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Improving Energy Efficiency in Manufacturing Systems — Literature Review and Analysis of the Impact on the Energy Network of Consolidated Practices and Upcoming Opportunities

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Additional information is available at the end of the chapter

1. Introduction

Global energy context has become more and more complex in the last decades: raising prices of depleting fossil fuels, together with economic crisis and new international environmental and energy policies, are forcing companies (and manufacturing industry in particular, which is responsible for 90% of industry energy consumptions, in turn making up the 51% of global energy usage, as listed on EIA, the Energy International Agency, website, last accessed on the 5th of October 2014) to cut energy wastes and inefficiencies, and to control their consumptions.

Besides the existing analysis of the above mentioned regulatory and economic concerns, Energy Efficiency criticality for manufacturing systems has recently been investigated and proved also by the analysis of its connection with Productivity Efficiency [1-4], which resulted to be strong and mutual, and of the numerous non-energy benefits achieved while performing energy efficiency measures [5], such as the improvement of corporate image and the environmental impact reduction.

Over most recent years, Energy Efficiency has therefore become a critical factor for industrial plants' competitiveness, and is now definitely considered as a key driver to economic development and sustainability.

But, despite it all, it is often still difficult for many companies to understand its effectiveness, in good part because of the difficulties met in focusing its technical and economic benefits, as Laitner [6] highlights:

"Energy Efficiency has been an invisible resource. Unlike a new power plant or a new oil well, we do not see energy efficiency at work. (...) energy efficiency may be thought of as the cost-effective investments in the energy we do not use either to produce a certain amount of goods and services within the economy."

As a matter of fact, Energy Efficiency still represents a challenging goal for most companies. As above mentioned, numerous problems are yet to overcome in quantifying its benefits and evaluating the cost-effectiveness of related investments, and most of all the huge variety, complexity and changeability of fields, technologies and methodologies involved in its improvement in production systems are responsible for the slowing down of their resolution and of the spread of Energy Efficiency measures and culture.

In fact, in order to individuate and prioritize suitable improvement interventions and Energy Efficiency opportunities, and to design and customize the Energy Management System or the Monitoring and Control System according to a particular company's needs, a deep and complete knowledge of many different subjects and disciplines (ranging from physics and thermodynamics to economy and project management) is needed, besides a good ability and practical sensibility to direct one's efforts in the right way.

Considering that Energy Efficiency isn't obviously the core business of manufacturing industry, such effort might sometimes be very laborious, and in recent years many companies have decided to demand Energy Management activities to specialized external companies, the so-called Energy Service Companies (ESCos). ESCos generally own the know-how required to individuate Energy Efficiency measures and are also able to fund Energy Efficiency investments (see [7] for a specific literature review); what they usually do not own is a deep understanding of the company's dynamics, situations and needs, as well as the capability to draw a long-term development path towards the achievement of a diffused Energy Efficiency culture within the company, which shall be consistent with the company's vision and policies and is essential in order to consolidate and continuously upgrade improvements in such sector. It is then crucial for companies to have at least a general consciousness of all intervention areas and of all possible improvements, both managerial (and/or behavioural) and technological, that could be pursued and achieved, in order to be able to lead their own way towards their sustainable development, and also to capitalize ESCOS' assistance and services.

In order to overcome part of these difficulties, and in particular to make it easier for companies to address their efforts and catch best efficiency opportunities, a logical and systemic approach is necessary: it would help not to overlook any possible area of improvement, to easily classify and understand those areas, but also to identify the most suitable and cost-effective, and eventually to prioritize them.

In the light of this, some studies have already been conducted in order to find out methods and tools to assess the current level of maturity of a company in the Energy Management field [8], and to help individuating a possible development path. However, although they point out some possible development scenarios, they do not provide a complete and organic categorization of all possible areas of intervention, so as to make it easier for practitioners to address their efforts into the right way.

In this chapter, a new conceptual scheme to organize and classify Energy Efficiency measures is defined, leading from the definition of Energy Cost per Product Unit and further breaking it up in order to identify and define all possible areas of intervention, providing for each of them a brief overview of possible measures and opportunities and a specific literature review. All scientific papers, books and technical papers considered for the literature review of each area (chosen on the basis of a wide literature research and on authors' on-field experience) are recalled and systematized in Table 1, so that the reader is guided through their examination and rapidly addressed to their consultation.

In addition, a qualitative evaluation of the impact of some possible Energy Efficiency measures from each area on the energy network is given, in order to give both practitioners and researchers a first input to further focus on this additional feasibility evaluation criteria for Energy Efficiency measures, which enables to evaluate them on a national or international level rather than considering the benefits or concerns belonging to a single company.

			Reference number
Specific Cost of Energy	**Supplier and tariff choice**	Amount of total energy consumption	28, 29, 30, 31
		Peak Demand	20, 23
		Demand Response and dynamic price systems	32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44
		Power Factor correction	45, 46, 47, 48, 49, 50
	Compliance to contractual purchasing conditions		22, 51, 52, 53
	Onsite energy production		54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77
Specific Energy Consumption	Energy transformation, distribution and use (Design phase)	Technologies selection	22, 25, 78, 79, 80, 81, 82
		Modulation technique selection	22, 83, 84, 85, 86, 87
		Dimensioning	22
	Energy transformation, distribution and use (Operations and Maintenance phase)	Human behaviours	51, 53, 88, 89, 90, 91, 92
		Best practices	93, 94, 95, 96, 97, 98
		Monitoring and Control	22, 25, 45, 53, 99, 100, 101, 102, 103, 104, 105

Table 1. Summary of the specific literature review for each intervention area.

