Outsourcing in the Compressed Air Sector – Financial Opportunities in Industry

Diego Vittorini, Roberto Cipollone

University of L’Aquila, Department of Industrial and Information Engineering and Economics, L’Aquila, Italy
diego.vittorini@univaq.it, roberto.cipollone@univaq.it

Abstract. The compressed air sector is currently responsible for up to 10% world-wide overall industry electricity consumption, 30% of which ascribable to the compressor technology alone. Such a datum makes the saving potential from a proper compressor selection (30-35% overall consumption) as appealing as those associated with other energy measures and in line with the 20-20-20 timeline. Plus, every electricity saving on the compressor virtually corresponds to an income from selling Energy Saving Certificates (usually referenced as White Certificates) and CO₂ quotas from avoided emissions on dedicated markets, which can eventually reduce the payback time of the additional investment. Outsourcing in the CAS is addressed as the most effective alternative to efficiency ownership and its development is supported by the common perception of the compressed air as a utility, analogously to electricity and thermal energy. An in-depth net present value analysis is performed on market compressors for industrial purposes, based on the environmental market model, the electricity cost and compressors market policy in the average European context. In addition to the financial advantage from White Certificates and Carbon markets, the outsourcing always benefits from the lower investment cost on the compressor and the higher compressors efficiency: this results in lower sale prices for the cubic meter of compressed air, with little or no difference among different machine types. The relative importance of energy and investment-related costs is assessed as well. The outsourcing allows a m³ cost reduction with respect to the purchase of new compressors in the 15-20% range, dependently on the machine size and operation regime.

1. Introduction

The lack of a concerted energy policy on a global scale, along with a continuously growing energy demand and the relevance of emissions related climate changes, make presently energy saving and CO₂ emissions reduction the only eligible responses to the sustainability issue both locally and globally. Many independent studies [1-3] agree on a 2°C threshold for temperature increase in the 21st Century, not to be overcome, in order to avoid irreversible damage to climate systems and to prevent present socio-economic models from collapsing [1, 4-9]. Industry is currently responsible for the biggest share of electricity consumption, i.e. for up to 6673 TWh (i.e. more than 50% global electricity demand) [1, 10-12]. The Compressed Air Sector (CAS) contributes to this figure for up to 20% (i.e. 1400 TWh/y), thus ranking to the top of the list of electro-intensive utilities to undergo a major revision. The compression section alone accounts for 280 TWh/y electricity consumption and calls for, among others, (i) great care in compressor technology selection [13-17], (ii) cost analyses, (iii) performance assessment campaigns for market compressors – as those by CAGI and Pneurop [18, 19] – and (iv) the thriving literature on both the
energy consumption and Carbon dimension of market compressors [17, 20-22]. The environmental markets are expected to play an important part in the promotion of effective efficiency policies in the CAS, as they virtually assure a financial reward to every efficiency enhancement intervention that leads to either a lower electricity consumption (and eventually to fuel saving) or CO₂ emissions avoidance. Nonetheless, their success – particularly that of energy Saving Certificates - hinges on their ability to cope with highly diversified scenarios and actual applicability to a long-term strategy [23, 24]. Moreover, whilst a direct comparison between the current 412 ppm and limit 450 ppm concentration threshold by 2050 is possible for CO₂, both the fuel shortage and sources availability are less predictable. This paper focuses on the benefits-to-costs ratio, when a compressor is replaced with a more efficient unit and assesses all the benefits associated with CO₂ markets and energy saving obligations in different scenarios, for market compressors. The cost of the cubic meter of compressed air is presented as a function of flow rate and operating hours per year. The option of outsourcing the compressed air production to compressors manufacturers directly - i.e. the situation where the compressed air is purchased from a compressors manufacturer, instead of purchasing the compressors and then operate it in-house for production, analogously to what already happens with other utilities, e.g. electricity – is presented as a viable alternative to the purchase of more efficient compressors. The outsourcing, indeed, invites to reconsider the compressed air as a utility: this reinforces the perception that, similarly to all other utilities (e.g. electricity, water, thermal power, material scraps), the reduction in its consumption is beneficial to the profit associated with each unit of production. Generally speaking, the outsourcing does not modify the overall compressed air plant layout (e.g. piping, valves, pressure settings, reservoirs, condensing devices): the Company, willing to manage the outsourcing, replaces the compressors, with more efficient units, at its own expenses. The payback is in the lower operating costs for the service-related electricity and hence a higher revenue from the compressed air sale at a specific cost (i.e. cost per cubic meter compressed air produced at a given delivery pressure), as established by the contract. The relative importance of each investment variable and the combined effect on the compressed air costs are discussed and the energy merit and financial feasibility of both options are assessed.

