Ecodesign Preparatory Study on

Electric motor systems / **Compressors**

DG ENER Lot 31

FINAL Report of Task 6, 7 & 8

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Contents "Task 6, 7 & 8"

List of common abbreviations

BAT = best available technology

BNAT = best not yet available technology

FS = fixed speed

LCC = life cycle costs

LLCC = least life cycle cost point

OIS/OIV = oil-injected screw and oil-injected vane compressors

OL = oil-lubricated compressor

VS = variable speed

VSD = variable speed drive

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1 Task 6: Improvement options

1.1 Introduction to Task 6

This is the final report of Task 6 of the preparatory study on electric motor systems/compressors in the context of the Ecodesign Directive: **'ENER Lot 31 – Products in motor systems outside the scope of the Lot 30 and the Regulation 640/209 on electric motors, in particular compressors, including small compressors, and their possible drives'.**

This study is being carried out for the European Commission (DG ENER). The consultant responsible for the study is Van Holsteijn en Kemna B.V. (VHK).

1.1.1 Aim of Task 6

In accordance with the tender specifications[1], Task 6 is to provide a "technical analysis not of current products on the market, but on currently available technology, expected to be introduced at product level within 2-3 years. [It should provide] part of the input for the identification of part of the improvement potential (Task 7), i.e. the part that relates especially to best available technology.

1.1.2 Subtasks Task 6

The technical tender specifications for the Task 6 subtasks are:

Subtask 6.1 - State-of-the-art in applied research for the product (prototype level)

Subtask 6.2 - State -of-the-art at component level (prototype, test and field trial level)

Subtask 6.3 - State-of-the-art of best existing product technology outside the EU

1.1.3 Task 6 report structure

The subtasks required for task 6 are covered in this report according the structure below.

Table 1-1 (Sub)tasks for Report Task 6 & 7

Subtask required	Included in report Task 6/7
Subtask 6.1 - State-of-the-art prototype level	Combined into sections dealing with explanation of spread in efficiencies (section 2.2) and the actual efficiencies (best, worst, average) of models currently on the market section 2.3).
Subtask 6.2 - State-of-the-art test and field trial level	
Subtask 6.3 - State-of-the-art outside the EU	

[1] European Commission, Tender specifications ENER/C3/410-2010, which are the basis for the study.

1.2 Efficiencies of compressors for standard air applications

1.2.1 Limitations and difficulties in data collection

The identification of average and improved products (in order to identify BAT and enable calculation of the LCC of various options) requires as inputs performance, sales and cost data. With performance is meant the isentropic efficiency, to be based on volume flow rate, pressure increase (bar(g)) and power input calculated at standard rating conditions.

As volume of sales and cost information is obviously not contained in sales literature, the study writer, in order to collect the data, was dependent on inputs and willingness to cooperate by manufacturers.

The technical analysis allowing delivery of such data to be incorporated in this report proved to be extremely time consuming, for both study writer and the manufacturers involved in the study as this data was not collected before at this level and these metrics (isentropic efficiency per specific flow class segment). Furthermore, as this kind of data is very sensitive information and individual manufacturers do not want this information to be made public for obvious commercial reasons the collection had to be organised in a way that respected manufacturers' wish for anonymity, anti-trust laws and still provide sufficient level of detail.

In order to streamline the data collection process and provide a uniform approach, the study team (writer and Pneurop JWG) developed a so-called statistical approach in order to collect this kind of data and deal with the sensitive nature of this data.

The industry collaborated with the study writer and created a system which would allow collection of performance and sales data at manufacturer level, then transfer of this data to a neutral entity which would render the data anonymous and generic through aggregation. The aggregated data was made available to the study writer for further analysis.

An alternative method for data collection appeared not feasible / not in line with the study requirements as the performance of the products is not generally specified in sales literature allowing easy comparison.