2. General scheme for the literature review

Energy Efficiency in industrial sector has often been interpreted and studied as Specific Energy Consumption of processes, machines and factories [9-13], referring to its thermodynamic meaning and stressing the concept of 'using less energy to provide the same amount of services or useful output' [14], as well as its connection to environmental and ecological issues (and in particular to carbon dioxide emissions [15-19]). Similar approaches have however the blemish of neglecting a critical aspect, which is probably the most important to companies (whose fundamental objective is to improve their business), which is the reduction of energy costs.

Energy costs are in fact obviously tightly connected to energy consumption, but it would be a significant conceptual error to ignore energy market flows, tariffs and options, and therefore the variability of the Specific Cost of Energy, while trying to minimize them.

From a business point of view, it might therefore be much more useful and complete to define a physical-economic index, and to evaluate Energy Efficiency through its evolution in time; the index here proposed is the Energy Cost per Product Unit (Cost of Energy and Production Volume ratio, the inverse ratio of Energy Productivity), i.e. the energy cost paid for the single product unit, that can be calculated as the product of Specific Cost of Energy (the cost of the single consumption unit, Cost of Energy and Energy Consumption ratio) and Specific Energy Consumption (the energy consumption for the single product unit, Energy Consumption and Production Volume ratio), as represented by the following formula, where Cost of Energy is expressed in Euros, Production Volume in units and Energy Consumption in kWh.

$$\frac{Cost\ of\ Energy}{Production\ Volume} = \frac{Cost\ of\ Energy}{Energy\ Consumption}\ x\ \frac{Energy\ Consumption}{Production\ Volume} \tag{1}$$

The reduction of energy costs can therefore be achieved by minimizing Specific Cost of Energy, Specific Energy Consumption or both, depending on companies' policies and existing opportunities.

Leading from the definition of this physical-economic index, it is possible to define a conceptual scheme to categorize Energy Efficiency measures in manufacturing systems. In fact, all possible intervention areas can be classified according to which one of the two main factors (Specific Cost of Energy or Specific Energy Consumption) they do affect, as Energy Efficiency measures are generally aimed at reducing one of them. Specific Cost of Energy and Specific Energy Consumption can then be respectively affected by interventions performed in three different areas, which are:

- *Supplier and tariff choice*, the choice of the most suitable energy purchasing contract, according to the company's own consumption and to the considered market;

- *Compliance to contractual purchasing conditions*, all of the actions aimed at being compliant to the chosen energy purchasing contract's clauses and provisions (and to avoid incurring into fees and sanctions), and

- *Onsite energy production*, i.e. the production of the needed energy onsite, reducing or eliminating the quantity of energy purchased, for the first one, and:

- *Energy transformation*, the process of changing a form of energy into a more usable one, to be held in the most efficient way, avoiding all possible losses;

- *Energy distribution*, the process of delivering energy to the place where it is needed, to be held in the most efficient way, avoiding all possible losses, and

- *Energy use*, the final use of energy that shall be effective and efficient, for the second one.

By acting to improve one of these areas (for example applying existing best practices of the particular sector), the company can reduce energy costs and increase Energy Efficiency.

In particular, four different improvement areas concur to the "Supplier and tariff choice" factor, i.e.:

- *Amount of total energy consumption*, the actual amount of energy used, that has to be accurately considered in order to take advantage of economies of scale;

- *Peak demand*, the maximum power employed at a time, that shall be compliant to the contractual conditions;

- *Demand response and dynamic price systems*, all of possible actions aimed at beng able to modify the plant's demand profile in order to improve the system's reliability and to take advantage of special tariffs and purchasing conditions, and

- *Power factor correction*, the process aimed at reducing the amount of reactive power and increasing the amount of the active power employed.

The measures and opportunities connected to the three intervention areas affecting the Specific Energy Consumption have different implications according to the life phase of the plant they are applied to (*Design phase* or *Operations and Maintenance phase*). During the Design phase, Energy Efficiency is influenced by:

- *Technologies selection*, the choice of the Best Available Technology from an Energy Efficiency point of view;

- *Modulation technique selection*, the choice of the best method or technology to follow production needs without reducing Energy Efficiency, and

- *Dimensioning*, the choice of the most appropriate system's dimension,

while during the Operations and Maintenance phase is influenced by:

- *Human behaviours*, i.e. actions taken by people on the basis of their education and information about Energy Efficiency issues;

- *Best practices*, lists of existing best methods and techniques to operate a system in the most efficient way, and

- *Monitoring and control*, all of the actions aimed at keeping the system under control once it has started to operate.

