QUADERNI DEL DIPARTIMENTO DI SCIENZE ECONOMICHE E SOCIALI

COST-BENEFIT ANALYSIS OF ELECTRIC DEMAND-SIDE MANAGEMENT

Filippo Insinga

Serie Azzurra: Economia Aziendale – Quaderno N. 61 febbraio 2010

UNIVERSITÀ CATTOLICA DEL SACRO CUORE

PIACENZA

I QUADERNI
Possono essere richiesti a:

Dipartimento di Scienze Economiche e Sociali, Università Cattolica, Via Emilia Parmense 84, 29100 Piacenza tel. 0523 599342. Oppure si può ottenere una copia dall'area di download del Dipartimento al seguente indirizzo: **http://www.unicatt.it/dipartimenti/ScEcoSoc/default.stm**

FILIPPO INSINGA
COST-BENEFIT ANALYSIS OF ELECTRIC DEMAND-SIDE MANAGEMENT

Contents **page**

Index of figures

1. INTRODUCTION

"The user did not want energy *per se* but "energy services" which are the output from the equipment that use energy as an input"[1].

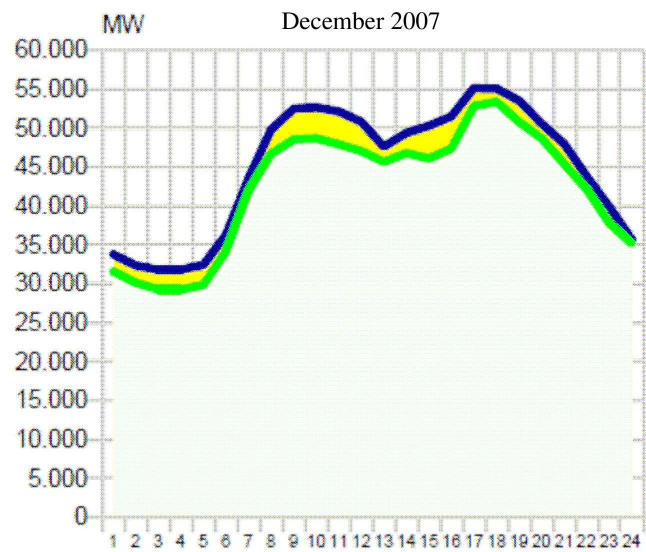
Electricity is a uniquely valuable form of energy[2] (infinitely superior to chemical energy form), offering unmatched precision and control in application and, hence, in

[1] H. Nilsson, Demand Side Management (DSM) – A renewed tool for sustainable development in the 21st century, IEA, Brugge, 2007, p. 2.

efficiency. Besides, electricity offers unrivalled advantages in comfort and in its environmental friendliness.

Because of these advantages, in just over a century electricity has altered the lifestyles of the entire world. As nations increasingly rely on electricity to improve their efficiency and quality of life, it is very likely that the fraction of electricity on global energy use will grow to one-half[3].

The pattern of electricity consumption varies in the course of a day, typically reflecting the pattern of human activity – high during the working day and low at night, weekend, and holidays (Figure 1 – Source: www.terna.it).



The higher curve represents the hourly power demand, while the lower curve represents the corresponding power produced in Italy. Their difference is equal to the power imported from abroad.

Figure 1 –Italy's load diagram of a typical working day in December 2007.

This simple fact has fundamental implications on electric utilities business in which electricity is not economically storable. As a consequence, adequate generating-transmission and distribution capacity has to be available to serve the demand during the peak period[4], even though much of this capacity is idle during the periods of low demand (off peak), how illustrated in Figure 2 (Source: www.terna.it. with integrations).

---

[2] That embodies the basis of all energy: the electron. Electricity heats, cools, and lights our homes and business, refrigerates our food, runs electric motors, facilitates the use of advanced medical diagnostic tools, and powers mass information and communication technology systems.

[3] For instance, in Italy today electricity accounts for about 36% of global energy use, while fifty years ago such share was about 22%.

[4] With an adequate reserve margin to face, with a degree of confidence, the failures of the plants and the randomness of demand. Tipically, at least 30% of electricity supply industry investment goes toward reserve generating capacity and redundant network facilities, *Security of Supply in Electricity Markets*, IEA, 2002.

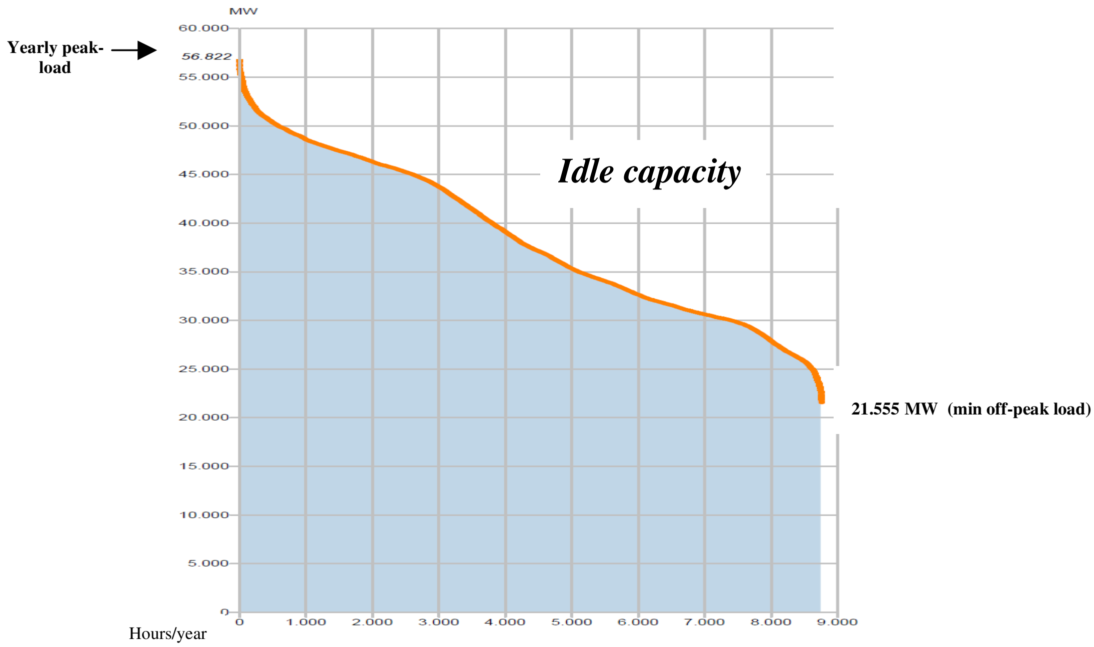


Figure 2 – Italy's yearly (2007) load duration curve.

As illustrated in Figure 3 (Source: www.terna.it. with integrations), the power of 6.822 MW is equal to 12% of annual peak-load. This requires a very small number of utilization hours[5] and therefore the use of facilities for a small time compared to their actual availability. Thus the total investment costs of 5,1 billion Euros (equal to ~ 0,75 M€/MW multiplied for 6.822 MW) could be avoided[6]. The decrease of power peak load as above could allow us, in the hypothesis of a 2% average yearly peak-load rate of growth, to save the related investment aimed at generation and network systems reinforcement for a period of ~ 6 years.

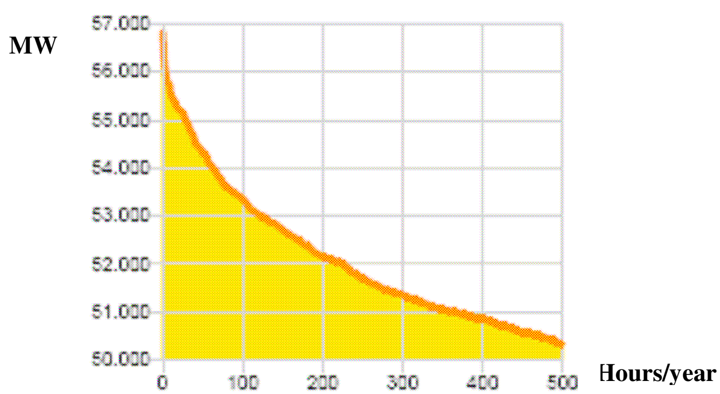


Figure 3 – Zoom of the load yearly duration curve of the 500 hours of peak-load

Demand-Side Management (DSM) programs try to modify the aforesaid pattern of consumption by means of a set of activities that a utility and/or society sponsor to attempt to alter the configuration or magnitude of a customer load shape.

DSM encompasses the planning, implementation and monitoring of utility/society activities that encourage customers to modify their pattern of electricity usage,

[5] That supply only 0,5% of the total annual energy consumption!

[6] The IEA calculated in their World Energy Outlook 2004 a conservatory measure of savings in investment for power generation, transmission and distribution during 2003÷2030 was found to be ~ 10%, *World Economic Outlook 2004*, IEA, Paris 2004.

including the amount and the timing of electricity demand, over and above any changes that might occur due to the natural operation of the market. These activities implies a broad set of technologies[7], measures[8], or marketing activities that the utility and/or society undertakes mainly because they can be less expensive than meeting the load that would otherwise result in the absence of such activities.

DSM programs are designed to achieve two basic objectives:

1. **realize energy savings[9]**;
2. **reduces or modify load** just during certain time periods or events.

The first objective can be reached by:

a) Energy efficiency: reducing overall energy consumption without a reduction in customer comfort or value, by promoting high-efficiency equipment and building design. Energy efficiency typically refers to the permanent installation at the customer of energy efficient technologies or the elimination of energy losses in existing systems to handle the climate change. The aim of energy efficiency (the invisible resource!) is to maintain a comparable level of service, but reduce energy usage;

b) Energy conservation: reducing energy consumption, changing energy use behaviour by means of good operating practice (e.g., through educational projects, setting ahead thermostats in the summer and back in the winter, building envelope improvements, eliminating the stand-by consumption of equipments[10]).

The second objective can be reached by:

a) Load management or load shifting that seeks to consistently reduce on peak demand or shift demand from peak periods to off-peak periods;

b) Demand response programs that seek to reduce demand specifically just on critical peak days or during system emergencies;

c) Reliability programs to reduce load to contractually determined levels in exchange for an incentive, usually a bill discount;

d) Price response programs: customers choose how much load reduction they can provide when triggered the day-ahead of a critical peak day based on the price of electricity or load reduction incentive (“pay-for-performance”).

Thus, DSM programs have an impact both on annual energy consumption and on daily winter and summer peak and off-peak power demand. This impact must be measured with connection to a reference consumption level, determined with the demand considered as an exogenous variable.

The economic evaluation of DSM programs is a complex process. These programs affect many various groups of people in different ways, from customers participants in the programs to society at large. Decisions whether or not to implement specific DSM activities should be based not only on comparison of all the program costs and benefits, but also on the analysis of to whom and in what manner these impacts occur.

---

[7] *End-Use* (e.g. LED, Heat-Pumps, HVAC, Motor Drive, Electric Car, …), *ICT* for communication and automatic control between utility and customers, *miniaturisation* to build intelligence into appliances, *small-scale renewable supply technologies*, etc.

[8] Fiscal, financial and administrative incentives, and regulatory tools.

[9] In Italy to encourage energy saving and removable energies had been introduced three types of certificates: white, green, black, and the energy photovoltaic account.

[10] In a typical private home ~ 4% of this consumption is due to absorption in standby mode (TV, HF, VCR, ...) . In Italy, this represents a waste of energy of ~ 2.7 TWh corresponding to a average power of 310 MW committed, that is the equivalent of a new generation plant of combined cycle with a capital investment of ~ 300 million Euros.

Economic analysis is the systematic enumeration of all benefits and all costs associated with a DSM program and their processing by means of capital budgeting rules in order to obtain some merit figures (NPV, PI, …) that can guide the decision-making.

In this paper we describe briefly the state of the art on new philosophy on which the utility planning process is based, the groups of subjects (defining the perspectives) and the costs and benefits considered by the different capital budgeting tests employed for economic comparison, and some theoretical foundations that justify the DSM activities. In the Appendix we illustrates a simple cost-benefit case study on energy efficiency program.

2. GENERALITY ABOUT DSM PHILOSOPHY

Electric utilities world-wide face a key challenge in the next years: they must integrate traditional supply planning and operation methods (Supply-Side Management - see Figure 4[11]) with the process of actively influencing the demand for electricity (Demand-Side Management - see Figure 5[12]).