1.2.2 Data collection - method applied

Based on isentropic efficiency

The data collection is based on isentropic efficiency[2] data of products and not on, for instance, the specific energy requirement (SER) of products (see Task 1 for 'specific energy requirement'). The reasons for selecting isentropic efficiency to express energy efficiency of products within the standard air application range, are:

- Isentropic efficiency is a dimensionless number, no unit conversions are necessary;
    - Due to the possible combinations, SER can have at least ten different units (e.g. kW/(m³/min), kW/(m³/s), J/m³, N/m², kW/(ft³/min), W/(l/s), J/l) which complicates direct comparison;
- Isentropic efficiency can only have values between 0 and 1, therefore direct performance judgement is possible. Specific energy requirement (SER) does not allow for direct judgement.
  Examples: Compressor "A" that compresses air from 1 to 10 bar (abs) and has (at a certain volume flow rate) a SER of 7.87 kW/(m³/min) is obviously better than "B" with a SER of 8.23 kW/(m³/min) under the same conditions. And how is compressor "C" that compresses air from 1 to 9 bar(abs) and has (at a certain volume flow rate) a SER of 7.5 kW/(m³/min)

[2] See task 1, Annex I for formula's and other changes of state

performing compared to "A" and "B"? The isentropic efficiencies are: "A" = 0.69; "B" = 0.66 and "C" = 0.68.
- Judgement of the performance of a compressor operating at different pressures is not possible using SER (but this is important for off design operation, or part load operation, which can include less than full pressure as well as less than full volume flow rate)
- For standard air compressors operated at typical outlet pressures, isentropic efficiency is in a first order approximation independent of outlet pressure, whereas SER is highly dependent. This will be shown later on in this chapter based on the results of the data collection for the "statistical approach".
- SER changes extremely even if only slight deviations in operation conditions appear, whereas isentropic efficiency is less sensitive to deviations as the real process is always compared with the ideal process under the same conditions.
- SER is basically only used in the compressor industry and there mainly for "smaller" air compressors. Isentropic efficiency is widespread used in all industries related to energy production (e.g. power plant technology, turbines, gas turbine compressors and the like).
- A SER value is absolutely meaningless if in- and outlet pressures are not given.
- Compressor maps, that give the full picture of the characteristics of a certain compressor, can only be drawn using efficiency.
- The name "specific energy requirement" is wrong. It should better be (and sometimes is) named "specific power requirement" as it relates a power requirement to a certain volume flow rate. Cancelling down "per time" in the fraction incorrectly results in a relation of energy per volume which is misleading as this energy is not contained in a certain volume of air.
- The statistical approach (at least the steps needed for aggregation, anonymisation and averaging) would not have been possible using SER.
- Using SER would result in regulations with many tables like the Chinese regulation (see Annex at end of Task 1-5 document).
- If compressors are to be compared at exactly the same conditions, SER is not necessary as the power requirement itself can be directly compared. In all compressor offers today, the inlet volume flow (free air delivery) and the power requirement are given in absolute numbers and are quite often penalized in the contracts.

Data collection

Of all compressors collected the isentropic efficiency of the basic package was calculated, per volume flow segment. The power input was determined, as well as the sales, also per volume flow segment.

A function for the average isentropic efficiency vs. volume flow rate (FAD) is determined using the method of weighted least squares.

The general type of function that allows good representation of the isentropic efficiency vs. volume flow rate (FAD) (also checked on CAGI data) was found to be

$$\boxed{eta_{mean} = a \ln^2(VF) + b \ln(VF) + c}$$

The task is to minimize the sum of all squared deviations between the individual data points and their estimation that is calculated by the function which is to be determined. In order to consider the power requirement of the compressors, the deviations are weighted by the product "sales quantity" * "sales quantity weighted averaged power".

The regression function that has to be brought iteratively to a minimum is therefore as follows:

$$\boxed{\sum_{cell=1}^{n}\left(\left\{ \left[a \ln^2(SQwaVF_{cell}) + b \ln(SQwaVF_{cell}) + c\right] - eta_{cell}\right\}^2 SQ_{cell}\ SQwaP_{cell}\right)}$$

When the coefficients a, b and c are determined in such a way that the sum above has a minimum value, than the function for the mean isentropic efficiency depending on the volume flow rate and weighted by sales quantity and sales quantity averaged power is known.

$$\boxed{regression\ curve = eta_{mean} = a \ln^2(VF) + b \ln(VF) + c}$$

This regression curve provides a general shape for regulation curves to be derived from the regression curve.