All possible Energy Efficiency measures can be framed into these categories. In the next paragraphs, all of these categories and sub-categories will be introduced and defined, a brief overview of some possible Energy Efficiency interventions will be given and a specific literature review (summarized in Table 1) will be presented for each intervention area.
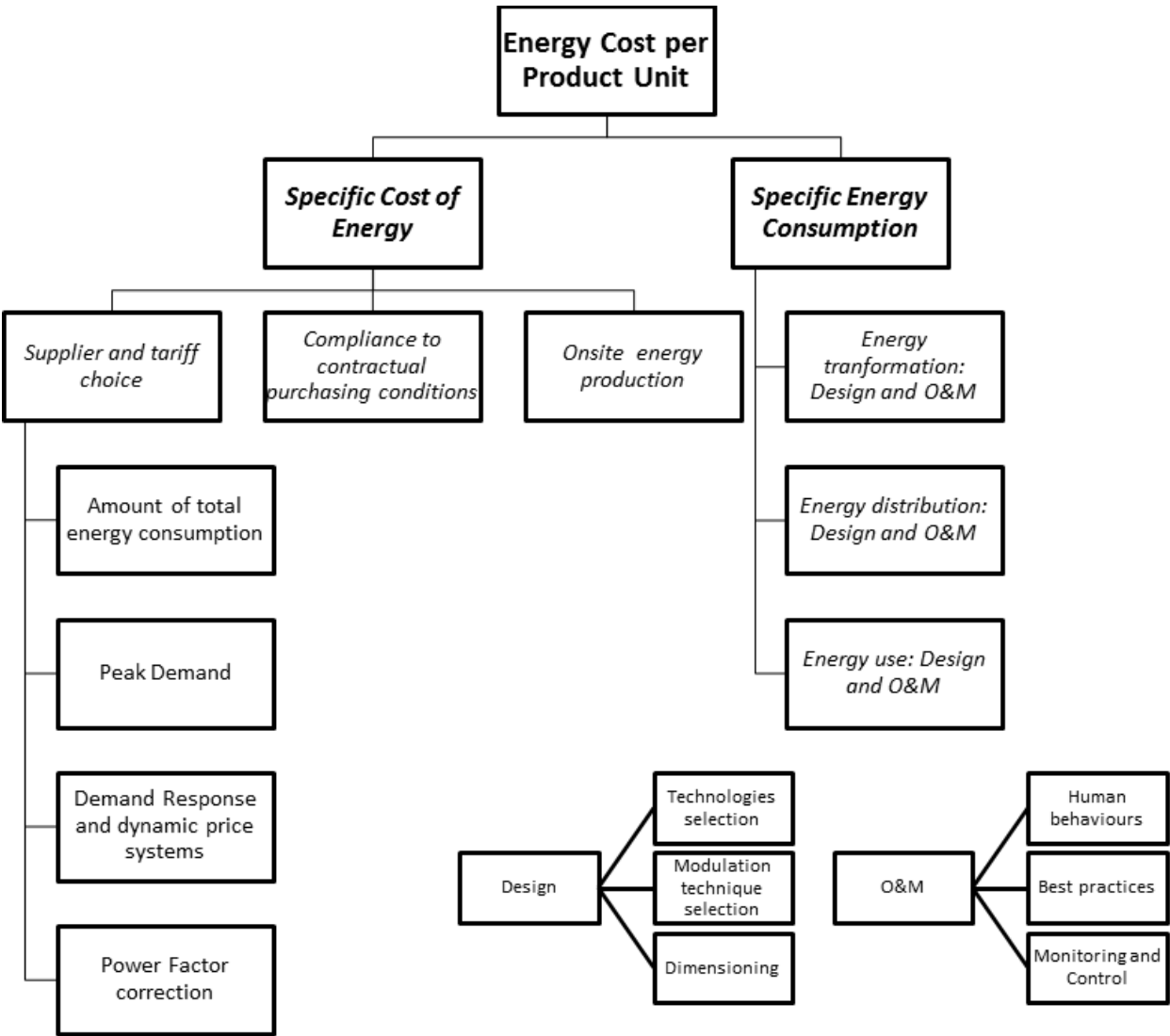

Figure 1. Conceptual scheme for Energy Efficiency measures' and intervention areas' categorization.

3. Specific cost of energy

Specific Cost of Energy [€/kWh], as aforementioned, is the payment due for the consumption of the single kWh (here expressed in Euros); its value and variability are often concerned and tackled by companies of remarkable dimensions (furthermore positively affected by scale effects), whilst medium and small sized companies are often not sufficiently aware of the problem, have little bargaining power, or have not got the possibility to take any measure.

Specific Cost of Energy directly depends on the capability to ensure energy supply at the lowest possible price, and therefore:

• On the capability to choose the most suitable supplier and tariff;

• On the capability to be compliant to contractual purchasing conditions;

• On the capability to produce the energy needed onsite.

To achieve these capabilities, having a complete knowledge of the present state of consumption, the historical consumption and the responsiveness of the system to changes (planned or unpredicted) is essential [20].

The importance of Specific Costs of Energy reduction is also due to the fact that it is achievable through immediate and cost-effective measures, that might generate huge savings in a very short period, and can therefore create an initial asset to finance further and more expensive improvements [21].

3.1. Supplier and tariff choice

The complexity of the supplier and tariff choice, here particularly referred to electricity, highly depends on the Country where the industrial site is located, as energy markets can be rather different from one Nation to another, as much as electricity bills' components (which are also inclusive of taxes and duties); anyway, as most of industrialized countries have nowadays adopted deregulated and liberalized markets (although important parts of the sector, like transmission and distribution, are usually still natural monopolies) [22], there is normally at least one element of the bill which is not subject to central government's regulation, but open to competition [23]. That situation leads to a huge complexity and quantity of options, but also to a wider range of savings opportunities and to customer services enhancement.

In order to take the right decision, several skills and tools are needed, which often require time consuming activities and transversal capabilities to be achieved: a deep knowledge of consumption logics and dynamics, a reliable forecasting system (based on predictive simulation models and tools), a complete comprehension of market rules and a continuous information process about available tariffs and options, as well as the capability to perform a comparative analysis.

In any case, a simulative approach might be implemented to characterize and forecast energy consumption, aiming at evaluating and comparing electricity rates by analysing the influence of all possible drivers on the electricity cost. Different methodologies have been proposed to allow industries developing their own strategies for the contracts' renewal. Some of them, like the one developed by Cesarotti, Di Silvio and Introna [24], focus on the use of statistical tools (like regression analysis and control charts) to characterize electricity consumption in the industrial process, forecast the energy demand basing on energy drivers and consumption characterization, and to analyze tariffs in detail, also performing a sensitivity analysis of energy price variability, that, for some of them, can also be coupled to the analysis of the cost of petroleum (and/or of other fossil fuels), by the introduction of a specific index (savings opportunities coming from that kind of price calculation can be consistent, but need users to

deeply understand the mechanisms used to generate the index, to analyse various forecasts of the index variability and to accept a very high risk [25]).