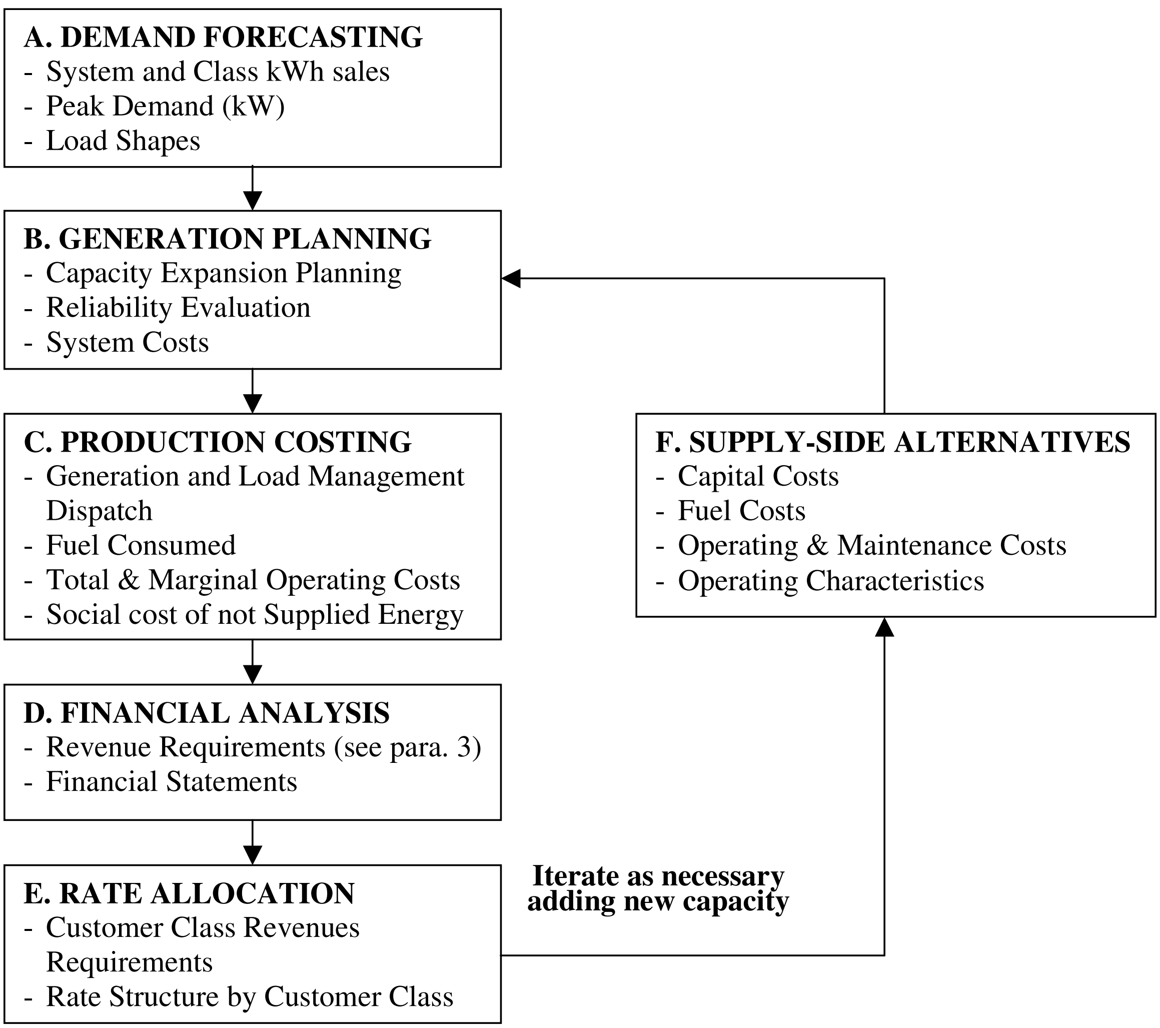
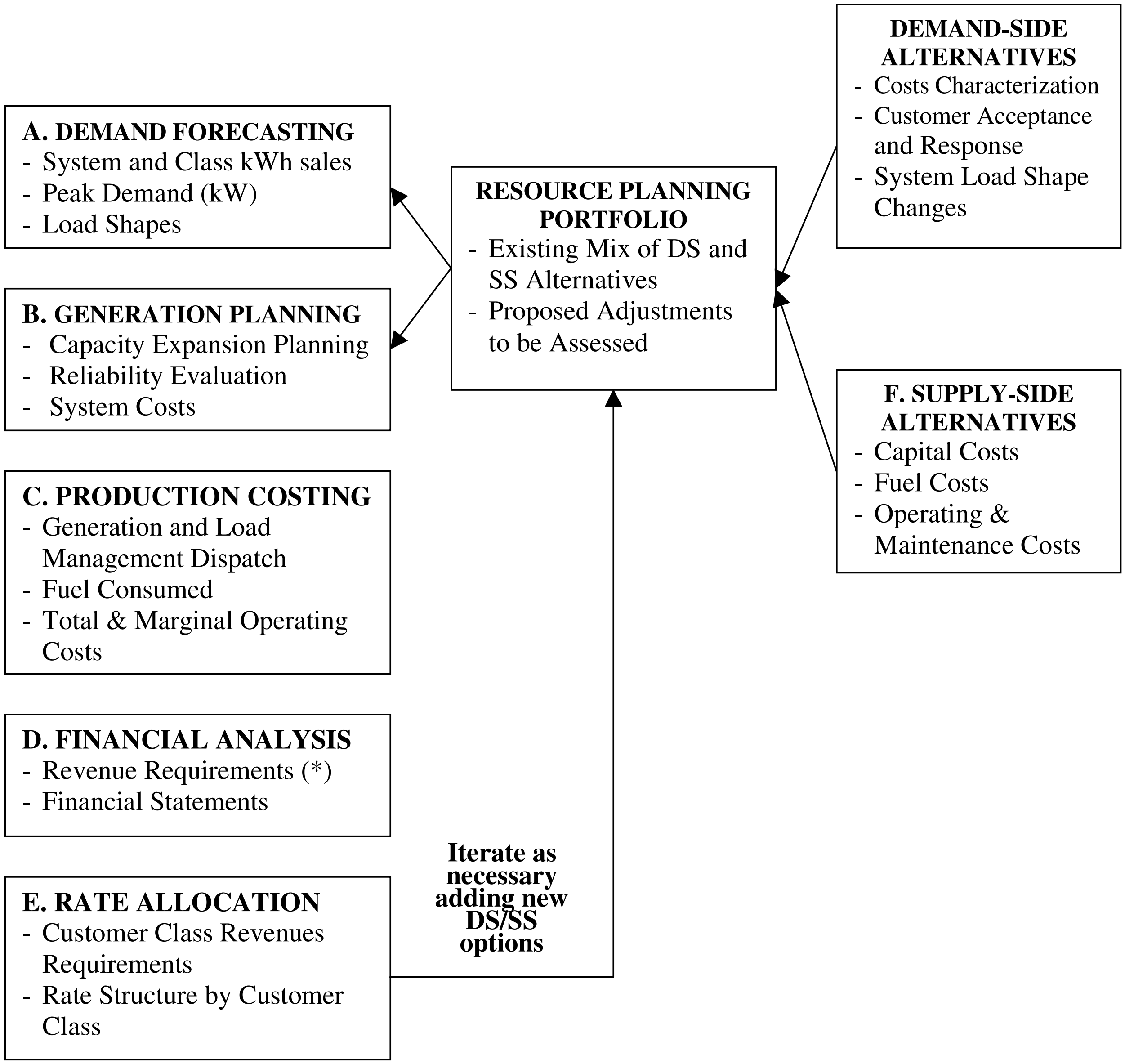


Figure 4 – Supply Side Planning Process

[11] Enel-Cesi Engineering Consulting, "The Power System Planning", Milan, 1984. The Author developed the models on Demand Forecasting, Financial Analysis and Reliability Evaluation.

[12] Electric Power Research Institute. "Demand-Side Management", Vol. 2: Evaluation of Alternatives, EPRI EA/EM-3597, Palo Alto, CA, December 1989.



(*) See para. 3.

Figure 5 - Supply Side and Demand Side Planning Process

Uncertain marketplace conditions, including competition, rising in oil, gas and coal prices, and increasing environmental concerns, will prompt utilities to adopt a flexible and diverse management strategy. DSM must be part of this strategy[13]; it can help assure efficient utilization of facilities by increasing its utilization hours, efficient end-use technologies, reduced CO_2 emission, deferred generation and network reinforcement, improve reliability of supply and augment the range of energy choices available to utility managers.

For the successful implementation of customer-focused programs such as DSM, it has become necessary to understand how customers make energy purchase decisions. As shown in Figure 6, the utilities understanding of customer decision making –

[13] The least-cost options for the energy system performance should be chosen when more supply (Megawatthours) or less demand (Negawatthours, the invisible resource) were compared in equal terms.

through use of a choice model – can help the utility determine expected participation in the program and thus implement the program with greater cost-effectiveness.

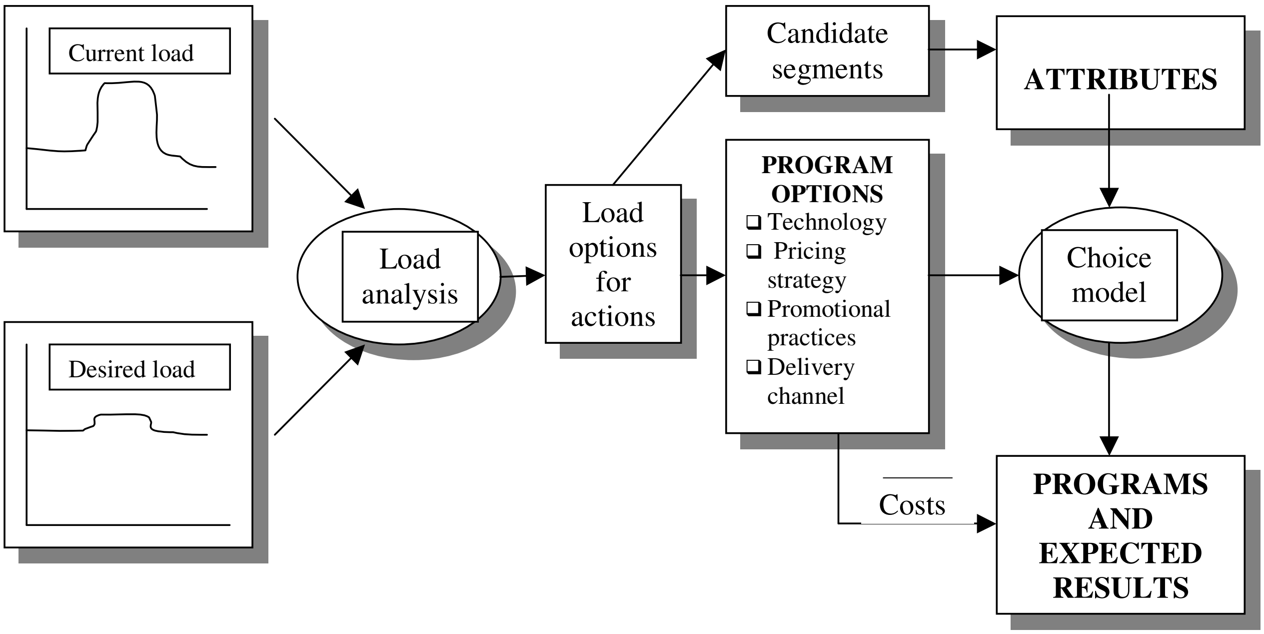


Figure 6 – Customer Preference and Behaviour: the missing link in effective DSM planning

The configuration of marketing instruments (or program options), which are being used by the utilities in order to perform an integrated DSM, define their marketing mix (see Figure 7). The main instruments of the marketing mix are: the price (both level and structure), the load management, the market assessment, the electricity supply reliability (continuity and quality), the sales force, the customer service, and the promotion.

AREAS OF IMPACT / MARKETING INSTRUMENTS	SALES		CUSTOMER MIX			OPERATING COSTS				
	LEVEL	COMPOSITION	PROFITABILITY	STABILITY	ECONOMIC DISPATCH	GENERATION	TRANSMISSION	DISTRIBUTION	CUSTOME SERVICE	MARKETING
PRICE LEVEL	●	●	●	○		○	○	○	○	○
TARIFF STRUCTURE	●	●	●		●	●		●		
LOAD MANAGEMENT			○		●	●		○	○	
ENERGY EFFICIENCY & CONSERVATION	●	○	○		●	●		○	○	
SIZE OF SALES FORCE	●	○	○	○					○	●
SKILLS OF SALES FORCE	●	●	●	●		○	○	○	○	●
ORGANIZATION OF SALES FORCE	●	●	○	○		○	○	○	○	●
PROMOTION (ADVERTISING & OTHER)	●	●	●	●		○	○	○	○	●
HARDWARE SERVICES	○	●	○					○	●	
ADVISORY SERVICES	●	●	●		●				●	○
SUPPLY RELIABILITY	○	○				●		●	●	
ATTRACTING NEW INDUSTRY	●	●	○	○	○	○	○	○	●	●

● = a direct and strong influence
○ = an indirect diverted or weak influence
= an empty square means a very weak influence or indirect influence, or the total lack of it.