The following sections present the result of the above described statistical approach for fixed speed OIS+OIV, variable speed OIS+OIV and piston compressors.

1.2.3 Sub grouping into fixed, variable and piston,

The statistical approach was applied to compressors in the standard air application range. Within this range, compressors may be operating in very different application areas, and this has a big effect on the typical technologies found in these sub-application ranges.

Together with industry stakeholders a grouping into three segments was proposed, based on typical duty cycles, technologies and control strategies.

Table 1-2 Standard air sub categorisation

Typical duty cycle	Typical compressor technology (other types are possible, but rare)	air in contact with oil for:	Typical Individual control strategy	Subcategory in application range designated as
Steady state use	Oil injected rotary screw and vane compressors	sealing, lubrication and cooling	Load / Unload	Fixed speed OIS/OIV
Fluctuating use	Oil injected rotary screw and vane compressors	sealing, lubrication and cooling	Variable flow control	Variable speed OIS/OIV
Sporadic or intermittent use	Reciprocating oil-lubricated piston compressors	lubrication	Start / Stop	OL Piston

The sub-grouping is therefore based on the differences of these product groups as regards their secondary performance parameters described in Task 1.

1.2.3.1 Basic package

For the standard air base cases, a 'basic packaging' has been defined which describes the technical product boundaries.

Table 1-3 Description of basic packages in standard air application range

Type	SCREW	PISTON	VANE
Indicated power input	90 kW	4 kW	11 kW
Oil	oil-injected	oil-lubricated	oil-injected
Stages	single stage	two-stage	single stage
Speed	fixed speed	fixed speed	fixed speed
Cooling	air-cooled	air-cooled	air-cooled
Bill-of-material includes...	(basic package)	mounted on 270 ltr air receiver	canopy excluded: 190 kg canopy included: 235 kg
Received by VHK	12-12-2012	18-4-2013	18-4-2013
Electric Motor	Yes	Yes	Yes
Cooling fan	Yes	if applicable	Yes

Compression element	Yes	Yes	Yes
Transmission (belt, gear, coupling, ...)	yes (if applicable)	Yes	Yes (if applicable)
Inlet filter	Yes	Yes	Yes
Inlet valve	Yes	No	Yes
Minimum pressure check valve / backflow check valve	Yes	yes (as "check valve")	Yes
Oil separator	Yes	No	Yes
Air piping	Yes	Yes	Yes
Oil piping	Yes	No	Yes
Oil pump	if applicable	No	if applicable
Oil filter	Yes	No	Yes
Oil cooler	Yes	No	Yes
Thermostatic valve	Yes	No	Yes
Electrical switchgear (if compressor is sold as FIXED speed compressor)	Yes*	If applicable	Yes*
Frequency converter (if compressor is sold as variable speed compressor)	Yes*	No	Yes*
Compressed air after cooler	Yes	No	Yes
Compressor control device (pressure switch, pressure transducer etc...)"	Yes	Yes	Yes
Pressure regulator	No	Yes	No
Pressure vessel	No	**no** (regarding the performance measurement, however it is in most cases supplied as part of the whole package)	No
Drain	No	Yes	No

* = electrical switchgear and frequency converter regarding the main electric motor; a fixed speed machine may have variable speed fans with frequency converter; a variable speed machine may have an electrical switch gear e.g. for fans