An alternative methodology has also been provided [25-27], based on budgeting techniques and on the development of a set of first and second level metrics and indicators to identify effects of external factors' variations (including energy price fluctuation) on energy consumption and cost.

Factors mainly affecting electricity cost for an industrial plant, which can discriminate various tariffs and suppliers' offers, are:

- Amount of total energy consumption;

- Peak demand;

- Demand Response and dynamic price systems;

- Power Factor correction.

3.1.1. Amount of total energy consumption

Purchasing a large amount of energy is the way to take the best advantage of economies of scale (the higher the amount of total energy purchased, the lower the cost of the single kWh), but difficulties may arise for both big and small companies, because of the fragmentation of production processes into different sites or because of moderate production volumes. Savings opportunities in that field might be found in concluding a unique contract for all scattered production sites or, referring to medium and small companies, in gathering in a consortium with other companies which have similar or compatible demand curves, loads' distribution and needs; that latter solution follows the 'industrial symbiosis' logic, which is the engagement of traditionally separate industries in a collective approach to business and environmental management [28-31], a managerial practice that has already given appreciable results in containing costs of other sources supply, like row materials and water.

Unfortunately, the practical implementation of these actions is often frustrated by big companies' purchasing policies, and by the unawareness of this problem of medium and small companies.

3.1.2. Peak demand

Electricity bills often include an additional fixed cost which depends on the maximum power employed (average values in a small time interval, usually of some minutes, are considered), and is introduced by many suppliers as a cost signal, an incentive for companies to control and reduce their capacity requirements, helping suppliers themselves to easily manage supply-demand balance. Thus, correctly forecasting energy consumption and load profile, principally basing on observation of historical data and statistical analysis, is essential to avoid penalties and surcharges [20]. By monitoring load profile and comparing actual peak load values to contractual one, it might be possible to highlight energy savings opportunities, summarized in the following table [23].

Peak Load	Saving Opportunity
Always exceeded	Negotiate a higher value of peak load to avoid penalties
Occasionally exceeded	Adapt operational practices and scheduling to contractual requirements
Always under the contractual value	Negotiate a lower value of peak load to achieve significant savings

Table 2. Savings opportunities in peak load value determination and monitoring.

3.1.3. Demand response and dynamic price systems

To enhance system's efficiency, cost signals (as aforementioned) are often send to end-users by suppliers, in order to steer their demand, flattening it as much as possible [32], and therefore improving system's reliability (as demonstrated by Samadi, Javidi and Ghazizadeh [33], who calculated the variations in the amount of Expected Energy Not Supplied after the implementation of different Demand Response programs through a Monte Carlo simulation); such strategy ends up in high electricity cost variability and/or in incentives assignment, principally depending on time of use, production and consumption scheduling, and capability to select a range of loads to be switched off if necessary.

Profitability of that solution for both suppliers and end-users has been studied and proved: Sezgen, Goldman and Krishnarao [34] used option-pricing methodology, a stochastic simulative approach which, by the means of Monte Carlo simulation (a tool that had already been exploited by Bhanot [35], having similar purposes) and of key financial components like forward curves of energy prices, price volatility, correlation between prices and interest rates, was capable to reproduce and forecast the stabilizing effect of Demand Response programs on electricity wholesale market; Faria and Vale [36] implemented a non-linear Demand Response simulator to calculate retailer's benefits when price variability is applied to single consumers or groups of similar consumers; finally, Torriti [37] and Gaiser and Stroeve [38] respectively highlighted the impact of variable tariffs on electricity demand and on end-users bills, considering residential customers.

Demand Response has been defined by U.S. Federal Energy Regulatory Commission (2012) as:

> "changes in electric use by demand-side resources from their normal consumption patterns in response to changes in the price of electricity, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized."

End-users can generally response to price variations by implementing three kinds of actions: reduce the amount of electricity used during high pricing periods (incurring in reduction of quantity or quality of outputs, and therefore accepting deriving risks), shifting part of electricity usage from high pricing to low pricing periods (rescheduling some production activities) or partially satisfying demand during peak periods by the means of onsite generators (this very last action will be discussed in next chapters) [32]. The decision to implement

one or more of these actions and therefore to catch resulting saving opportunities has got to be supported by both the use of forecasting and simulating approaches (like the financial instruments based simulation proposed by Oren [39] to forecast electricity price behave, assuming it to be close to a Brownian motion process, or the mathematical model relying on Non Linear Integer Programming framework, developed by Fernandez, Li and Sun [40] to optimize buffer inventory management policies and determine corresponding load management actions to be taken without affecting production and quality), and of systemic managerial approaches (like the one conceived by Bush [41], following seven steps, from evaluating rate schedules and incentives to analysing operations plan, to identifying and quantifying interruptible loads, the one described by Wang and Li [42], who proposed a methodology to solve production system modelling and scheduling problems while optimizing energy efficiency and minimizing electricity related costs, or the model proposed for medium and small users by Bello et al. [43]). Catching opportunities in that field requires companies to have a high maturity level in energy efficiency implemetation, as a robust consumption plan and control system is needed.

Demand Response Programs are divided into two categories: Incentive Based Programs and Price Based Programs. The first one includes all those programs involving incentives assignment to end-users who manage to interrupt and/or curtail part of their load when required by the supplier, in order to ensure reliability and react to emergencies; these incentives can be 'Classic' (a fixed, periodic incentive to compensate users for their willingness to interrupt or curtail their load) or 'Market-based' (an incentive assigned in proportion to user's performance in interrupting or curtailing loads) [44]. The second one includes programs which propose fluctuating rates, following the real time cost of electricity, such as TOU (Time Of Use) program, in which different cost of energy coincide with different time of the day [42].