Figure 7 – Matrix for marketing relationships[14]

[14] Clark W. Gellings, Utility Marketing Strategies, The Fairmont Press, 1994.

Through the implementation of DSM activities, utilities worldwide seek to directly influence customer demand for electricity in predetermined options. This influence may result either or in shifts in use from one time period to another (*load management*) or in decreased (*strategic energy saving*) or increased (*strategic load growth*) electricity use, with the task also to serve customer and societal needs.

Within each of these options, the basic goal of any utility load shape objective is to influence the pattern and/or amount of electricity consumption in some way. More precisely[15]:

- **Load management (Demand Response)** is generally used to alter load shapes by peak clipping, valley filling, and load shifting. In addition, it can help utilities to achieve a flexible load shape.
  - ✓ Peak clipping aims to reduce the peak demand on a utility system by decreasing the on-peak electricity consumption. The main motivation for this action are to reduce:
    - ❑ current and future capacity requirements of the generation-transmission-distribution systems,
    - ❑ fixed and variable costs related to joule losses for the transmission and distribution systems;
    - ❑ the use of generation plants with smaller peak performance and employing expensive fuel;
  - ✓ Valley filling aims to increase load during the off-peak period. Such actions are appropriate to undertake when the marginal cost of serving this load is lower than the average cost of electricity. Adding off-peak load under those circumstances decreases average costs;
  - ✓ Load shifting transfers loads that would otherwise occur on-peak to off-peak periods, thus combining peak clipping and valley filling;
  - ✓ Flexible load shape is a concept related to reliability of the electric system, one of the main planning supply constraints. Load shape can be flexible if the options presented to the customers include variations in quality service in exchange of appropriate rates changes (e.g. increases or incentives)[16];

  For instance, smart utility meters allows both utility and customers to track power use by purpose and time of day. Figure 8 illustrates the four load management load shape objectives, while Figure 9 show the main load management tools as a function of the time.

[15] Veronica A. Rabl – Clark W. Gellings, The concept of Demand-Side Management, in Demand-Side Management and Electricity End-Use Efficiency, NATO ASI Series E: applied science, Kluwer Academic Publisher, London, 1987 pp. 100.

[16] For instance, this objective allows to vary the reliability of supply with the specific requirements of some customers (hospitals, software house, manufactory plants, food industries, ...) through the provision of supplementary services for increasing impact on the continuity of the service such as: the activation of emergency teams to accelerate the restoration of service; the installation, operation and maintenance at the customer of emergency generators; the installation, operation and maintenance at the client of groups of continuity.

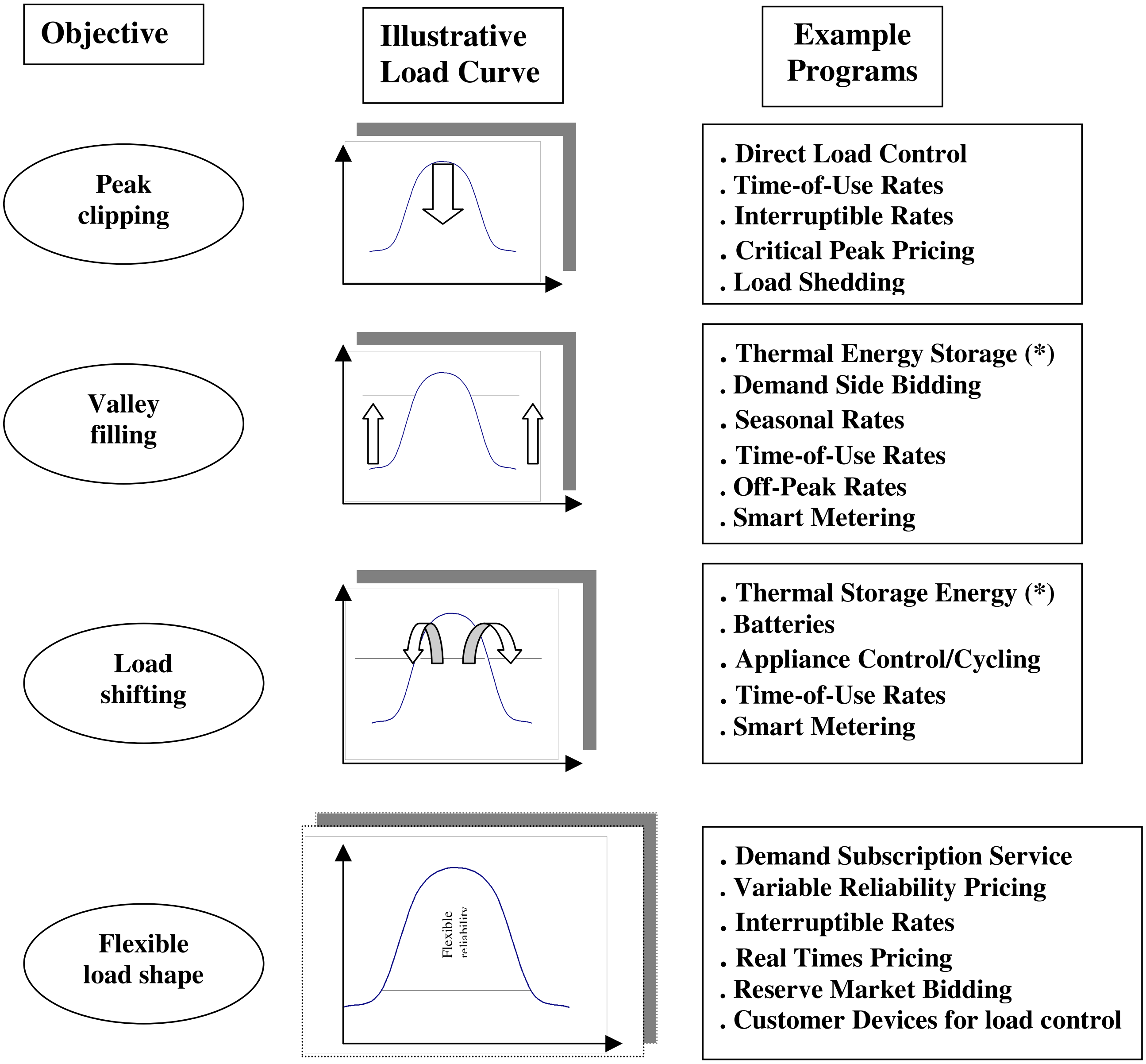


Figure 8 – Load management load shape objectives

(*)Technologies to transfer all or part of the electrical consumption from one period to the day through: a) accumulation of cold (by compressors) in the summer conditioning environments; b) accumulation of heat (by refractory material and electrical resistors), for space heating and domestic hot water. For instance, in the UK seven tariffs were developed to support night time storage heaters[17].

[17] G. Strbac, Demand Side Management: Benefits and Challengers, Energy Policy, London, December 2008, p. 4423.

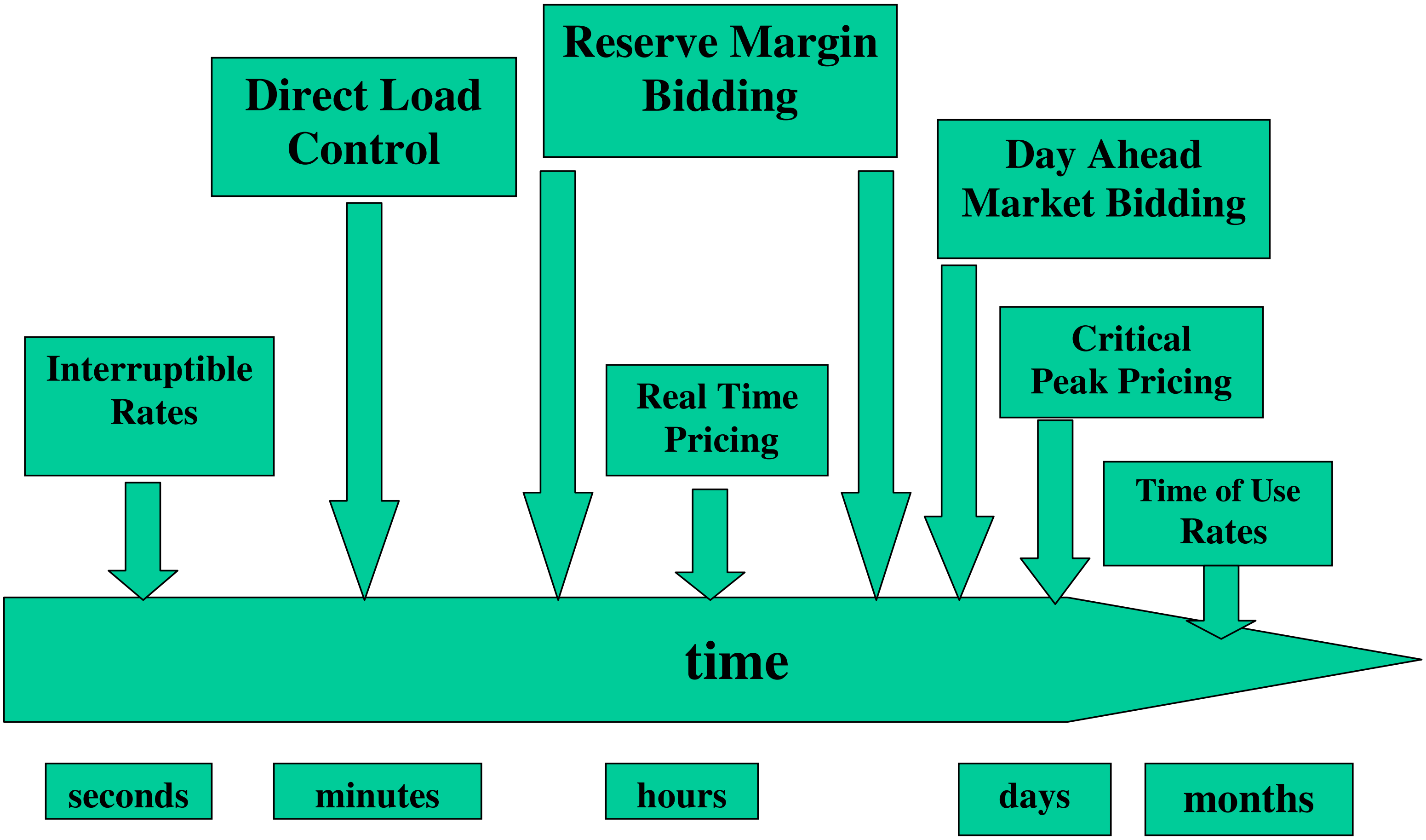


Figure 9 - Load management tools

As you can see, these tools are based on the new tariff options, on technologies, and on the market of electricity exchange. More precisely:

- *Interruptible rates* (for the provision of reserve services and for enhancing system reliability): the price of energy consumed is reduced if the customer accepts the outage, prior notice and for a fixed time interval (common participants include refining, melting, manufacturing, water treatment, …);
- *Real time pricing*: the price varies hour by hour connected to the electricity exchange listing[18];
- *Direct load control*: is applied to appliances that can be turned off or cycled for relatively short periods of time (e.g. water heaters, air conditioners, swimming pool pumps, …). Control is activated by an external signal emitted through ICT;
- *Load limiters*: limit the power that can be taken by individual consumers. The level at which the limit it set can be adjusted to reflect system conditions;
- *Time-of-use pricing*: are designed to more closely reflect the investment and cost structure, where rates are higher during peak periods and lower during off-peak periods;

[18] Smart digital electricity meters and real-time pricing are an important first step in modernizing our electrical grid.

- *Demand bidding*: the customer is willing to reduce or forgo their consumption of electricity at a certain price in the *day ahead market bidding* or in the *reserve margin bidding*. This tool is based on thermostats connected with ICT technologies;
- *Critical Peak Pricing*: include high prices for just a few days or hours of the year (e.g. the rate *Time* in France);
- *Smart Digital Utility Meters*: this new technology will permit utilities to move toward variable rates for electricity, charging more during peak demand and less at night. For instance, some U.S. utilities have created a night time rate for plug-in cars that is half its daytime rate. These meters are fully electronic and truly smart, with integrated bi-directional communications, advanced power measurement and management capabilities, an integrated, software-controllable disconnect switch, and an all solid-state design. The system provides a wide range of advanced features, including the ability to remotely turn power on or off to a customer, read usage information from a meter, detect a service outage, detect the unauthorized use of electricity, change the maximum amount of electricity that a customer can demand at any time; and remotely change the meters billing plan from credit to prepay as well as from flat-rate to multi-tariff. In Italy Enel has estimated the cost of the project of smart meters at approximately 2,1 billion Euros for over 27 million customers and the savings they are receiving in operation of 500 million Euros per year, a convenient 4 years payback and an eloquent demonstration testament to the power of next-generation advanced metering systems. This allows the management of consumption remote reading, intervention on/off, voltage monitoring and requests for supplier change.