2. Compressed air carbon footprint and environmental markets

A direct evaluation of the CAS Carbon dimension is possible, through the datum on specific emissions for electricity generation (i.e. kgCO₂/kWh): the average EU datum is 0.324 kgCO₂/kWh, among the lowest worldwide [1-5, 25]. Based on CAGI and Pneurop data [18, 20], a thorough assessment of market compressors performances per machine type, size and delivery pressure is possible, according to Figure 1 (the Carbon per cubic meter datum on the right y-axis, ccm in kgCO₂/m³ refers to the EU). A proper machine selection for electricity saving is crucial in high performance-scatter size segments (i.e. 10 m³/min flowrate). Moreover:

- ccm decreases at higher flowrates: specific emissions top 44 gCO₂/m³, 37 gCO₂/m³ and 36 gCO₂/m³ for 8 bar delivery pressure, 10 m³/min, 30 m³/min and 50 m³/min, respectively;
- the performance scatter is asymptotic at higher flowrates, with a 1.2 kW/m³/min maximum and 0.7 kW/m³/min minimum scatter, for a 50 m³/min delivered at 9 bar and 8 bar, respectively.

The standard deviation (SD) in Figure 1 expresses the spread in data around the average specific consumption (Equation (1)):

\[
SD = \sqrt{\frac{1}{N} \sum_{j=1}^{N} (q_{s,j} - \bar{q}_s)^2}
\]  

with \(N\) values of specific consumption per group, \(q_{s}\) and \(\bar{q}_s\) are the values of specific consumption and the average (arithmetic) specific consumption for the group [kW/m³/min], respectively.
The European Emission Trading Scheme (EU-ETS) covers 45% EU GHG emissions (i.e. 10-12% whole emissions) at present, associating to each ton CO$_2$ emitted an allowance – currently, 23.40 €/tCO$_2$ [26] - the subscribers must surrender. Nonetheless, the specificity of the Carbon taxing policy - whether fixed (e.g. Carbon tax scheme) or variable (e.g. national and subnational ETS) [5, 27-29] - each Country sets-up, along with the market sensitivity and growth expectations vanish any attempt to define a shared platform for Carbon price setting, in the mean-long term [30-34]: an average severity scenario considers a 21 €/tCO$_2$ price, a more stringent commitment shifts toward a 30 €/tCO$_2$ price by 2020 [34].

A similar paradigm applies to White Certificates obligations - whose price is fixed by the demand/supply matching - in spite of the adverse effect obligations unpredictability, regionalisms and financing provisions constraints have on the large-scale deployment of Energy Saving markets [23]. White Certificate obligations impose energy saving targets for companies to reach, in order to be certified and trade Energy Saving Certificates (ESC, corresponding to 1 TOE saving); companies that fall short of their goals are forced to buy certificates from other subscribers or third parties (e.g. energy service companies, ESCO). In most recent ESC markets, the saving ($S$, kWh/y) is calculated with respect to a baseline and the overall technical life ($L_{tech}$, 15-20 years before obsolescence kicks in), discounted (δ) and contributed to the first year to calculate the ESC quantity ($N_{ESC}$) in Equation (2) [35-38]:

$$N_{ESC} = S \cdot L_{tech} \cdot \delta$$

(2)

In more mature ESC markets (e.g. Italy), certificates are eligible only when the energy saving takes place [39, 40], with obvious positive effects in limiting the uncertainty on the certificates value over the years [41-44]. Equation (3) expresses the corrected discount factor dependence on the technological life of the investment, the financial life of certificates ($L_{finan}$, 5-8 years during which they are recognized) and the base discount factor ($\tau$). A kWh-to-TOE conversion factor (k) is then needed (Equation (4)).

$$\tau = 1 + \frac{\sum_{j=1}^{L_{finan}} (1 - \delta)^j}{L_{finan}}$$

(3)

$$N_{ESC} = k \cdot S \cdot \tau$$

(4)