Principal Demand Response Programs are summarized in Figure 2.

3.1.4. Power factor correction

Control and correction of the network's Power Factor are almost common practice in manufacturing systems: they are implemented to both avoid incurring in penalties and fines established by suppliers and to improve energy efficiency of distribution system within the industrial plant (reducing Joule losses) [45].

Different methods for measuring and controlling Power Factor values have been developed, depending on the load's characteristic and on the quality of the transmission [46], and various methodologies have been proposed to optimize capacitors' number and allocation for industrial users, by the means of a wide range of simulative algorithms [47]. Those methodologies have been studied at an extremely high level of detail, including Life Cycle Cost Assessments, to justify the installation of a certain number of capacitors, evaluating the possibility to use these devices to face lines' disturbs or mitigate harmonics [48], and therefore to take more advantages from their usage, as well as accounting of external factors variations, such as air temperature, affecting their efficiency.
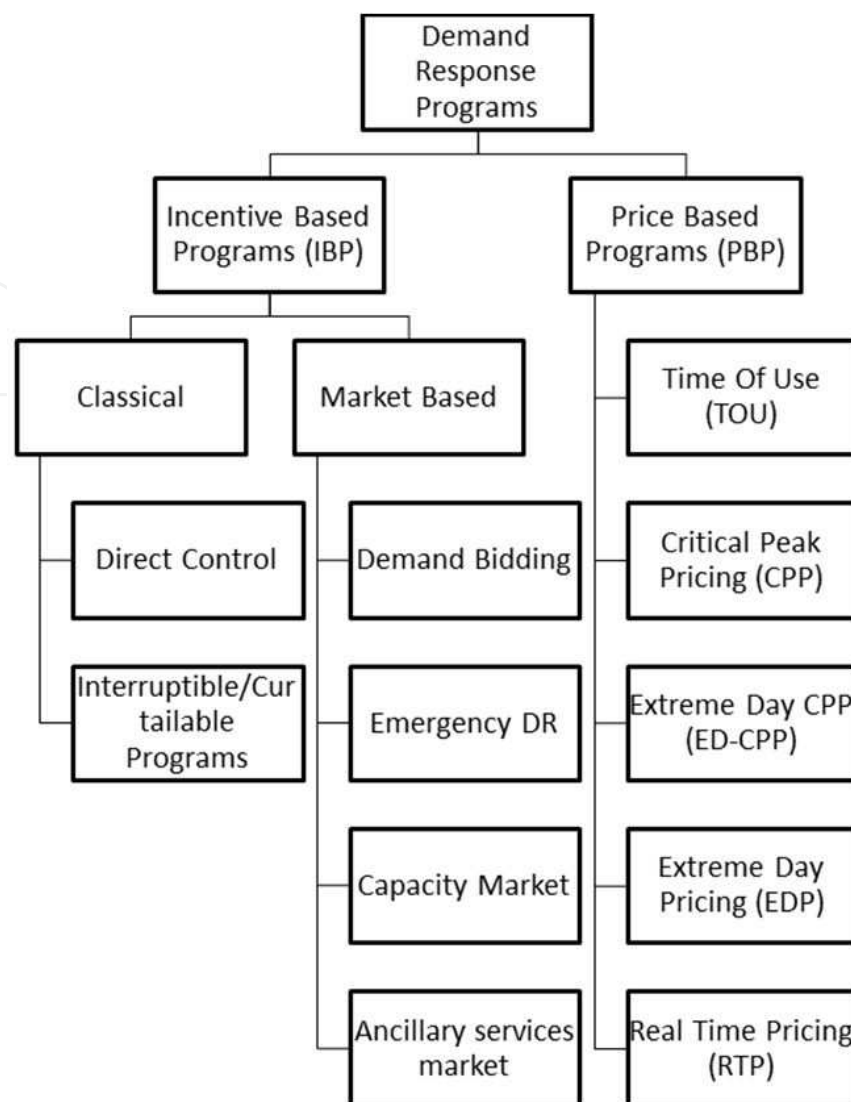
Figure 2. Classification of Demand Response programs [32].

Researches recently focused on Power Factor control through automatic system, and in particular by the means of artificial neural networks, a technology which eases variable loads control and provides more accurate and faster compensation compared to capacitor groups [49, 50].

3.2. Compliance to contractual purchasing conditions

Once all conditions illustrated in previous paragraphs have been contemplated and decisions have been taken according to companies' policy and existent saving opportunities, an anything but trivial source of Specific Cost of Energy variability is the capability of users to be compliant to contractual agreements.

On the one hand, in large firms, that capability strongly depends on various functions' commitment to energy saving and on their attitude in understanding process dynamics and

issues; in fact, the finance or purchasing department is often responsible for buying energy, but not for managing it, so it is essential to increase peoples' awareness of the implication of their choices on global costs and on energy management and consumption.

On the other hand, small and medium enterprises often lack in know-how and skills to efficaciously manage compliance to contractual agreements, and therefore have to strengthen their employees' understandings and abilities by the means of training, awareness and motivation programs [22, 51-53].

3.3. Onsite energy production

A drastic solution to abate energy costs (that also affects primary energy consumption) is to autonomously provide to its generation onsite, a decision that requires high initial investments and advanced managerial capability to correctly run the system, but can definitely be cost-effective, and also returns additional benefits, like enhancement of supply quality and security and support provision to Demand Response management.

This solution has recently widespread, thanks to the proliferation of new renewable energy production technologies, whose diffusion has been fostered by public funding, and also to Smart Grids' development, that has introduced the possibility to input extra energy production into the networks, being remunerated (the general impact of Smart Grids on Energy Efficiency will be discussed in the following paragraphs).