- **Strategic energy saving** (**Energy Efficiency and Energy Conservation**) (Figure 10), which gained more support starting in the in the 21st century, with the imperative goal to create sustainable energy systems in order to prevent the climate change and at the same time allow for more welfare to more people, is the load shape change that results from programs directed at end-use consumption. These programs seek to reduce energy sales as well as change usage patterns. Such reduction is generally achieved by substituting technically more advanced equipment to produce the same level of end use services (e.g., lighting, heating, motor drive, efficient building design, ventilation and air conditioning, refrigeration, TV/HiFi/PC/Internet) with less electricity, or reducing energy consumption, changing energy use behaviour (e.g. setting ahead thermostats in the summer and back in the winter, building envelope improvements, eliminate the stand-by consumption of equipments); it is important to observe that energy efficiency in not a tradable good in itself, because it is a invisible characteristic embedded in products that must provide the energy service. Therefore, very few end-users will make calculations the economic theory assumes;

- **Strategic load growth** (Figure 11) is the load shape change that refers to a general increase in sales beyond valley filling. In the industrial sector, new electro technologies (laser, electrolysis, robotics, electro thermal heating, ultraviolet radiation, electrical car) are just beginning to provide major increases in productivity as well as sales, while ICT uses such as personal computers and Internet will spread in the residential and commercial/services sectors.

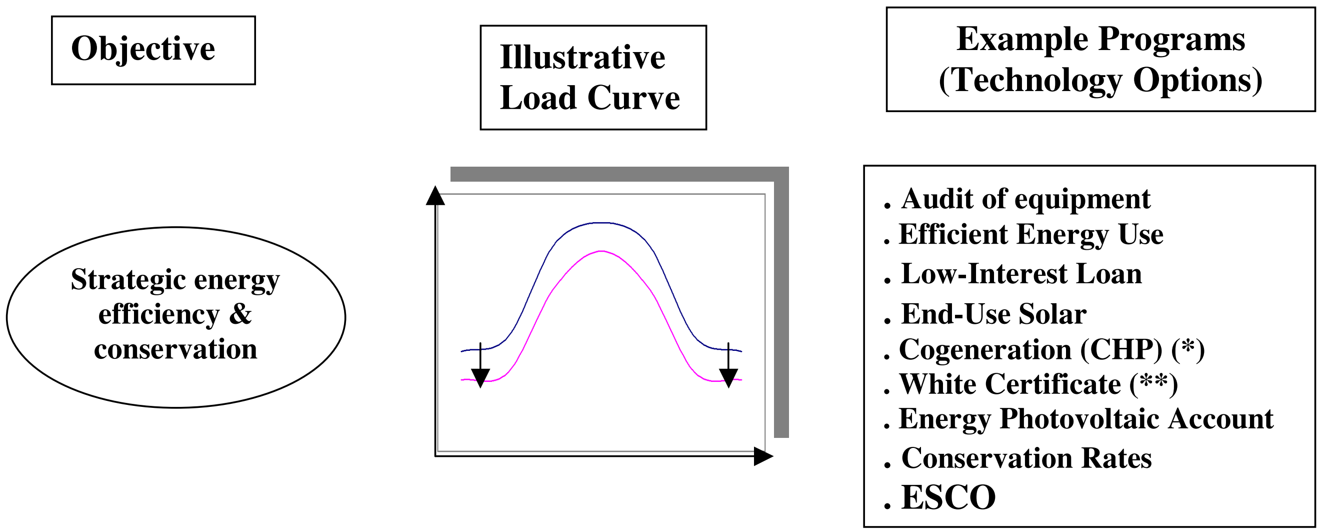


Figure 10 - Strategic energy saving load shape objective

(*) That allows the use of residual heat, otherwise lost, in the process of thermal energy conversion in electricity.
(**) In Italy it is estimated that since the beginning of 2005 until May of 2008 have been spared ~ 5,5 TWh of electricity by burning ~ 5 Mtep oil less.

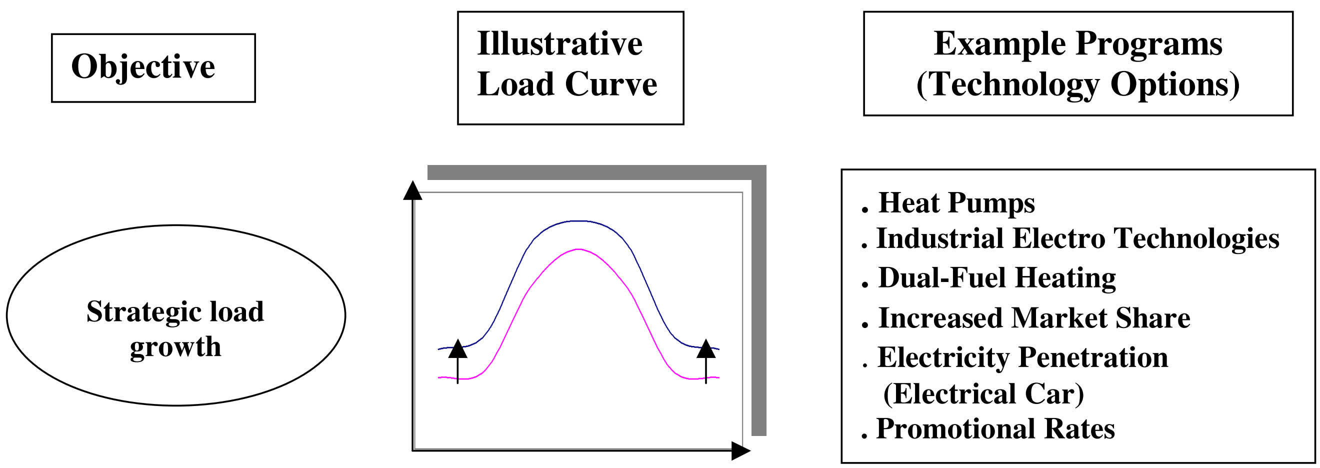


Figure 11 - Strategic load growth load shape objective

Each of the aforesaid DSM load shape objectives (load management, strategic energy efficiency & conservation, and strategic load growth) is, of course, not mutually exclusive. They can be combined in one form or another to yield either reduction or increases in load. Off course the realisation of DSM programs require the implementation of ICT for the control of electricity networks in order to obtain an integrated energy and communications system architecture that put together two systems in the power industry: the electrical delivery system and the information system (communication, networks and intelligence equipment) that controls it.

3. SUMMARY OF ECONOMIC COST-BENEFIT ANALYSIS

Cost-Benefit analysis is a valuable tool for analysing Demand-Side Alternatives.

Traditionally, electrical system planners have begun their task with the premise that customer demands are fixed by the customer market (exogenous variable).

In this case, the standard procedure for capital budgeting in the electric utility industry is the Revenue Requirements Method[19]. Revenue Requirements consist of all the elements of a utility's cost of service, including fuel, operating and maintenance expenses, depreciation, interest, taxes, social cost of curtailed energy, and net income. Applications of the revenue requirements method involve projecting these costs by means simulation production costing programs (see Figure 4) over the useful life of an investment and discounting them to obtain the present value. This present value provides a basis for choosing among investment alternatives: the decision rule is to choose the alternative for which the present value of revenue requirements is a minimum (see Figure 12). Thus, the present worth of revenue requirements is a measure that reflects future as well as current costs.

It is very important to observe that the present worth of revenue requirements is a method for choosing among investment alternatives that provide an equivalent amount and quality of service and thus that produce the same operating revenues, take into account the social cost of the curtailed energy[20].

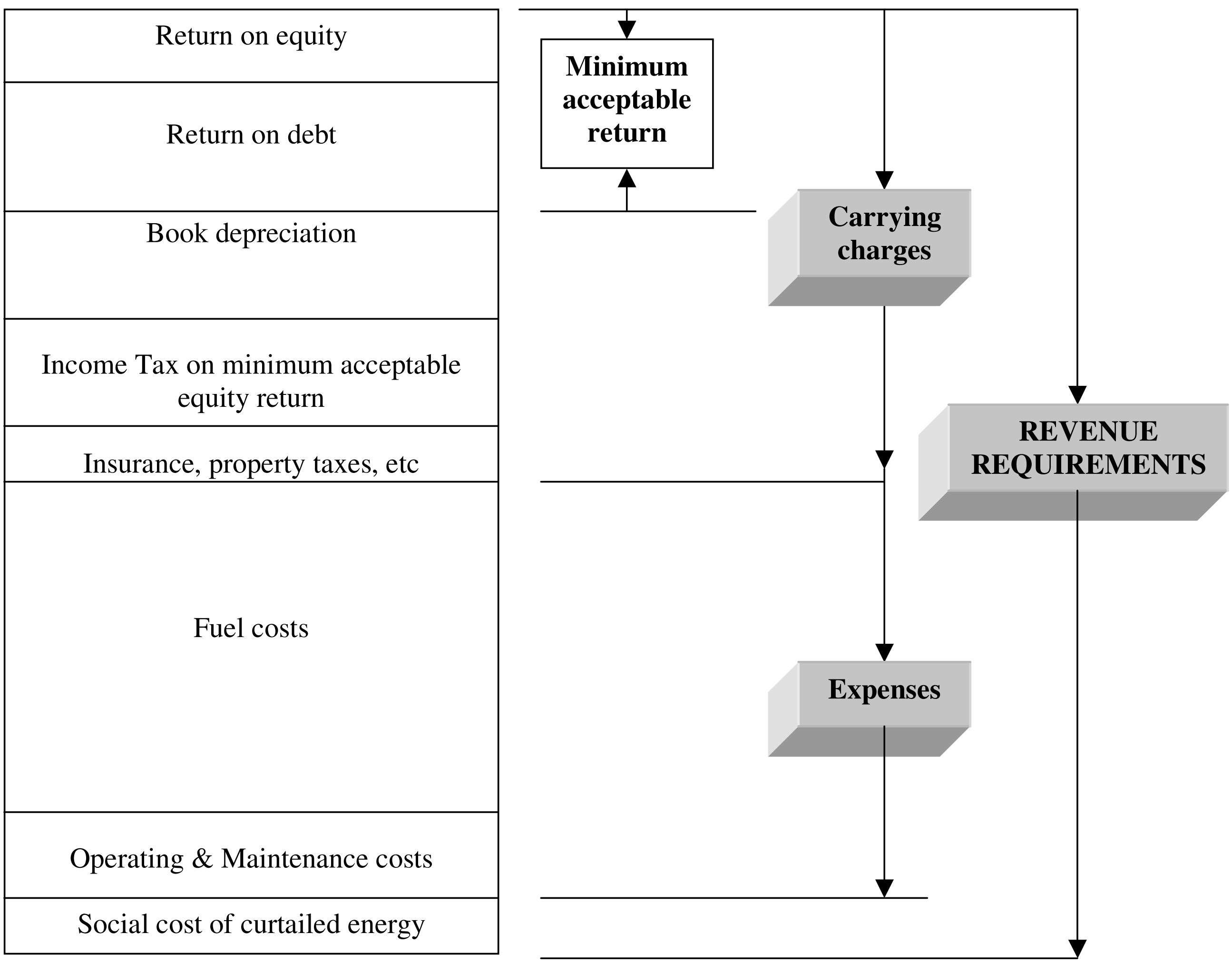


Figure 12 – Revenue Categories for the Revenue Requirement Method of Economic Comparison

---

[19] F. Insinga, "La pianificazione dei sistemi di distribuzione dell'energia elettrica", ISU, Università Cattolica del S.C., Milano, 1990.

[20] It is the cost of expected energy not supplied to the consumers due to unavailability of the electric system. This cost is evaluated by means of sophisticated reliability models. See F. Insinga, "Il costo sociale dell'affidabilità del servizio elettrico", in Problemi di Gestione dell'impresa, Università Cattolica, Milano, 1990, n. 10, pp. 133-170.

If the alternatives provide different levels of quantity and/or quality of service, then the appropriate economic comparison involves the value of service as well the cost, and the present worth of revenue requirements is not a measure of the value of service. In this case it must be used a measure of investment profitability like the Net Present Value or the Profitability Index[21].

Traditional planning methods have focused on the revenue requirements, minimizing mix of reserves needed to provide a uniform, undifferentiated electric service. With growing competition in energy market, however, factors other than cost (i.e. quality of service, customer responsiveness, customer confidence…) have become increasingly important. As a result, it is now essential for utilities to identify the types of services sought by customer as well as to determine which options are financially attractive and technically feasible for the utility.