3. Efficiency ownership and outsourcing in CAS

Due to its intrinsic low operating characteristic efficiencies, interesting margins for efficiency growth in the CAS are associated with the integration of dedicated ancillary systems in existing plants, as well as with the implementation of recovery measures, with little or no increase in plant complexity or control logic. An extensive literature proves that in both Screw and Sliding Vanes machines the actual thermodynamic transformation is very close to an adiabatic [45, 46], in spite of the vane-to-vane
dynamics, in Sliding Vanes [45, 46] and friction, in Screw compressors [47, 48] and that the lower compressed air temperature at the machine’s exit - with respect to the much higher adiabatic value - depends on the strong cooling effect produced by the abundant oil injected during compression, whose temperature doesn’t follow the one of the air. The electric motor and the auxiliaries (e.g. the pump/fan for coolant circulation) exhibit efficiencies already at the asymptote [14], which advises from looking into them for further margins for package consumption reduction. The achievable reduction on the specific consumption through a dual stage compression, with a 30°C pinch point, is in the 10-15% range, without considering the few more percentage points associated with pressure reduction for each compression stage. In order to establish a baseline for CAS performance and assess the minimum achievable gain each measure allows, machines delivering air at 9 bar and particularly those processing higher flowrates, can be conveniently considered, as those characterized by the smallest performance scatter and the lowest specific consumption. In addition to this, the paper focuses on compressors for industrial applications, often big size compressors operating in heavy duty regime and full load, hence the analysis accounts for 40-80 m$^3$/min flowrate compressors. For each size, only compressors with a specific consumption below the average underwent the analysis, as in Table 1.

| Machine size | Specific consumption (kW/m$^3$/min) |
|--------------|------------------------------------|
|              | SVRC Air cooled Water cooled Screw Air cooled Water cooled |
| m$^3$/min    |                                     |
| 40           | 6.60 6.30 6.80 6.50                 |
| 60           | 6.20 6.15 6.40 6.33                 |
| 80           | 5.95 5.87 6.13 6.05                 |

Table 1. Machines considered in the analysis

The investment for purchasing a compressor depends on the processed mass flowrate $m$ (l/s) and the normalized efficiency (i.e. the efficiency calculated as ratio between the actual specific consumption in Table 1 and the specific consumption calculated in ISO 1217 conditions, $\eta_{norm}$ (%), [13]), according to Equation (5), where a standard 0.5% aging factor for industrial compressors applies:

$$I(\epsilon) = (170 \cdot m + 2500) + [(4800 \cdot m + 10000) \cdot \eta_{norm}^3]$$

The analysis accounts for Screw and SVR compressors, being the former the most diffused machine type on the market and showing the latter a greater potential for energy saving improvement [44-48]: the cost assessment for Screw compressors includes the additional expense for sixth year overhauling, which tops 60% initial investment. Operation-related costs (i.e. O&M, both ordinary and exceptional, oil and personnel) can be conveniently seen as a percentage of the investment, since they basically go with the machine size, i.e. with the flowrate being processed (Table 2). Moreover, the contribution margin of the cubic meter of compressed air is proven to be not sensitive to the drive mode, with fixed and variable speed machines exhibiting values close each other, when not identical.

The incomes from the sale of energy saving certificates, provided by Equation (2), are slightly underestimated with respect to those calculated according to Equation (4), so that a worst-case-baseline is fixed. A conservative 2.5 c€/kWh ESC price is assumed [35]. In light of a more stringent Carbon market regulation, 50 €/tCO$_2$ ETS price is considered. The sale price of the cubic meter of compressed air results from a combination of the increased investment ($I$, in €) at year 0 - for purchasing more efficient compressors - and the year-by-year incomes (cash flows, $CF$, in €/year) associated with the lower electricity consumption, ESC and ETS markets. The Net Present Value ($NPV$) is in Equation (6), where $\alpha$ is the discount factor for cash flows actualization (15%, in line with present standards for industrial applications, [20, 21]) and each variable is referred to the $i$-th year. The actualized cash flows are cumulated over a $n$-year timespan, on whose length the cost of the cubic meter depends. The timespan corresponding to a nil NPV is considered a parameter and different values lead to different cubic meter costs, with the general rule that the wider the timespan, the lower the cubic meter cost.
Minimum market price of compressed air [c€/m$^3$] at 9 bar delivery pressure

| Tech. life [years] | 2   | 4   | 6   | 2   | 4   | 6   | 2   | 4   | 6   | 2   | 4   | 6   |
|-------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Speed drive       |     |     |     |     |     |     |     |     |     |     |     |     |
| 40 m$^3$/min      | 3.90| 3.94| 1.95| 1.97| 1.30| 1.31| 4.01| 4.22| 2.01| 2.11| 1.34| 1.41|
| 60 m$^3$/min      | 3.72| 3.81| 1.86| 1.91| 1.24| 1.27| 3.83| 4.11| 1.92| 2.05| 1.28| 1.37|
| 80 m$^3$/min      | 3.59| 3.72| 1.80| 1.86| 1.20| 1.24| 3.71| 4.03| 1.85| 2.01| 1.24| 1.34|