A wide range of technologies is available for energy onsite production; the selection of the most suitable technology strongly depends on the location, the existence of feed-in tariffs and the possibility to use available waste products as fuel, or to recover part of the energy that is unloaded and dispersed by different processes [54-56]. Several guides and method-ologies have been developed and published to help companies evaluating different solutions and taking the right decision through the implementation of both simulation tools and feasibility studies, mainly focusing on hydroelectric and wind turbines and micro-turbines [57], solar photovoltaic [58], geothermal energy, biomasses, anaerobic digestion and fuel cells for electricity generation and solar thermal, biomasses [59] and heat pumps for thermal energy generation [60].

Anyway, in most industrial plants, electricity and heat production from renewable sources is not adequate to system's demand, because of the variability of its capacity according to different weather condition and to the limited power concentration. Therefore, the most implemented energy generation technologies in industrial plants are combined heat and power (cogeneration) and trigeneration systems, being available for production in various scales and particularly fitting those manufacturing systems using heat and steam in production process besides in spaces heating systems.

Cogeneration, the simultaneous generation of usable heat and power (mainly electrical, but also mechanical depending on the proper site's needs) within a single process [61], allows companies to reduce the total amount of primary energy needed to supply the whole plant; to achieve those systems' maximum efficiency, they have to be operated as much as possible near their nominal conditions, which means keeping the ratio between electricity and heat pro-

duced almost constant. To achieve this goal, exceeding electricity production can be sold to the network, while exceeding heat can be used in cooling systems, like heat pumps or absorption units (trigeneration systems), especially in summer, when heating needs are lower.

Convenience of cogeneration and trigeneration systems has been studied and proved by many authors, through surveys, case studies analysis and feasibility studies [62-68], and also simulative approaches [69-70].

Methods and systems to optimize their sizing and operation planning have been developed, generally based on non-linear simulations to minimize costs and/or to maximize efficiency, according to heat and electricity demand variability [71-75].

Other multi-energy systems are also currently being studied, basing on the same concept as cogeneration, i.e. improve energy efficiency by making different energy vectors (electricity, heat, cooling, fuels, and so on) interact at various levels, from both operational and planning point of view [76].

A viable alternative, particularly interesting for small and medium enterprises, who may find it difficult and onerous to manage and maintain generation systems, and to assume related risks, is to commission onsite energy production to third companies (Energy Service Companies), stipulating an agreement to share final savings [77].

4. Specific energy consumption

Specific Energy Consumption [kWh/unit] is the energy consumption for the single product unit; its minimization involves an actual energy efficiency improvement besides an economic benefit, and is linked to technical, managerial, thermodynamic and physical issues. Its optimization not only affects the final user, but also has environmental consequences, making primary sources exploitation become more sustainable.

It directly depends on the capability to maximize energy efficiency of manufacturing systems, and therefore to optimize energy transformation (minimizing the Energy Consumption and Energy Vector Produced ratio), distribution (minimizing Energy Vector Produced and Energy Vector Delivered ratio) and utilization (minimizing Energy Vector Delivered and Production Volume ratio) within the plant, i.e. to carefully design, operate and maintain utilities, distribution lines and production systems.

$$\frac{Energy\ Consumption}{Production\ Volume} = \frac{Energy\ Consumption}{Energy\ Vector\ Produced} \times \frac{Energy\ Vector\ Produced}{Energy\ Vector\ Delivered} \times \frac{Energy\ Vector\ Delivered}{Production\ Volume} \tag{2}$$

Utilities and distribution lines in particular have often a high influence on Specific Energy Consumption, as most part of energy losses and wastes are located in transformation and distribution phases, but also offer the largest number of energy saving opportunities, as they can be easily modified without affecting production or expose product quality to any risk.

Energy-oriented optimization of Design and Operations and Maintenance of utilities, distribution lines and production systems will be concurrently discussed below, as basic principles and methods can be assimilated.

4.1. Design

In order to minimize energy losses and wastes, Design phase requires considerable attention in selecting technologies to be adopted, choosing the most suitable modulation technique and correctly dimensioning systems; it both determines system's maximum energy efficiency and the possibility to keep it at its highest levels as long as possible.

4.1.1. Technologies selection

In order to maximize energy efficiency of a system, a cost-intensive opportunity, requiring high investments but also tremendously reducing operating costs, is to select and adopt Best Available Technologies (BATs), whose huge potential has been assessed by Saygin et al. [78] and Letschert et al. [79].

The adoption of some of those BATs is regulated by national and international policies (Joint Research Centre of European Commission periodically releases BATs lists for many industrial sector), while studies aimed at developing methodologies to identify BATs according to Countries' geo-economics are undergoing [80].

Different approaches to best technologies selection have been developed. Most environmentally suitable methodologies seem to be those based on Life Cycle Assessment [81, 22, 25], comparing different kinds of equipment on their whole-life cost, considering purchasing, maintaining, energy and release; less common, more simulative and analytics approaches rely on Multi-Criteria Decision Analysis or Analitic Network Process [82].

4.1.2. Modulation technique selection

Choosing the most suitable modulation technique for different machineries and systems means keeping energy efficiency as high as possible, as long as possible, by matching variable demand and production.

The more variable the demand (of vectors considering utilities, of product considering production systems), the more efficient shall be the modulation system, and therefore a preliminary assessment of demand variability is required when approaching this issue [22].

Considering as an example electrical motors-driven devices, if the demand is almost constant, a simple on/off modulation shall be sufficient, while if it regularly floats a stand-by system would be necessary, or a more efficient Variable Speed Drive [83-85], whose convenience can be assessed by the means of simple financial methodologies [86], or by the means of simulated environments [87]. This latter solution is required especially when a complex and multiple-machineries system is analysed, and an automatic control system is therefore needed.

