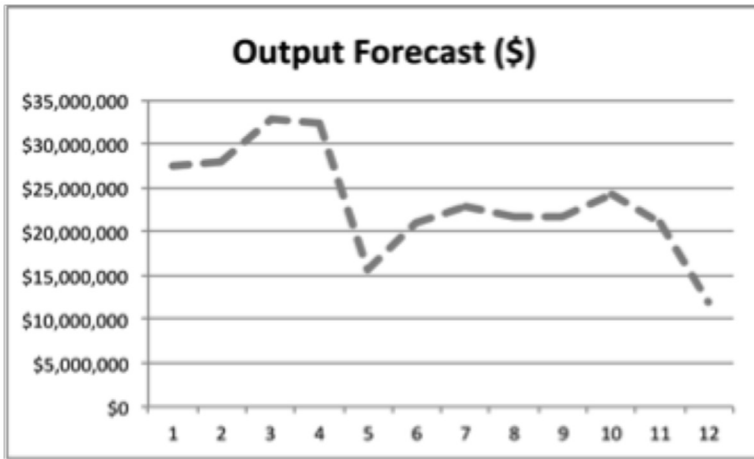
Energy cost and productivity differ from each other with respect to earned value. The cheapest energy has no positive effect on energy productivity if its pricing structure does not accommodate variations in consumption. Endx has some sensitivity to economic output, and care must be taken to accurately reflect this forecast for the energy planning periods.

We take a zero-based approach, i.e., we assume that zero energy cost is the desired long-term goal. As C gets very small, S will necessarily become large, as external market suppliers will be unable to offset absorbed costs with efficiency increases. Therefore, the sufficiency ratio will approach unity, by virtue of the constraint  $S \leq D$ . The O to C ratio remains, which is likely to be a large scalar value.

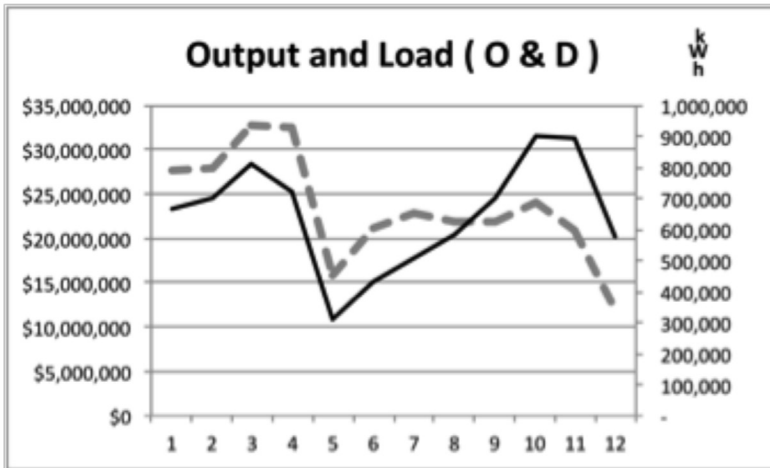
Setting periodic goals for Endx improvement is dependent on historical performance and the degree of organizational and managerial commitment. Examples are 1% improvement per quarter or 10% improvement per year. It is important to consider the impact of the constituent parameter dynamics when setting Endx goal values:

- Reductions in output O over time without corresponding reductions in D will cause Endx declines. It is important to institute effective load profile management that increases efficiency and aligns variations in O with D (see 5. M).
- Requisite C and S values can be derived by setting target Endx growth rates, as discussed in the example below. Unrealistic C results skew both D and/or S are out of line with business requirements.