1.3 Explanation of range in efficiencies of screw or vane compressors

1.3.1 General approach

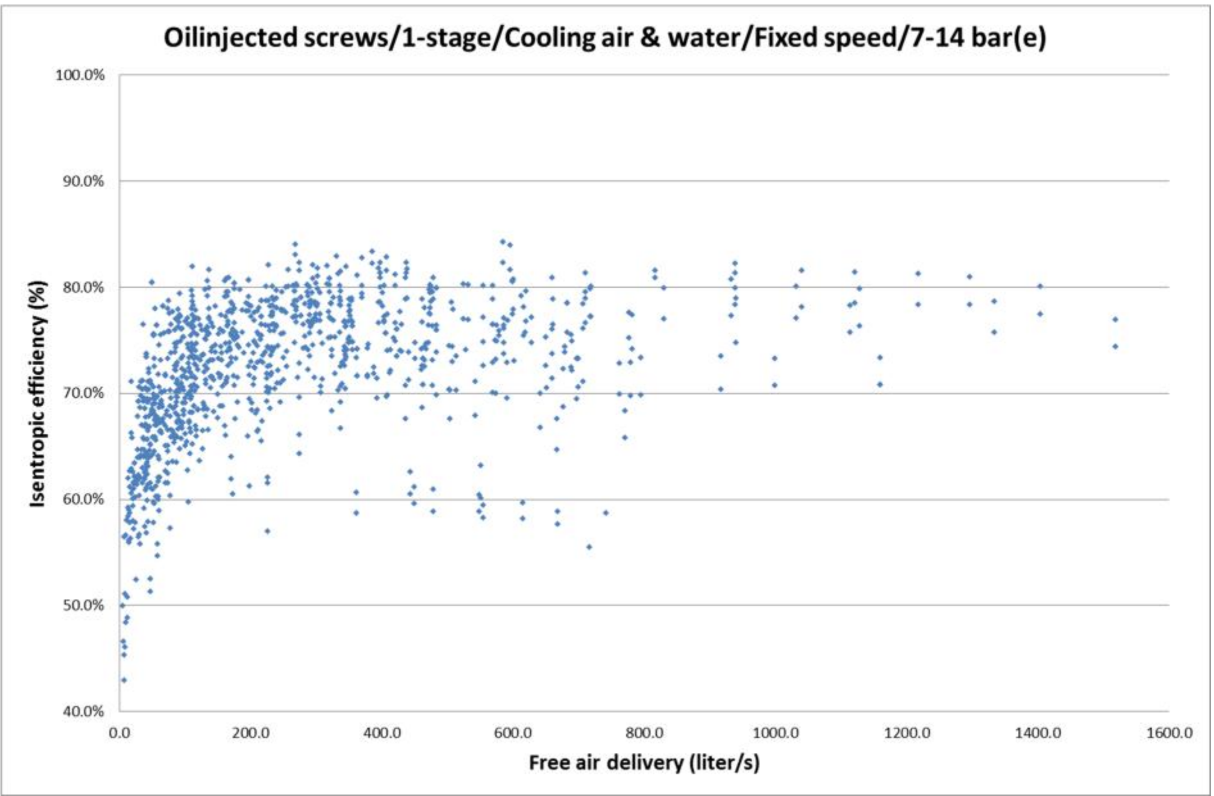
As will be shown further on in this section, typical screw, vane and piston compressors exhibit a range in energy efficiency. When energy efficiency (expressed as isentropic efficiency) is plotted against volume flow (free air delivery) a 'cloud' with a typical asymptotic shape can be recognised.

The below presented “dot-cloud” is based on publically available data sheets published by companies participating in the CAGI performance verification program (USA) and

– was compiled for fixed-speed compressors only

– depicts full-load efficiency data

Figure 1-1: Typical efficiency 'cloud' showing range in efficiency for specific volume flow ranges (based on CAGI data)



The cloud shows that for each volume flow category (or segment) a range in efficiency exists. This specific section will explain the reasons for this spread in energy efficiency.