4.1.3. Dimensioning

Besides choosing the best technology to implement, particular care must be given in selecting the optimal size for the designed systems, as oversizing might lead to technical difficulties and inefficiencies when modulation is required, while opting for modular and/or decentralized systems, made up of a number of small units working in parallel, might contrast advantages derivable from economies of scale [22].

4.2. Operations and maintenance

A huge number of cost-effective opportunities to enhance energy efficiency can be caught while planning and optimizing systems' Operations and Maintenance, acting on human behaviours, implementing best practices and monitoring and control techniques.

4.2.1. Human behaviours

Fostering employees' and staff's awareness of energy efficiency importance and their consequent correct behaviours, like switching devices off when not needed, correctly regulating set points, or point out malfunctioning, is an actually cost-effective energy efficiency opportunity, which is also often mandatory to enable all other improvements, and can bring high savings.

Lots of different activities have been realized to achieve that particular issue, from publishing an internal energy policy to planning periodic trainings, competitions and recognition [51, 53, 88] and to influencing people's behaviours by the means of awareness campaigns and social influence, even if, particularly in medium and small enterprises, they are still hardly put into practice, because commonly underestimated [89-92].

4.2.2. Best practices

Operation and Maintenance and energy efficiency measures have a mutual positive influence: the optimal management of a system is as significant as the efficiency of its components to energy saving purposes [93, 94], and energy consumption control can foster maintenance and operations planning and practices [95]. A number of different best operating and maintaining practices [96] have been identified and collected (principally through clustering, benchmarking tools and databases [97]), as well as methodologies to select the ones to be applied by determining energy savings potentials in various fields [98], and are also published per industrial sector or specific system by national and international research organisms (i.e. ENEA, IEA, U.S. DOE, Carbon Trust, Energy Star ecc.).

Most common and cost-effective best practices are related to optimal set points determination, operating procedures optimization, preventive maintenance planning and machineries optimal scheduling [95].

4.2.3. Monitoring and control

Many difficulties are certainty met by most companies in correctly implementing a Monitoring and Targeting system, that allows to continuously measure, control and forecast consumptions

as well as improvements actions' benefits (giving the possibility to immediately correct negative trends) [99-101], both analysed in relation to previously identified baselines and also influencing external factors, known as energy drivers [22, 25, 53, 102].

Those systems, besides bringing Energy Efficiency improvements, are also useful to identify Operation and Maintenance improvement measures for both utilities and production machineries, and to evaluate those already implemented, by the means of Energy Efficiency evaluation criteria.

Barriers in achieving a complete knowledge and understanding of consumption trends are partly due to the plethora of metrical instruments (listed and described by Beretta et al. [25] and Petrecca [45]) and information technology systems to buy, implement, operate, manage and maintain, and to the resulting amount of data to analyse.

Widespread of Energy Management Systems in recent years has fostered metering systems diffusion, as well as protocols and procedures guiding users to implement Monitoring and Targeting systems.

Metering and sub-metering methods, as well as metering schedules and strategies have been discussed by Carbon Trust's Metering practical guide [103]; Monitoring and Targeting systems and techniques have been instead illustrated in the International Performance Measurement and Verification Protocol by Efficiency Valuation Organization (2012), focusing on the identification of consumption variation's causes and energy drivers, and on savings evaluation, through the application of statistical tools and methods, in Carbon Trust's Monitoring and Targeting practical guide [104] and also by Morvay and Gvozdenac [22], discussing in detail applications of statistical methods to forecast and control consumptions (whose influence on energy efficiency is described by Cesarotti, Deli Orazi and Introna [105]).

5. Qualitative evaluation of the impact of Energy Efficiency measures on the energy network

The industrial energy demand is progressively undergoing a deep change process and, not considering the physiological fluctuation due to the production volumes' contraction, its reduction is partly guided by national and international strategies and partly imposed by the firms' need to abate energy costs, its impact being inevitably strong on the global primary energy and resources consumption.

The defined and presented Energy Efficiency intervention areas and measures will now be qualitatively evaluated according to the effect they have on the energy network, meant as the combination of energy production, distribution and utilisation systems interacting on a national or international level. In fact, by acting to reduce the Specific Cost of Energy and/or the Specific Energy Consumption, the company affects not only its own Energy Cost per Product Unit, but also the general balance and functioning of the whole energy network. The energy network has therefore to be able to counterbalance energy demand fluctuations that can be given by the implementation of Energy Efficiency measures (the analysis of all the

possible causes of energy demand fluctuations and the review of the methodologies and technologies currently used for this counterbalancing are demanded to more specific texts, here attending only to the evaluation of the impact on the network of the Energy Efficiency measures belonging to the previously examined intervention areas).

The effects that Energy Efficiency measures can have on energy demand, and therefore on the energy network management, can be grouped into three main categories:

- *Variation of the required amount of energy*, after the implementation of an Energy Efficiency measure the amount of energy required by the manufacturing system is reduced;

- *Variation of the energy demand profile*, after the implementation of an Energy Efficiency measure the manufacturing system requires energy at different times, i.e. at different hours of the day or in different periods of the year;

- *Partial or total isolation from the network*, after the implementation of an Energy Efficiency measure the manufacturing system does no more require energy from the network (or it can just occasionally require it).

As they have obviously different implications on the general balance of the network and usually require the adoption of very different strategies to be counterbalanced, their evaluation can be useful to deeply analyse the consequences of the implementation of an Energy Efficiency measure, to prioritize Energy Efficiency measures on a higher level (according to national and international policies and regulations) and eventually to study their influence on the global industrial energy demand.