Integrated Value-based Planning (IVP)[22] is a new planning approach that uses value, as well cost, as the common denominators for evaluating supply and demand-side resources. This approach can be viewed as part of the evolution of utility methods developed in response to increasing competition in utility markets (see Figure 13).

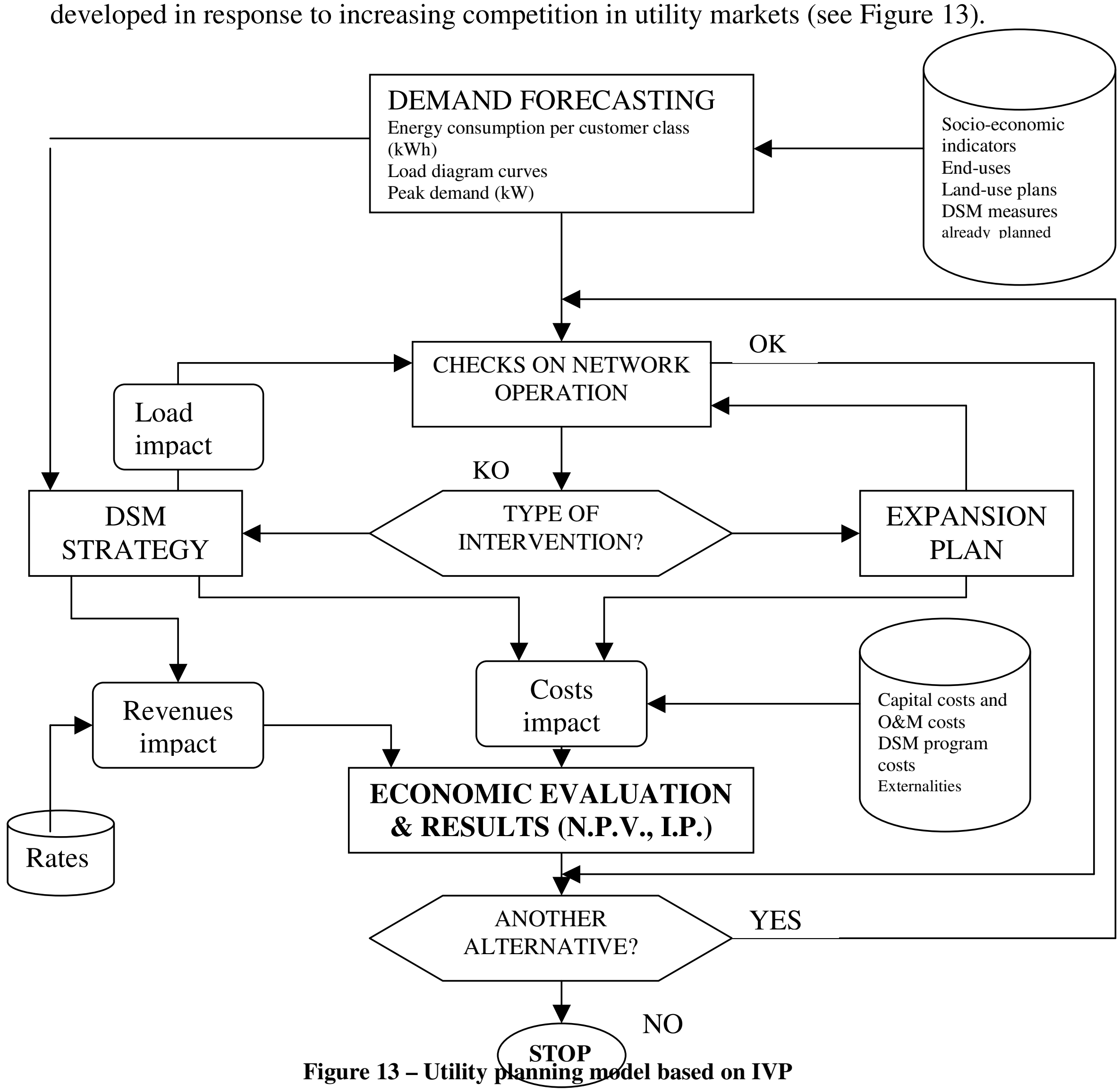
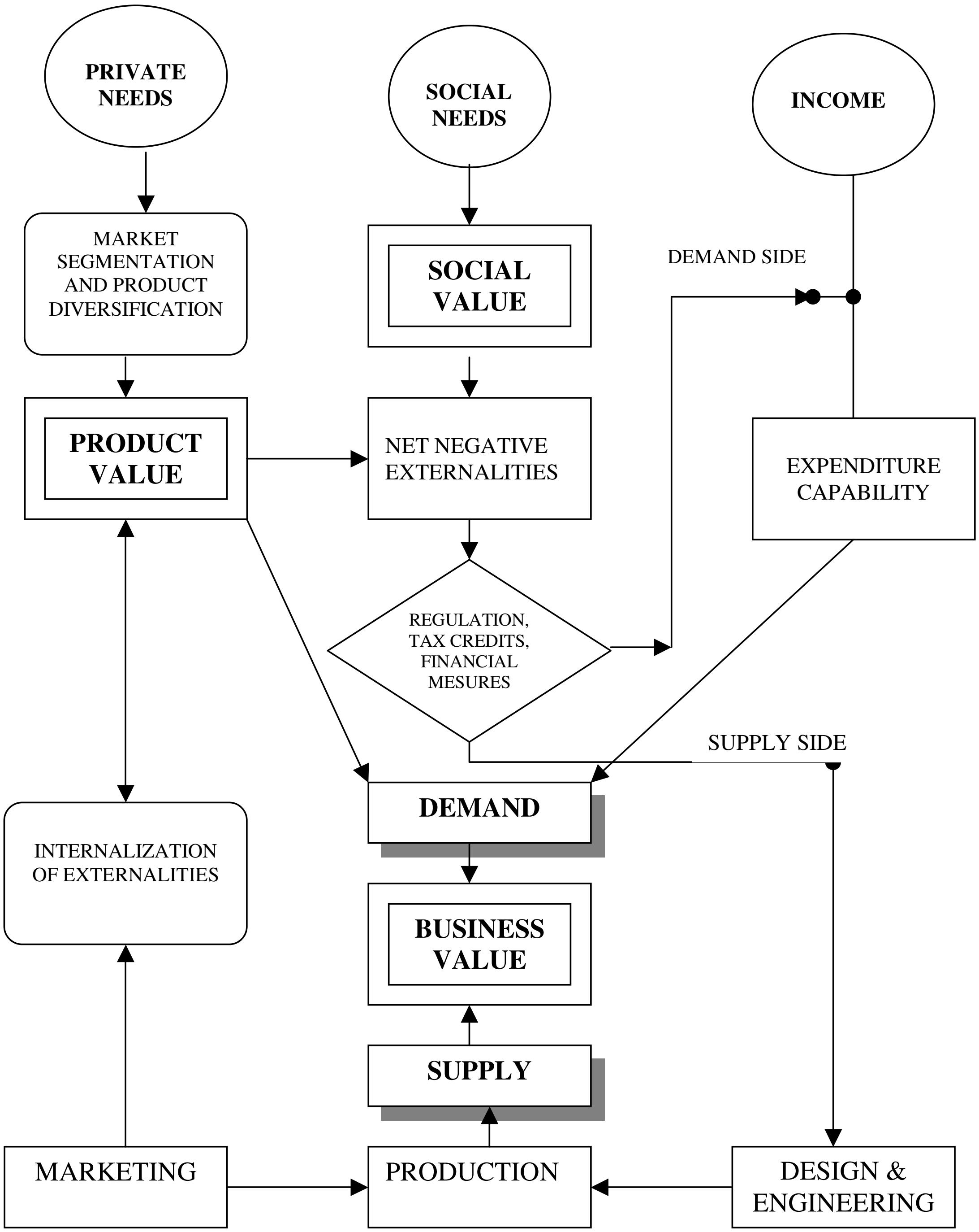


Figure 13 – Utility planning model based on IVP

[21] F. Insinga, "Guida pratica alle decisioni aziendali", Il Sole 24 Ore, Milano, 1993, pp. 114÷125.
[22] Electric Power Research Institute, "Integrated Value-Based Planning: An Overview", EPRI CU-6534, August 1999.

The IVP approach incorporates the competitive strategies of markets segmentation, product differentiation, and externalities internalisation to promote the broadening of the electric utility business from a single focus (i.e. providing electricity) to one dealing with multiple customer service options (see Figure 14)[23].



Source: F. Insinga, Il valore quale principio guida del processo di pianificazione aziendale, in Prisma, Rivista Trimestrale della Coopers & Lybrand, Milano, n. 22/1993, p. 37.

Figure 14 – Relationships between the three concepts of value

---

[23] F. Insinga, "Record of discussion about the Paper NO. 6.05", 12th International Conference on Electricity Distribution, Birmingham, 17-21 May 1993, p. 350.

Providing customers with expanded choices of service options increases the value that customer can obtain from the utility, as well as lowering the costs to meet these values. It also helps the utility to compete with the increasing array of services provided by third parties in energy market.

By linking the needs of customers, utilities, and policy makers, IVP can form the cornerstone of a successful long-term utility business plan- one that benefits both the utility, its customer, and the society.

Unlike the method for the evaluation of supply-side investment alternatives, which focuses on the minimization of the present worth of costs, DSM programs requires that the hypothesis of revenues invariance between alternative projects be rejected and a complete cost-benefit analysis be carried out. The cost-benefit analysis aims at giving a framework for the quantification of benefits and cost of DSM programs. Positive results may be either expressed as Net Present Value>0 or as Profitability Index>1. Both cases share a simple basic idea: a program is effective if, and only if, the Present Value of benefits is higher than that of costs.

A fundamental characteristic of DSM programs is that different groups perceive varying set of program costs and benefits. Indeed, with the exception of some forms of load control and metering, the physical devices producing demand-side modifications do not usually belong to the utility, but to its customers. The total costs and benefits of demand-side resources are thus distributed differently between the different groups. Moreover, the operating characteristics, system impacts, and availability of demand-side resources are quite different from those of utility-owned sources.

For the above mentioned reasons, in order to rationalize the analysis, special evaluation test have been developed based on capital budgeting methods. These take into account the different perspectives, i.e. the different impacts that the application of a DSM program may have on various groups.

In practice, cost/benefit perspectives of DSM programs are categorized in six ways[24]:

1. The consumer absent in any utility DSM program (**consumer perspective**);
2. The consumer participating in a utility DSM program (**program participant perspective**);
3. The utility owners **(utility perspective)**;
4. The ratepayer not participating in a utility DSM program (**nonparticipant perspective**);
5. The electric utility ratepayers, or the program participants and nonparticipants (average ratepayer perspective);
6. The society at large, including all customer and people living in the nation or in the area under study **(societal perspective)**.

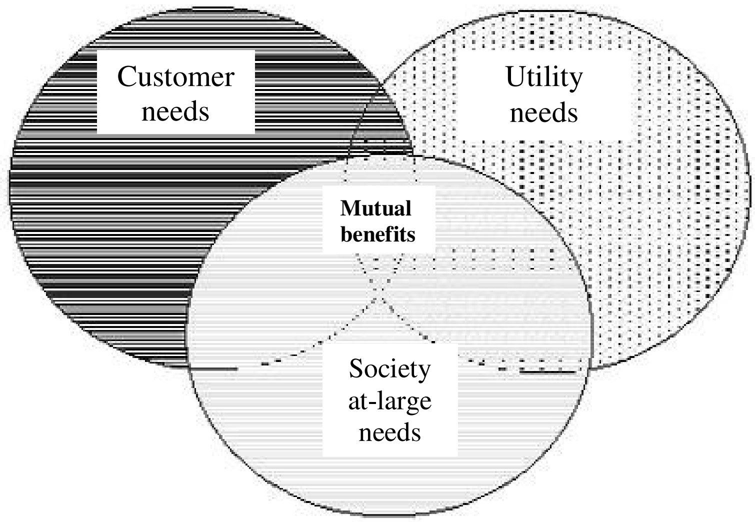
These diverse population segments represents three broad stakeholders to consider in doing cost-benefit analysis of end use technologies: customers or consumers, utility owners, and society at large.

The capital budgeting tests of the cost-benefit analysis are used to examine the cost-effectiveness of DSM options at the program level from different stakeholder perspectives.

The tests employ a net present value analysis of benefits and costs over the life the energy efficiency measures promoted by DSM programs.

Figure 15 graphically illustrates the relationship among these groups, and explains the main DSM benefits of the three broads groups.

[24] Electric Power Research Institute, "End-Use Technical Assessment Guide (End-Use TAG)", Volume 4: Fundamentals and Methods, EPRI CU-7222, Palo Alto CA, April 1991.