A similar picture is to be expected for compressors available in the EU27, however some differences might be caused by the following effects:

- EU27 products are designed for 50 Hz and in USA for 60 HZ (USA). There are also some other differences and different operating points (rotational speed)
- manufacturers represented on the USA and EU27 market are not 100% identical
- market requirements and forces are partly different

The following sections illustrate (in a simplified way) the technical reasons and the background for the efficiency spread of a certain product type in the application range “standard air”:

– of standard air compressors

– of the oil-injected screw compressor type

– with fixed speed drive

– with air- or water-cooling

– with discharge pressures in the range 7 – 14 bar(e)

– limited to basic packages (no options).

1.3.2 The efficiency curve of a single compressor element

Like most fluid dynamic equipment (fans and pumps) a typical compressor can be characterised by an efficiency curve, where the horizontal axis is the performance (for example the volume flow) and the vertical axis can be the efficiency (here isentropic, so independent from final pressure delivered).

This curve applies to the single/individual compressor element (the “air end” or moving members only), and is without effects caused by transmission or motor applied.

The “efficiency curve” of this single/individual screw compressor element is e.g. affected by:

- compressor element size (e.g. in terms of displacement volume);
- geometry (L/D ratio, rotor tooth numbers and profiles, control edges, built-in volume ratio, wrap angle, shape of suction and discharge flow channels …);
- details of oil injection ports (position, orientation, shape…);
- nominal clearances;
- manufacturing precision;

For most of these parameters no single optimum exists. Instead the design choices are taken as

- a reasonable combination of parameters;
- being suitably chosen for a certain operation range (speed, pressure…).

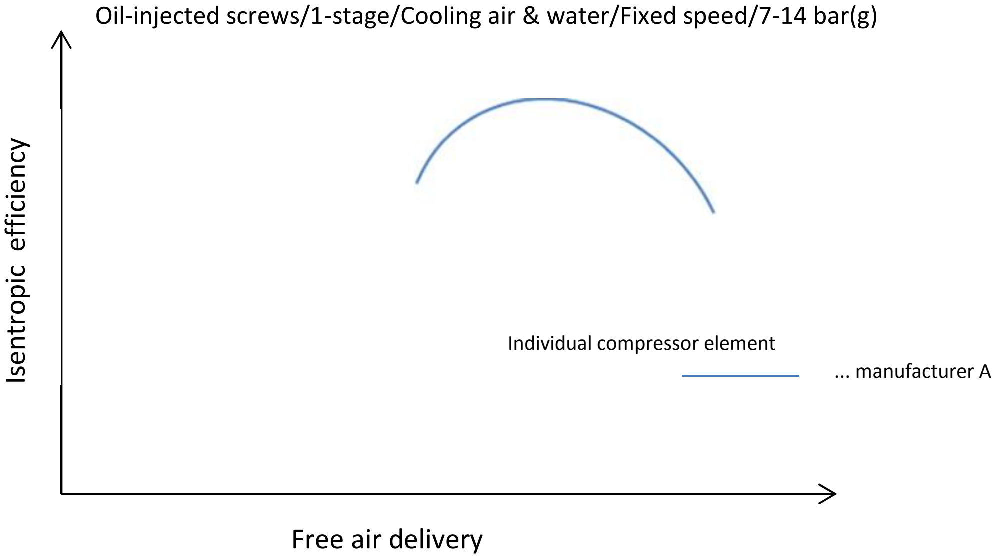


Figure 1-2: Efficiency curve of single/individual air end (illustrative)

The shape of “efficiency curve” of an individual oil-injected compressor element is mainly caused by the following effects (extremely simplified!)

- the power requirement for displacing (shearing) the injected oil between rotor(s) and/or housing (viscous losses) is – in first approximation – a quadratic function of peripheral speed
  - ➔ this causes the efficiency drop at high flow = high rotation speed = high peripheral speed

- the quantity of internal leakage flows (=losses) is strongly influenced by internal air gaps between rotor(s) and housing and internal pressure differences between compression chambers, which both are – in first approximation – not depending from rotational speed;
- when lowering rotational speed the quantity of internal leakage remains on approximately the same level, but its relative effect (=related to the produced flow, which is reduced with rotational speed) increases.
  - ➔ this explains the efficiency drop at low flow = low rotation speed

The point of best efficiency is between the two extremes, i.e. between the dominant effects of internal leakage at low flow and viscous losses at high flow

The same compressor element (or air end) therefore can operate in different conditions, at different volume flows and different pressures, within boundaries of course.