Table 3 shows the qualitative evaluation of the impact of Energy Efficiency measures on the energy network, obtained by associating each intervention area defined in the previous paragraphs to the category or categories of the possible effects the Energy Efficiency measures of that particular area might have on the energy network.

In particular, from the analysis of Table 3 it is possible to observe that, referring to the "Supplier and tariff choice" area, the "amount of total energy consumption", the "peak demand management" and the "demand response and dynamic price systems" areas all insist mainly upon the variation of the demand profile (generally by shifting or shaving demand's peaks and by varying the production scheduling), while the "power factor correction" area abates the total amount of energy needed by both reducing the reactive power exchanged with the network and reducing Joule losses within the plant.

The onsite energy production can both isolate the plant from the network (considering cogeneration and trigeneration systems) and change the energy demand profile (considering renewable sources, such as photovoltaic, that produce energy in a determined range of hours per day).

Eventually, referring to the Specific Energy Consumption Reduction, all of the possible intervention areas affect both the amount of energy required and the energy demand profile (as they have all influences on the capability of the system to modulate and vary its demand according to the production fluctuations) but the Best Available Technologies Selection, that mainly affect the amount of energy required.

			Effects on the energy network		
			Variation of the required amount of energy	Variation of the energy demand profile	Partial or total isolation from the network
Specific Cost of Energy	Supplier and tariff choice	Amount of total energy consumption		X	
		Peak Demand		X	
		Demand Response and dynamic price systems		X	
		Power Factor correction	X		
	Compliance to contractual purchasing conditions		X	X	
	Onsite energy production			X	X
Specific Energy Consumption	Energy transformation, distribution and use (Design phase)	Technologies selection	X		
		Modulation technique selection	X	X	
		Dimensioning	X	X	
	Energy transformation, distribution and use (Operations and Maintenance phase)	Human behaviours	X	X	
		Best practices	X	X	
		Monitoring and Control	X	X	

Table 3. Qualitative evaluation of the impact of Energy Efficiency measures on the energy network.

5.1. Smart grids implementation

A brief but specific dissertation is here reserved to Smart Grids, whose development and diffusion over the last years have enabled and eased most of the previously illustrated Energy Efficiency opportunities (while the spread of Energy Efficiency culture all over the world has vice versa fostered Smart Grids' development), also allowing companies to manage and control their impact on the energy network (qualitatively discussed in the previous paragraph).

A Smart Grid is an electricity grid that allows the massive integration of unpredictable and intermittent renewable sources, and distributes power highly efficiently. It is an electricity network that uses distributed energy resources and advanced communication and control

technologies to deliver electricity more cost-effectively, with lower greenhouse intensity and with active involvement of the customers [106]. Smart Grids generally employ digital technologies and Information and Communication Technology (ICT) in order to improve reliability, security and efficiency of an electric system, coupling components that are typical of electricity grids (wires, substations, transformers, switches, etc.) and "smart" components, such as sensors (power meters, voltage sensors, fault detectors, etc.) and two-way digital communication technologies, which are able to continuously monitor the state of the network and of all the connected devices and therefore allow the real-time optimization of their functioning [107].

In other words, Smart Grids (or parts of them) are at the basis of most of the previously introduced Energy Efficiency measures, allowing companies to understand their own energy behaviour and needs, and therefore helping them making the best energy contract choice, verifying their compliance to contractual conditions, managing the integration of their onsite production to the energy distribution network, monitoring and controlling consumption and also verifying the effectiveness of the implemented Energy Efficiency measures.

It is a matter of fact that Smart Grids are currently used to correctly and effectively implement Demand Response Programs [108] and to take the best out of renewable sources, making it possible to overcome the problem of their intermittent and unreliable production. In addition, it is possible to state that they are essential to control and possibly mitigate (by promptly responding to the fluctuation of the monitored parameters) the variation of the amount of energy required and of the energy demand profile due to the implementation of Energy Efficiency measures, therefore gaining a relevant role in their feasibility evaluation.

Their role in implementing Energy Efficiency measure is about to be always more critical due to their continuous development and to their diffusion also at a medium and small scale and to the spread of the new Microgrids [107].

6. Conclusions

In the present chapter, authors have defined a conceptual scheme to organize and classify Energy Efficiency measures into different intervention areas in order to make it easier for practitioners to individuate and prioritize suitable improvement interventions and for researcher to frame their work in order to make it more accessible for industries.

While reviewing the specific literature of each intervention area, an evident gap between practical implementation and theoretical research evidently came out, also confirmed by authors' direct experiences and contacts with companies operating in the Italian context.

Considering that most researches in the field of Energy Efficiency of manufacturing systems are relatively recent and therefore not yet well known and widespread, companies are generally still far from being smart and efficient from that point of view, often applying quick fixes and improving isolated measures for Energy Efficiency enhancement rather than implementing a systemic and comprehensive approach, that would help catching all existent

opportunities and to whose development conceptual schemes like the one here presented can contribute.

Small and Medium Enterprises' situation is even more critical compared to big firms' one; main barriers to energy efficiency development are economic, information and behavioural, causing methods, tools and technologies discussed in previous paragraphs not or difficultly being implemented, as already highlighted for some of them, and also causing energy efficiency to be considered a marginal issue, scarcely correlated to systems' productivity and cost saving [109,110].

The present work and the approach to Energy Efficiency in manufacturing systems here proposed can therefore be considered as a starting point and a concrete contribution to the spread of the Energy Efficiency culture.

Eventually, a qualitative evaluation of the Energy Efficiency measures on the energy network has been proposed, in order to help evaluating benefits and consequences of the implementation of Energy Efficiency measure on a wider scale.

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