Table 2. Compressed air market price for fixed speed (FS) and variable speed (VS) compressors [22, 23]

\[ NPV = I - \sum_{i=1}^{N} \frac{CF_i}{(1 + \alpha)^i} \]  

Table 3 compares the NPV for Vanes and Screw compressors, as a function of the plant technological life, for a (i) technology-as-usual scenario, where no efficiency increase applies (+0%), (ii) a 10% efficiency enhancement, without the incomes from environmental markets (+10%) and (iii) a 10% efficiency increase, supported by the incomes from ESC and ETS sales (+10%, EM).

| Net Present Value [M€] | Machine type | SVRC | SCREW | SVRC | SCREW | SVRC | SCREW |
|------------------------|--------------|------|-------|------|-------|------|-------|
|                        | Tech. life [years] | 2   | 4   | 6   | 2   | 4   | 6   |
|                        | Speed drive   | FS  | VS  | FS  | VS  | FS  | VS  | FS  | VS  | FS  | VS  | FS  | VS  |
| +0%                    | -0.73         | -0.74| -1.20| -1.23| -1.56| -1.60| -0.74| -0.80| -1.22| -1.31| -1.62| -1.72|
| +10%                   | -0.66         | -0.66| -1.05| -1.07| -1.35| -1.38| -0.66| -0.73| -1.07| -1.15| -1.41| -1.52|
| +10%, EM               | -0.64         | -0.64| -1.02| -1.04| -1.31| -1.34| -0.64| -0.71| -1.03| -1.12| -1.36| -1.47|

Table 3. Net present value per machine type and drive – 60 m$^3$/min mass flowrate

Every efficiency increase results in a lower cumulated NPV over the technological life of the plant, i.e. in a lower market price, the cubic meter shall be allocated with for a nil revenue for the producer: the lower the price is, the more market-attractive the efficiency enhancement scenario is, with respect to the technology-as-usual one. The additional initial investment cost has little or no effect on the cumulated NPV variation, with respect to the situation in which no efficiency enhancement applies. Conversely, energy-related costs contribute to 85% of the cumulated NPV. Plus, the unbalance among the two terms is unaffected by the financial benefit induced by the environmental markets. For all the scenarios in Table 3, the NPVs of the base case and the case of efficiency-enhancement (from purchasing and installing a more performing unit) even up already within the first year (within the early 6-to-8 months), hence the only driver in the selection of an efficiency increase level to invest on is the cumulative NPV value over the plant technological life. As a consequence, the fact that the investment cost has a negligible effect on the CAS financial performance, could act as a game raiser in the compressors market, with both the compressors manufacturers and the end users encouraged to invest in compressors efficiency: the sales of more efficient compressors would be no longer discouraged by the additional purchase cost, proven the time-to-gain for buyers to be short. Figure 2 reports the minimum contribution margin of the cubic meter of compressed air for fixed and variable speed machines, air and water cooled. Given their little impact on the final cost of the cubic meter of compressed air, the environmental markets are neglected. Variable speed compressors exhibit a higher cost of the cubic meter of compressed air, due to an initial investment about 1.5 times the corresponding one for fixed speed type. At any given efficiency increase, the bigger the machine size, the lower the cubic meter cost. For any assigned machine size and efficiency increase, points above the line correspond to a market price higher
than the cubic meter cost for the producer: the higher the distance, the higher the margin for gain the compressed air producer can count on.

Figure 2. Cost of the cubic meter of compressed air per compressor type – SVRC (a)-(b) and Screw (c)-(d)

A residual advantage insists on SVRC, with lower cubic meter cost than Screw compressors. A sensitivity analysis to the electricity price (Figure 3) and plant technological life (Figure 4) comes out as well, with reference to a 60 m³/min machine size and 7900 hours/year of continuous operation:

- with a 10% efficiency increase and the electricity price between 0.10 €/kWh to 0.20 €/kWh, the cubic meter cost range is 0.53 c€/m³ - 0.96 c€/m³ for SVRC, 0.55 c€/m³ – 0.99 c€/m³ for Screw;
- for a 5% efficiency increase, every 5 c€/kWh electricity cost increase, the cubic meter cost experiences an average 40% and 43% increase in SVRC and Screw, respectively;
- for a 15% efficiency increase, every 5 c€/kWh electricity cost increase, the cubic meter cost experiences a 40% increase in both SVRC and Screw machines;
- for a 15 c€/kWh electricity price and a 10-to-8 years technological life reduction, the cubic meter cost becomes 1.3 times higher, for a 15% efficiency increase, both SVRC and Screw; similarly for other efficiency increase values, suggesting how sensitive the cost is to time.