Benefit of DSM

a) for customer
. satisfy needs/wants
. reduce cost
. improve value of service
. maintain/ Improve lifestyle & productivity
. conserve energy

b) for utility
. reduce cost of service
. improve operating efficiency, flexibility
. reduce capital needs
. improve customer service
. increase system utilization
. reduce critical fuel usage

c) for society-at-large
. reduce pollution
. saving resource
. protect global environment
. maximize customer welfare
. reduce deficit on fuel balance of payments
. improve security in fuel supply

Figure 15 – Relationships among customer, utility, and society-at-large

Benefits and costs do not accrue equally to all. For example, participants in a utility DSM program may receive an incentive payment in addition to being on an alternative rate. Neither of these benefits is paid to non participants. Moreover, the benefits may be costs to non participants. Thus, program benefits and costs may be calculated from several perspectives; no single perspective can capture the economic consequences of a program for each affected subset of society.

It is very important to note that the costs and benefits analysis in a DSM program must be conducted on incremental bases. Thus it is developed that fraction of the costs and benefits related to the implementation of DSM, without considering what would have happened anyway even without the program (Principle of Relevance).

The items of benefits (avoided costs and/or revenues) and costs (incremental costs and/or lost revenues) to be considered in tests of DSM program cost-effectiveness are the following:

1. Changes of supply costs;
2. Changes of revenues (utility's bills);
3. Costs of DSM programs to the utility;
4. Incentives and costs of participation;
5. Costs to the participants and costs avoided by participants;
6. Tax credits and payments by third parties to the participants;
7. Externalities.

1. *Changes of supply costs (marginal costs).* One of the main benefits of a energy efficiency or load management program to a utility and to a society as a whole is the reduction in supply costs that occur as a result of a general reduction in energy use or as a result of a shift of energy use from a more expensive period to a less expensive period. Supply costs include generation, transmission, and distribution costs, that is, all the costs involved in producing electricity and bringing it to the customer's meter. The marginal costs measure the variation in utility expected total costs due to an increase in power and energy required by the customer. Can be calculated using either a short or long term.

   The short run marginal costs are defined as the additional costs incurred within the same capacity. These include operating costs such as fuel, materials, supplies, services and various costs of operation and maintenance of the system, as well as the social cost of energy curtailed due to the supply reliability level.

   The marginal long-term costs include both variable costs associated with the additional production, and the investments required to improve production capacity.

   1.a Generation marginal costs

   The generation marginal costs can relate to both the power that the energy. The power costs are supported by the utility for the construction of new or the improvement of the existing plants to meet increased demand.

   The energy costs are given by the fuel additional expenses and by the variable operating costs required to produce a kWh more of energy. This cost item can fluctuate significantly linked to the load level supplied instantly.

   1.b Transmission marginal costs

   The transmission marginal costs can relate to both the power that the energy. The transmission marginal costs are additional costs due to the need to strengthen the transportation network following an increase in peak load. Typically, transmission costs are due to depreciation of facilities and the loss of power and energy, at these will add up the costs of maintaining and operating the network, which in turn are a function of consistency of the plant.

   1.c Distribution marginal costs

   In analogy to transmission costs, the distribution marginal costs including a share related to the power and energy. The first is needed to strengthen the distribution system to provide an additional kW at a time of peak demand. This share, related to electric power, is usually broken at primary voltage level (high or medium voltage), typical of specific industrial users and of large organized distribution, and secondary voltage (low voltage), referring to small traders, to household consumption and to street lighting. In contrast to that observed for the transmission, these costs are considerably variables as the type of distribution system is extremely volatile with the conditions of supply. Just think of the difference between urban networks (which include short lines with underground cables and high power stations) and rural networks (where there are long lines and low power substations). The second class of costs (linked to energy) is formed by joule energy losses.

2. *Changes of revenues (utility's bills).* Another large effect of DSM programs is a change in the total revenues that customers pay to a utility. A reduction in total revenues because of decreased sales from a DSM program is a loss to the utility from a point of view of rate levels, but this same amount is a benefit to program participants because it represents a reduction in their electric bill[25]. The change in revenues is based on the rate tariffs in effect for the customers who participate in the program. For these reasons the structure of electricity tariffs is increasingly used by utilities as a means of DSM as explained in Figure 9. In addition, the Treasury will suffer a reduction in the VAT and in the taxes applied on kWh consumed.
3. *Cost of DSM programs to the utility.* This category of costs includes all the direct expenses a utility incurs in planning, implementing, and evaluating a DSM program, except incentives paid to customer. Cost categories include the following:
   - ✓ Marketing and promotional costs
   - ✓ Administration costs
   - ✓ Equipment costs
   - ✓ Installation costs
   - ✓ Operation and maintenance costs
   - ✓ Program monitoring and evaluation costs.
4. *Incentives and costs of participation.* Incentives are monetary amounts that a utility pays to a participant customer. These incentives can take many forms, including direct monetary payments, reduction in bills, rate discounts, and reduction in financing charges (e.g. zero-interest loan).
   The opposite of an incentive is a cost of participation, which may be defined as any monetary amount that a participating customer pays to a utility that is directly related to participation in a program. Examples include a fee paid for a time of use meter, shared savings payments made to the utility or Esco, or the stream of leasing payments when a customer leases efficient equipment from the utility or from third parties[26].
5. *Cost to the participants and cost avoided by participants.* Participant costs include all the out-of-pocket expenses that a customer incurs as a result of program participation. These costs are before the participant receives any rebate or incentive.
   Cost categories include the following:
   - Equipment costs, including sales, tax and installation
   - Operation and Maintenance (O&M) costs
   - Any removal costs (less salvage value)
   - Value of the customer's time in arranging for the installation of the measure, if significant
   - Shared savings payments to third-party contractors
   - All others costs directly related to program participation.

   The benefits (avoided costs) are relating to the fact that DSM programs often involve much less energy and less commitment power by the customer with savings - through tariffs - on its bill.

---

[25] See case study developed in Appendix.
[26] Like, for instance, in the cogeneration plants, and in small renewable plants (wind and/or photovoltaic).

6. *Tax credits and payments by third parties to the participants.* This benefit category includes any monetary amount that a non utility source pays to a participating customers for program participation: White Certificates to promote energy efficiency programs, Green Certificates to promote of renewable energies, Energy Photovoltaic Account to incentive solar energy, tax incentives for energy saving.
7. *Externalities*. This category covers all costs and benefit that are external to the usual cost accounting method. Externalities include such effect as the environmental damage caused by generation plants and transmission lines, the employment benefits that come from utility resource investment, and the national security benefits that accrue from a reduction of dependency on foreign oil, gas and coal[27]. In order to reduce the CO_2, the emissions trading[28] (or black certificates) are an administrative approach used to control CO_2 by providing incentives for achieving reductions in the emissions of greenhouse gas.

After evaluated benefits and costs of a DSM program during its life cycle, economic tests are used to analyze the cost-effectiveness of such program from different stakeholder perspectives. Each test represents a different point of view of stakeholders, using the merit figures of Net Present Value (NPV)[29] or of Profitability Index (P.I.)[30] to assess the economic convenience of the DSM option.

This economic methodology is therefore based on three tests that take into account the different perspectives of stakeholders that reflect their economic interests.
Figure 16 provides a summary of the three tests, by means the benefits and costs that each perspective develops.

[27] O. Hoymeyer, "External Environmental Costs of Electric Power - Analysis and Internalization", Springer-Verlag, New York, 1991.
[28] H. Nilsson, Demand Side Management (DSM) - A renewed tool for sustainable development in the 21st century, IEA, Brugge, 2007, p. 8, "*If carbon-dioxide is priced and the utilities will have to pay for emissions either by tax or by buying "emission permits" it could be more rational for them to pay for energy efficiency improvements*".
[29] NPV of a stream of benefit-cost is expressed by the following equation:

$$NPV = \sum_{t=0}^{N} \frac{(benefits - costs)_t}{(1+r)^t}$$

where:
* t = time variable from 0 to N years
* r = yearly interest rate
* N = program economic life

For VAN positive values, the program is convenient in a specific perspective.

[30] $$PI = \sum_{t=0}^{N} \frac{(benefits / costs)_t}{(1+r)^t}$$

For IP > 1 the program is convenient in a specific perspective.

TEST	BENEFITS	COSTS
Customer	Lower costs (customer power and energy cost savings) + incentives	Costs of DSM technologies (customer incremental and installed measure costs)
Utility	Supply costs avoided due to power and energy savings achieved	Total cost of the program (administrative costs and customer incentives) + Lost revenues
Society-at-large	Avoided cost of supply side + environmental benefit	Costs of DSM technologies + Total cost of the program (excluded incentives) + Loss of social benefit

Figure 16- The three economic tests

Monetary values in all perspectives should be calculated in the same account units, in nominal or real terms. The discount rate will be the nominal interest rate for first case, and the real interest rate, or inflation adjusted rate, in the second case. It is very important to observe that in any case will be necessary to take into account the real escalation rates associated to the employed resources[31].

4. WHY CHANGE DEMAND?

This paragraph will demonstrate how the resource allocation associated with a regulated monopoly like those of the utilities could be improved utilizing DSM techniques[32].

The natural monopoly situation of public utility firm precludes a competitive price model. A classic monopoly price model is described in Figure 17, where with demand DD, the monopolist would maximize profit at output Q_1 and unit price P_1 were marginal revenue equal marginal cost.

31 F. Insinga, "Guida pratica alle decisioni aziendali", Il Sole 24 Ore, Milano, 1993, pp. 44÷61; E.L. Grant, W. G. Ireson, and R.S. Leavenworth, Principles of Engineering Economy, (8th ed.) New York, John Wiley & Sons, 1990.

32 G.E. Vollans, "Demand-side management: a tool to correct muted pricing signals to consumers", Utilities Policy, April 1993, pp. 113-114.

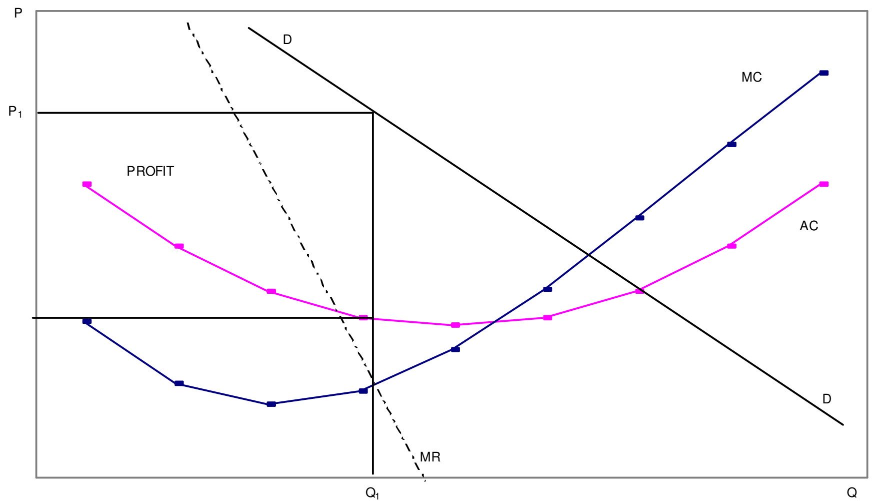


Figure 17 – Natural monopoly: short term monopoly profit maximization

To preclude such monopoly profit, prices may be regulated so as to approximate average cost, including a return on capital employed.

With price institutionally set equal to average cost, however, consumption will tend towards the level were demand DD intersect the average cost curve. Figure 18 shows three alternatives levels of demand with an assumed given capacity for a regulated monopoly. For demand D_1D_1, where average costs are falling as output increase, the marginal cost of an additional unit is less than average cost (= price). An additional sale at a price greater than marginal cost, but less than average cost, would yield social welfare gains, demonstrated by the fact that price (= average costs) would fall for all output.