We recommend that energy managers set their Endx targets as in the following 12-period planning example:



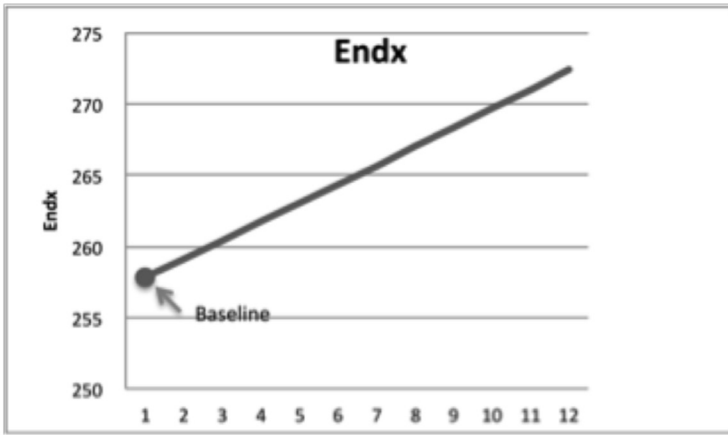
1. Determine reasonable expectation of Output forecast for some number of planning periods into the future



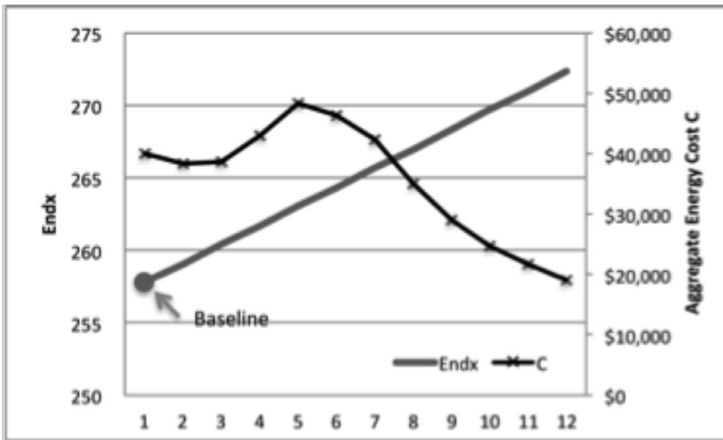
2. Determine the corresponding Demand requirement from the load profile, which has current and future efficiency improvements.

Period	D (kWh)	S (kWh)	C (\$)	O (\$)	Endx
1	667,767	250,000	40,000	\$27,550,000	258

3. Derive baseline Endx Value based on current or immediate future Sufficiency generation and current Cost



4. Plan desired rate of Endx improvement per period, here arbitrarily set at 1% per period



5. Derive the required C value

$$C = 0 \text{ (} \frac{S}{D \cdot EX} \text{), for } S = 0$$

$$C = \frac{0}{EX} \text{ for } S = 0$$

Dividing C by D will produce the required unit cost average across portfolio  $\Phi$ . Planners will soon see that these targeted unit costs may not be feasible while demand increases during falling production, as can be seen starting period 7 of the example. Two options remain: bring demand into line, install more sufficiency capacity with variable cost and supply features, or both.

## EXECUTING THE PORTFOLIO

This process is the physical act of switching contracts, turning on or off sufficiency resources, expanding resources, or some combination of the above. It is possible that no actions are taken here for the period in question.

## MANAGING ENERGY LOAD

This is the process at the heart of traditional Efficiency Kaizen [9]. Load profile management is a mandatory part of continuous energy productivity improvement.

The Energy Load Profile contains information about the energy requirements of a firm's processes, consumption, their reduction potential, investment opportunities, demand forecasts, building envelopes, ambient temperature data, thermal waste heat, and any other relevant information related to converting energy inputs into added value.

We list some essential points identified in Efficiency Kaizen, in the table on the opposite page.

## ANALYZING ENDX VARIANCE

The Endx Variance Analysis process is central to the Study phase of the Sufficiency Kaizen process. The goal of this activity is to determine what actions to take in the next round of portfolio optimization (Act) and goal planning (Plan).

Variance analysis in general concerns itself with the study of the differences between plan and actual values. Conclusions, drawn from the magnitude and timing of the observed variances, are the products of a proven and comprehensive set of root cause analysis techniques: 5 whys, causal factor analysis and Tree diagrams, and/or numerical analysis of variance (ANOVA). Suffice it to say that these techniques are well described in TQM and Six Sigma literature.