1.3.3 The same compressor element in different packages

This means that different compressor packages can be designed around the same compressor element. This then results in a curve for the same single/individual compressor element as shown below, where the dots represent the efficiencies when applied in different packages.

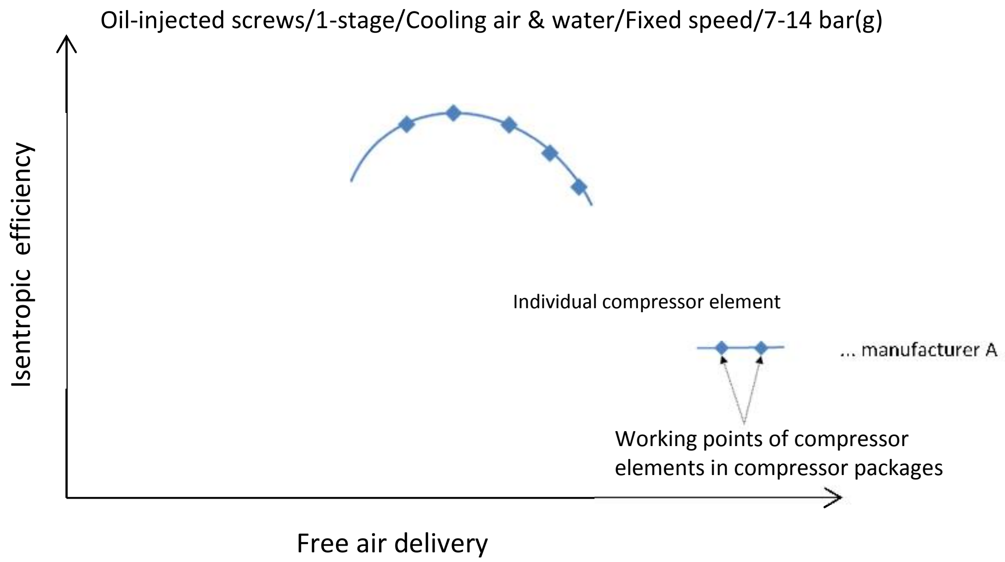


Figure 1-3: Isentropic efficiency curve with same compressor element in different compressor packages (only illustrative no quantitative data)

The above shown curve illustrates that a single/individual screw compressor element is used in different

- operating points (e.g. speed <-> volume flow <-> pressure <-> input power)
- and/or frame-sizes of compressor packages
- and/or configurations of compressor packages

The alternative usage (or application) of a certain individual screw compressor element is represented by dots on the "efficiency curve".

The influence of pressure / pressure ratio

- is a second order effect;

- is neglected in the previous and the following slides;
- would result - when considered accurately - in an "efficiency band" instead of an "efficiency curve" for each compressor element, i.e. would further increase efficiency spread;

Usually the compressor manufacturer offers equipment in a limited number of "frames". In practice

1.3.4 Different compressor elements to cover a broad range in volume flow

A completer coverage of air needs is provided by offering compressors that differ in air ends and packages. The figure below depicts (theoretical, illustrative only):

1) efficiency curves of 7 different compressor elements of one manufacturer
2) having different size (e.g. in terms of displacement volume)
3) including the operating points of these compressor elements in
    a) different frame-sizes and/or
    b) differ configurations and/or
    c) different operating points