Figure 3. Analysis of sensitivity to the electricity price, 10 years technological life - SVRC (a)-(b) and Screw (c)-(d)

Generally speaking, in case of outsourcing of the compressed air production, higher efficiencies apply and lower investment costs have to be considered, in comparison to the situation where the compressor or the whole package is sold to an end user: as a rule of thumb, the investment cost a compressor manufacturer has to face, when asked to provide directly compressed air to a client, can be assumed a 10% the market price of the same compressor for the end consumer. Figure 5 summarizes the results from the analysis in terms of cost of the cubic meter of the outsourced compressed air, for both fixed speed SVR and Screw machines.
The efficiency increase on the x-axis is the one the client expects from the seller in charge for compressed air production: a 12%-17% cost reduction for each efficiency increase comes out, with the biggest reductions associated with bigger size machines. Since the investment costs in case of outsourcing contribute to the cumulative NPV for a share never exceeding 10%, the energy costs play the biggest part in the definition of the cumulative NPV and cubic meter cost: the slopes of the cost lines for outsourcing and efficiency ownership are the same.

The sensitivity analysis to both the electricity price (Figure 6) and the technological life (Figure 7) further confirms this trend. As the plant life stretches from 8 to 10 years, a 21% decrease in compressed air cost is appreciated; for a 8 to 12 years increase, a 36% decrease occurs. As a matter of fact, the longer the plant life, the lower the acceptable cubic meter price for the provider to even up investment and production capacity-related costs with the incomes from the compressed air sale on the market. The average percentage cost reduction for the cubic meter of compressed air, achievable through outsourcing on heavy duty machines (i.e. 7900 operating hours per year) resulting in a 10% efficiency increase, incomes from ESC (2.5 €/kWh) and ETS (50 €/tCO$_2$) markets included, is in the 16-20% range for air cooled and 17-21% range for water cooled. Outsourcing is particularly effective on big size machines: moving from 40 m$^3$/min to 80 m$^3$/min flowrate machines, the cost reduction rises from 16% to 20%. Similarly, for water cooled machines (17% at 40 m$^3$/min and 21% at 80 m$^3$/min). Up to 2 percentage points variability applies to the saving, when accounting for plants with different life perspectives.

As a general rule, indeed, the older the plant grows, the less the cost reduction benefits from the ESC and ETS incomes: energy saving due to the higher compressor efficiency ends up being the only factor inviting to outsourcing instead of self-production. On the long term, a bigger role would the incomes from the sale of White Certificates and CO$_2$ quotas play, when (i) a higher price was assigned to
the saved kWh and ton CO$_2$ and (ii) White Certificates were corresponded to the energy saving achieved over a longer time-span.

Figure 6. Sensitivity to the electricity price for outsourced compressed air - SVRC (a)-(b) and Screw (c)-(d)

Figure 7. Sensitivity to the technological life for outsourced compressed air - SVRC (a)-(b) and Screw (c)-(d)

4. Conclusions

A thorough financial analysis of present compressed air systems for industrial purposes proves the option of outsourcing the compressed air production to compressors manufacturers to be an interesting alternative to efficiency ownership. For the analysis done, in order to stay conservative and to fix a baseline on which the relative effectiveness of efficiency outsourcing and purchase in compressed air cost reduction can be assessed, reference is made to an average EU CO$_2$ market scenario and to the Italian model of Energy Savings Certificates market. The Net Present Value analysis accounts for different scenarios, in terms of financial life of the investment, incomes from Carbon and Energy Saving Certificates markets, efficiency enhancement, and discount rates, on both Sliding Vanes and Screw machines. Main advantages of compressed air production outsourcing are in the lower investment cost for compressor purchase and the higher compressors efficiency, insisting on the market price of the cubic meter of compressed air, particularly on big size, heavy duty machines: an average 15% cost reduction with respect to the purchase of new compressors, comes out for 40 m$^3$/min flowrates, already, 20% at 80 m$^3$/min. The analysis shows that, at present, the benefits from environmental markets, as well as the additional investment increase are easily offset by the reduction in energy costs over the technological life of the plant: high-discount policies on the market price of the compressor could help filling the already tight gap between efficiency ownership and efficiency outsourcing, promoting self-production instead of treating compressed air as a utility. Anyway, due to the relevance of the energy-related costs, an increased investment on the compressors efficiency starts providing a financial benefit within the first year of plant operation: this should encourage both the manufacturer and buyer to invest on compressors efficiency.
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