We show in Figure 6 an example graphic variance analysis on the five elements of the Endx equation.

Waste Category	Description
1. Overproduction	Energy consumed in operating equipment to make unnecessary products, or 'benched' services.
2. Inventory	More energy used to heat, cool, and light inventory storage and warehousing space. Inventory includes unnecessary office space, storage areas, IT equipment, etc.
3. Transportation and Motion	More energy used for transport. More space required for work in process (WIP) movement, increasing lighting, heating, and cooling demand and energy consumption. Inefficient or wasteful transportation technology
4. Defects	Antiquated (wasteful) or defective energy conversion equipment Defective production or information requires more space for rework and repair, increasing energy use for heating, cooling, and lighting. Lost revenue due to poor energy quality.
5. Overprocessing	Unnecessary work or production consumes unnecessary energy. Oversized energy conversion equipment, e.g. oversized HVAC and pumping equipment, excessive lighting, etc. Incorrect information causes non-value added energy consumption beyond that which required.
6. Waiting	Wasted energy from heating, cooling, and lighting during production downtime. Production shut-down due to inadequate, poor quality, or no energy supply.

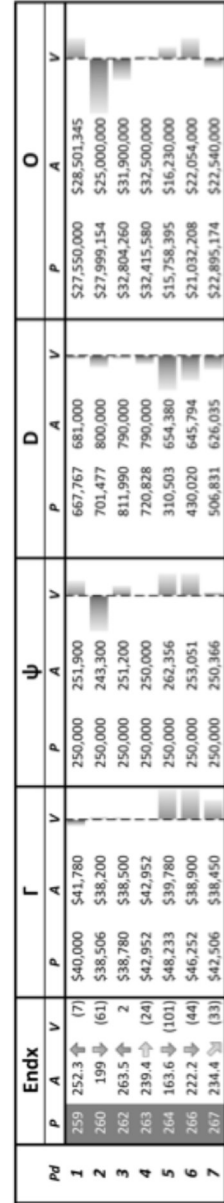


Figure 6. Example Endx Variance Analysis Dashboard

## SUMMARY

We have demonstrated a computational basis to project future requirement for an Endx value. Time increments can be structured to match the business cycle for production forecasts and energy demand.

We show by example a use scenario for continuous energy productivity improvement. The goal of this process, which we call Sufficiency Kaizen, is to drive energy cost and variance (waste) to zero. This process uses the dynamics of an energy index, called Endx, within the context of the Deming Cycle.

Endx is a single scalar value calculated as a factor of two ratios, efficiency and sufficiency. Each ratio is in itself a relationship of two functions, defined over a private energy portfolio and time.

Corporate energy managers can create optimal energy productivity outcomes by following the six steps of Sufficiency Kaizen. In fact, we have demonstrated that this process is antithetical to the conventional inflationary spiral of energy costs. By taking control over the allocation and production of energy, corporations can obviate energy cost impact and risk, with relief immediate, and absolute impact over time.

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## Endnotes

1. We will refer to Energy Sufficiency as an index term and DG (Distributed Generation) in terms of technological installation. In some cases they are synonymous.
2. O can be defined as net or gross receivables value shipped, or standard value earned units.
3. Operations theory considers the term 'demand' that which is required to produce an output. In Power Engineering this is called Consumption (kWh); Demand (kW) is the sum of connected load capacity averaged over a sample period.
4. It was thought that setup costs would make small batches prohibitively expensive. Few people considered that setup times could be brought from hours to seconds, effectively zero, allowing lotsize = 1.
5. m1, m2 are arbitrary contracts for grid energy (e.g., electricity, district steam); m3 is a resource contract that fires s1; s1 is a sufficiency system (e.g. Natural gas cogeneration).
6. Endx is discontinuous, it can be 0 or undefined for  $\Psi = 0$ .
7. E.g., Cuyahoga River, 1969; fish died instantly when exposed to the water of the Hudson and lower Rhine River in the 1970s.
8. See [3] chapter 3.2; a more complex model that adds mean reversion and price jump models can be reviewed under [4].

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