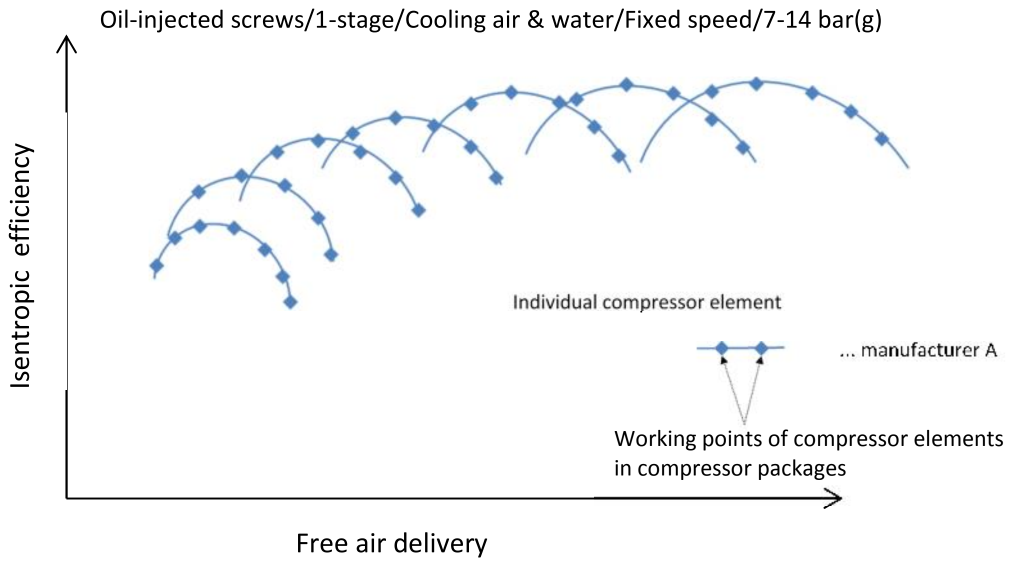


Figure 1-4: Efficiency curves of compressor elements in several compressor packages (illustrative)

The lower efficiency of the smaller air ends on the left side of the diagram is intrinsic, i.e. caused by inevitable technical reasons, mainly:

1) the manufacturing tolerances and – related to this – nominal clearances cannot be scaled down with the main dimensions, which results in relatively wider leakage paths in smaller compressor elements
2) the ratio of leakage path lengths (proportional to main dimensions) and displacement volumes (proportional to main dimensions cubed) is worse for smaller compressor elements compared to larger compressor elements

The number of compressor elements that are offered is limited as each (additional) model of screw compressor element:

- requires expensive tooling (casting moulds, type-specific grinding and milling tools, assembly tools ….);
- reduces the lot sizes per type in (serial) production;
- has to be kept available as spare part for approx. 15 years after the end of serial production of related compressor packages;
- generates costly effects in logistics (both in serial production phase of related compressor packages and later in support/service phase).

It is therefore not commercially viable to have an infinite number of optimized compressor element types for infinite operating points in numerous compressor package frame-sizes for many diverse applications.

This leads to a situation that manufacturers limit the number of their different compressor element models.

The limitation of number of air ends also means that a single air end can be used with three or four motors. At the transition point of one “frame size” to the next, the smaller frame usually has its air end combined with the largest motor possible whereas the next frame combines a bigger (next size) air end with the “next” motor size (possible the smallest of the motors for that specific air end).

This may result in two offers where the input power is nearly the same, as well as the volume flow, but the larger and more expensive machine is more efficient.