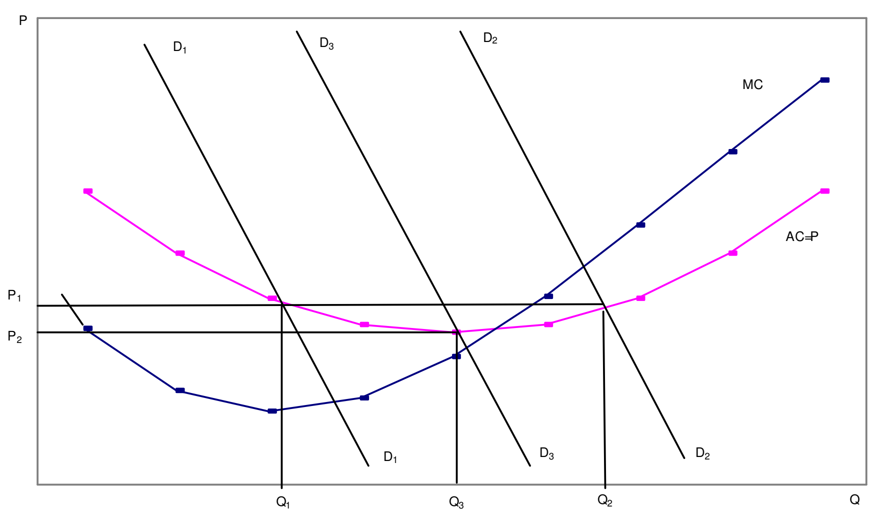


Figure 18– Regulated monopoly

Figure 19[33] depicts a case where a utility has marginal revenues (= average costs), which exceed marginal costs. In this case the firm can lower its price and increase its profitability. This might take the form of a DSM program like special rates for Thermal Energy Storage and so on. Also valley filling and strategic load growth programs could be cost-effective.

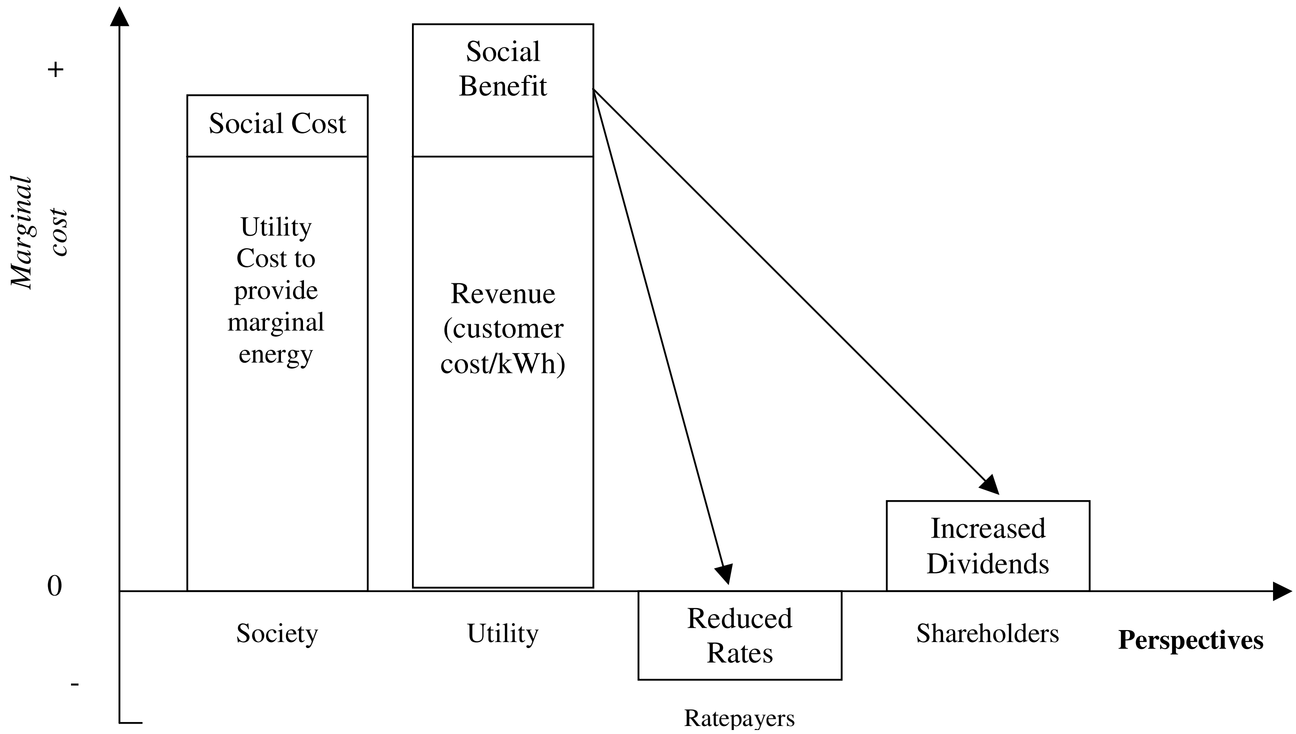


Figure 19- Customer/Utility Cost Perspectives

In practice, several techniques have been developed over the years to move towards marginal cost pricing when average cost is greater than marginal cost, such as declining block prices, interruptible tariffs, and new customer incentives. As long the value of incentive does not exceed the difference between price and marginal cost, the outcome should be Pareto superior to the status quo.

The converse would apply at an assumed demand D_2D_2: a reduction in demand when marginal cost exceeds price towards D_3D_3 would yield a gain in social welfare and a corresponding reduction in average cost (and in price). Only an output Q_3 with demand D_3D_3 would marginal cost equal price (= average cost), and there would be no social welfare incentive to modify the demand.

Many utilities have marginal costs of electrical energy, which exceed their average costs for all or a portion of a day. For small changes in sales, it is logical to argue that the utility could afford to use this difference (marginal less average) as an incentive towards DSM, like illustrated in Figure 20.

[33] C.W. Gellings – J.H. Chamberlin, "Demand-Side Management. Concepts & Methods", The Fairmont Press Inc., Lilburn, 1992, p. 283.

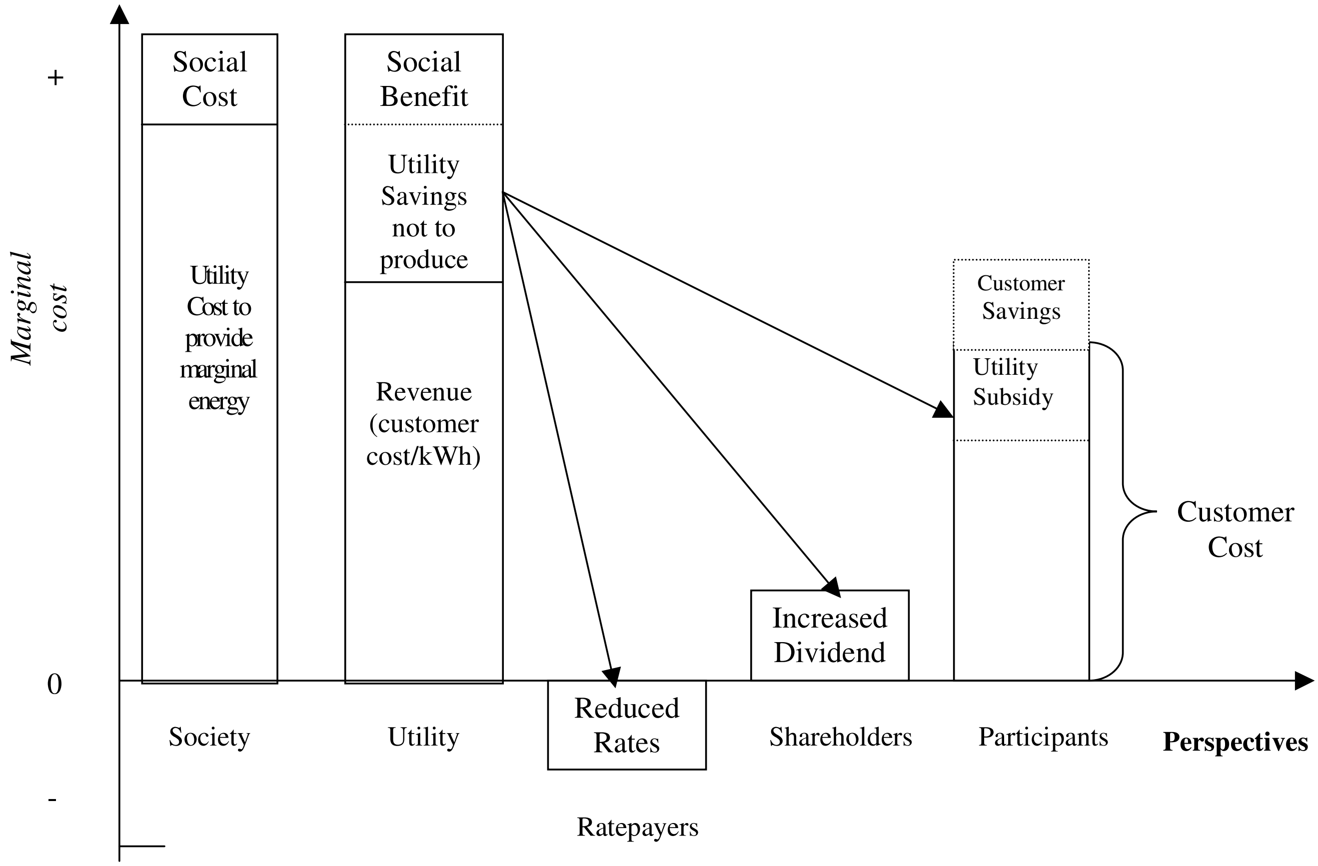


Figure 20- Customer/Utility Cost Perspectives

The first bar depicts society's cost for an incremental kWh of electricity produced and consumed. Societal costs include the utility's cost, as well as many social and environmental factors.

The second bar shows the utility cost itself, the best measure to use by the utility in evaluating any potential DSM action. A portion of the second bar depicts the revenue, which is obtained by sale of that incremental kWh. That revenue is shown here to be less than cost since the utility would not typical be interested in energy efficiency and load management type DSM program where revenue exceed costs (like in lighting). Figure 21 also shows the utility's savings if it does not need to supply the kWh lost. Saving that increment leaves a unit of revenue, which can either be spent on DSM or saved directly by the customer. The customer's participation can be encouraged further by offering an incentive. The incentive can be derived from the savings due the avoided costs for production of the increment of energy, and could be split between participants in a energy saving or load management type DSM program, ratepayers, and shareholders, or used to promote the program via advertising and marketing efforts.

Therefore, in both cases of marginal cost greater or less average cost (=price), if demand can be managed so as to shift demand to yield an output close to Q_3 at cost less than the amount by which marginal and average costs differ, there will be a social welfare gain which can shared with all consumers in the form of lower tariff rate.

5. CONCLUSIONS

In this time of expensive energy and environmental concerns, electrical systems planners are seeking ways to reduce system costs by looking at how electricity is used as well how it is supplied. The emphasis on how electricity is used is relatively new and is studied in Demand-Side Management strategies. These strategies involve special evaluation techniques that have to now been inadequately covered in the literature.

Cost-benefit analysis is a precious tool for analysing demand-side alternatives. Economic analysis is particularly useful in DSM because its complexity, its multiple, often conflicting objectives, and because many people are involved in the choices.

With regard to the complexity and conflicting values of a DSM evaluation, like shown in the Appendix, cost-benefit analysis offer a logical framework for organizing information, stating objectives clearly, and evaluating alternatives consistently.

With regard to the results, DSM programs, although in the short term benefits can achieve limited results for all stakeholders, reduce (Figure 21):

- the need for investment in capital intensive projects in the generation and transmission-distribution systems,
- the ratio of the peak power demand and the average power demand,
- the fixed costs (related to power) and increases the reliability of supply,
- the blackouts probability of the whole power system,
- the greenhouse gas emissions and the environmental impact, and thus are recognized as a major solution in the fight against climate change.

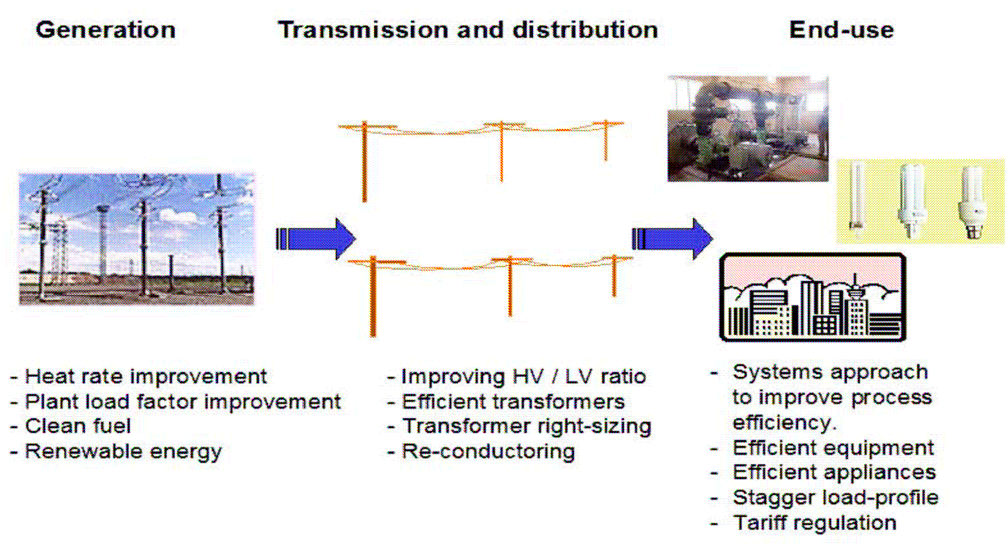


Figure 21- Main results obtained by the DSM

APPENDIX: EXAMPLE OF COST-BENEFIT ANALYSIS APPLIED TO THE END USE LIGHTING

In this simple example the two lamps options: Incandescent and Electronic fluorescent compact are economically compared on the base of this general features:

- Quantity of light: 1200 lumen (lm)
- surface to be illuminated: 20 m^2
- Utilization yearly hours: 1.000 hours
- Annual interest rate: 6%
- Tariff rate: 0,15 €/kWh.

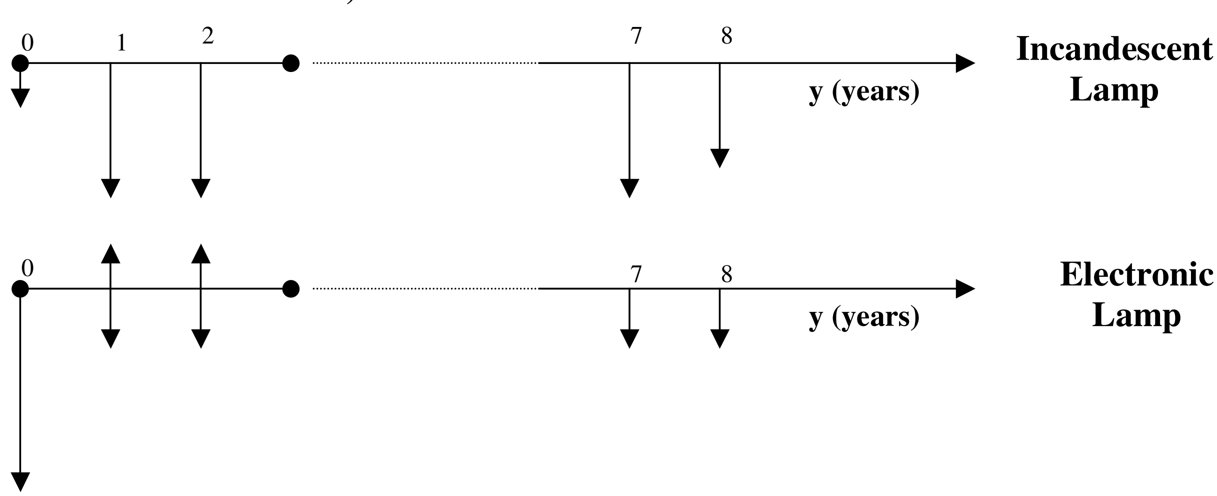
Moreover, the techno-economic parameters of the two aforesaid lighting sources are represented in the following Table 1:

Table 1 - Techno-economic parameters of the two aforesaid lighting sources

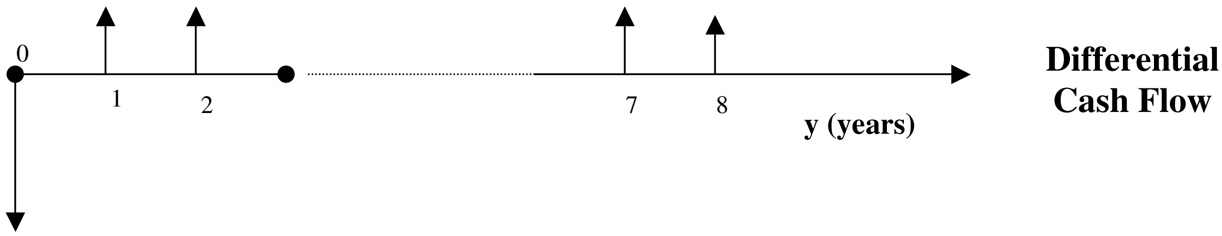
Type of lamp	Efficiency (lm/W)	Power of lamp (W)	Average life (hours)	Cost of lamp (€)	Operating cost (€/y)	Fiscal saving (%)	White certificate (€/kWh)	Externalities (€/kWh)
Incandescent	12	100	1.000	1,50	15,00	0	0	0,0125
Electronic	60	20	8.000	15,00	3,00	55%	0,016	0,0025

The operating cost is evaluated on the base of a tariff rate of 0,15 €/kWh (W*hu*OC).
The white certificates are evaluated on the base of a market price of 80 €/Tep equal to 0,016 €/kWh assuming an efficiency of 2000 kcal/kWh and 1 Tep = 10^6 kcal.
The negative externalities are evaluated on the base of a social cost of 62,50 €/Tep equal to 0,0125 €/kWh assuming an efficiency of 2000 kcal/kWh and 1 Tep = 10^6 kcal[34].
The fiscal saving equal at 55% of cost of electronic fluorescent compact lamp can be divided in 3 years.
Marginal costs of electric supply: 0,06 €/kWh.
Operating&Maintenance and disposal of waste of lamp are considered negligible costs.
The economic calculation [**Life-cycle cost (LCC)**] is made using constant Euro (excluding inflation) and thus with a real discount rate, and, for sake of simplicity, without real escalation rate applied to the costs and benefits.

a) Customer Test



[34] M.N. El-Kordy, M.A. Badr, *et alii*, Economical Evaluation of Electricity Generation considering Externalities, Elsevier Science Ltd, 2002.



$$\text{VAN (I)} = -\,(1{,}5 + 16{,}5 * a_{\overline{7|}\,6\%} + 15 * v^{8}) = -103{,}0205\ €$$

$$\text{VAN (E)} = -\,(15 + 3 * a_{\overline{8|}\,6\%} - 2{,}75 * a_{\overline{3|}\,6\%}) = -26{,}2786\ €$$

$$\text{VAN (E- I)} = -\ 26{,}2786 + 103{,}0205 = +76{,}7419\ €$$

If you want to calculate the annual financially equivalent cost (annuity) of the two alternatives is enough to make the following transformation:

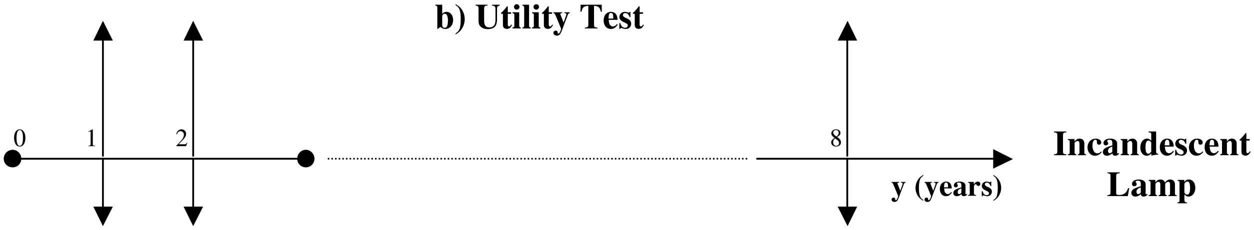
$$\text{ANN (I)} = \text{VAN (I)} / a_{\overline{8|}\,6\%} = -16{,}59\ €/y$$

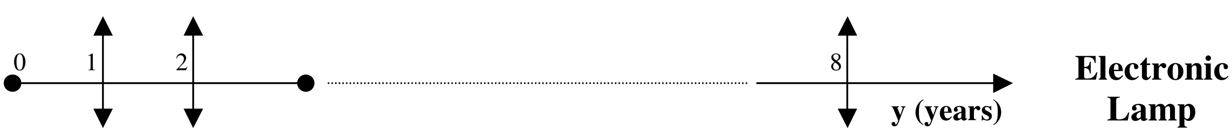
$$\text{ANN (E)} = \text{VAN (F)} / a_{\overline{8|}\,6\%} = -4{,}2318\ €/y$$

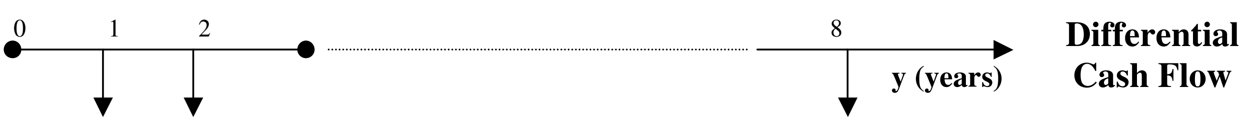
$$\text{ANN (E- I)} = -\ 16{,}59 + 4{,}2318 = +12{,}3582\ €/y$$

Thus the electronic lamp allows to the customer a yearly net saving of 12,3582 € and a total present worth of savings equal to 76,7419 €.

b) Utility Test







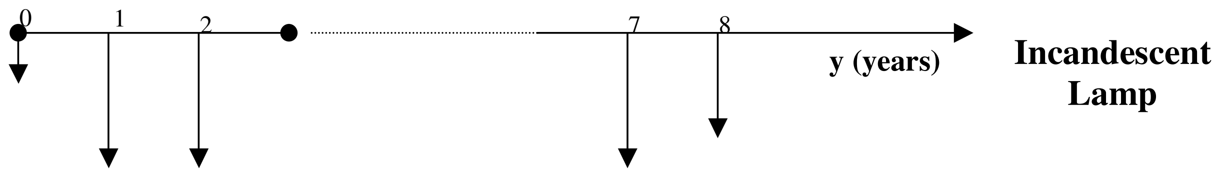
$$\text{VAN (I)} = (15 - 6) * a_{\overline{8|}\,6\%} = +55{,}8881\ €$$

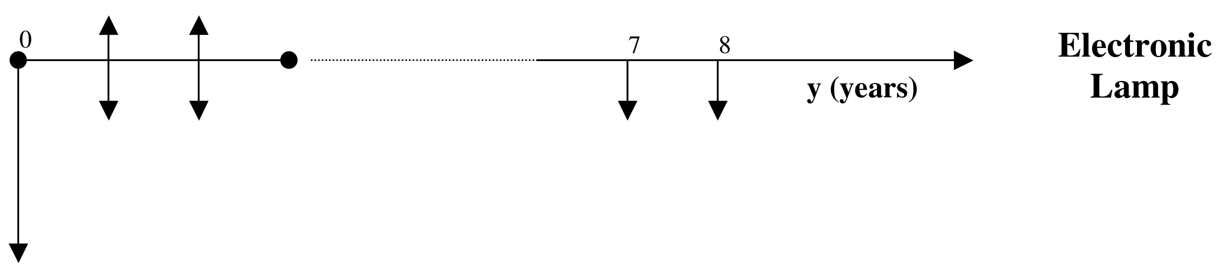
$$VAN\ (E) = (3 + 1{,}28 - \underbrace{1{,}2}_{\boxed{\text{White certificates}}}) * a_{\overline{8|}\,6\%} = +19{,}1216\ €$$

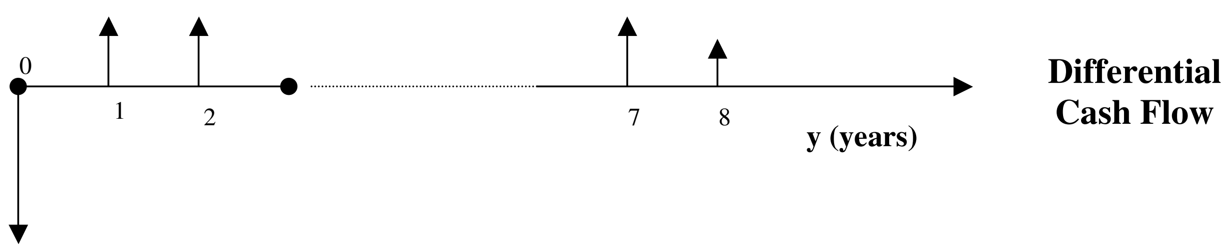
$$VAN\ (E\text{-}\ I) = 19{,}1262 - 55{,}8881 = -\ 36{,}7619\ €$$

Despite the incentive of white certificates (certificates of energy efficiency), today quoted a ~ 80 €/Tep, the utility would not have cost-effectiveness to promote this technology more energy efficient.

c) Society-at-large Test







$$VAN\ (I) = -\ (1{,}5 + 17{,}5 * a_{\overline{7|}\,6\%} + 16 * v^{8}) = -109{,}2303\ €$$

$$VAN\ (E) = -\ (15 + 3{,}2 * a_{\overline{8|}\,6\%}\ ) = -34{,}8713\ €$$

$$VAN\ (F\text{-}I) = -\ 34{,}8713 + 109{,}2303 = +74{,}3589\ €$$

In conclusion, while the consumer and society tests are positive, the utility test is negative. This explains the poor usage in Italy of energy efficient lamps[35]even though available in the market for over 20 years.

[35] The Finance Act of 2009 states that, by 2011, incandescent bulbs cannot be sold in the Italian market.