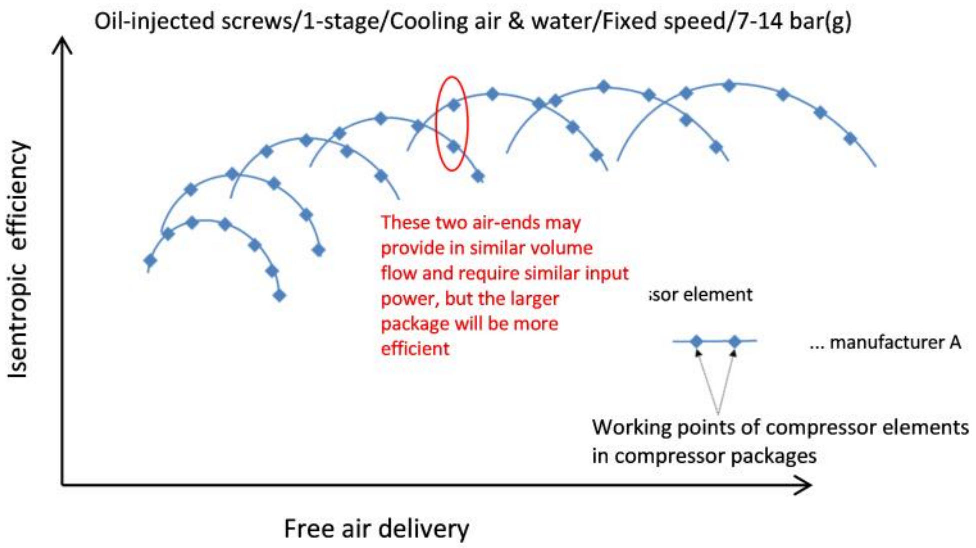


Figure 1-5 Explanation of package with same free air delivery, but difference in efficiency

1.3.5 Differences in compressor element efficiencies by different manufacturers

When the efficiencies of packages offered by different manufacturers are presented in a single graph, more possible operating points will become visible.

The figure below depicts the efficiency curves of 14 different compressor elements

a) of different size (e.g. in terms of displacement volume)

b) of (only) two manufacturers

c) including the alternative usage (or application) of these compressor elements in

    i) different frame-sizes of compressor packages and/or

    ii) different configurations of compressor packages and/or

    iii) different operating points

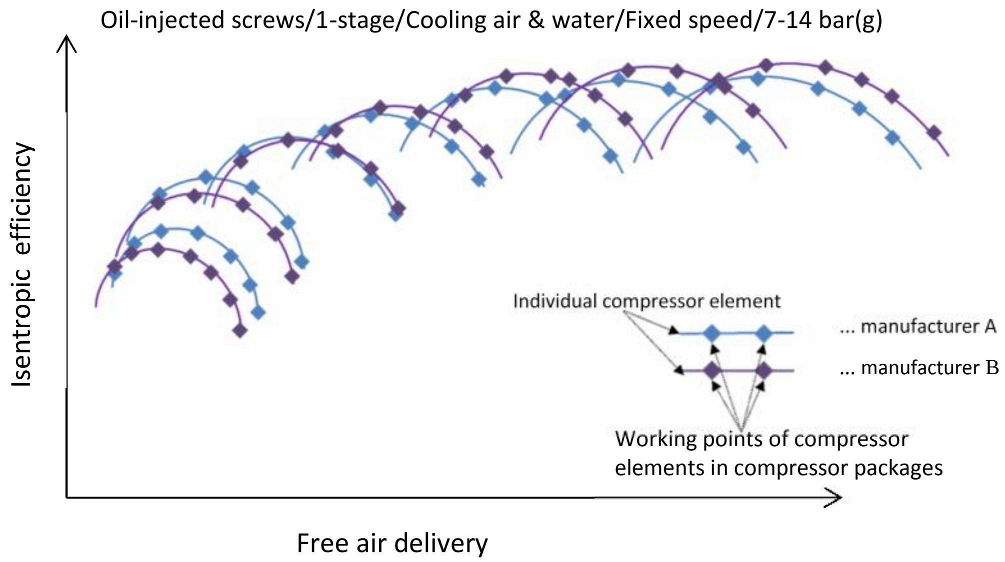


Figure 1-6: Efficiency curves with multiple compressor elements in compressor packages of different manufacturers (only illustrative no quantitative data)

The different efficiency levels of compressor elements of similar size are caused by

1) differences in “design quality” of different

    a) manufacturers and/or;

    b) compressor element “generations”;

2) different manufacturing quality:

3) different (but reasonably justifiable) design choices, e.g. regarding:

    a) optimization for different operating points (e.g. pressure / pressure ratio);

    b) choice of nominal clearances;

        i) whereas reducing nominal clearances provides better efficiency due to reduced internal leakage;

        ii) but causes larger susceptibility to critical rotor-rotor and/or rotor-housing contact with resulting damage during transient thermal conditions.

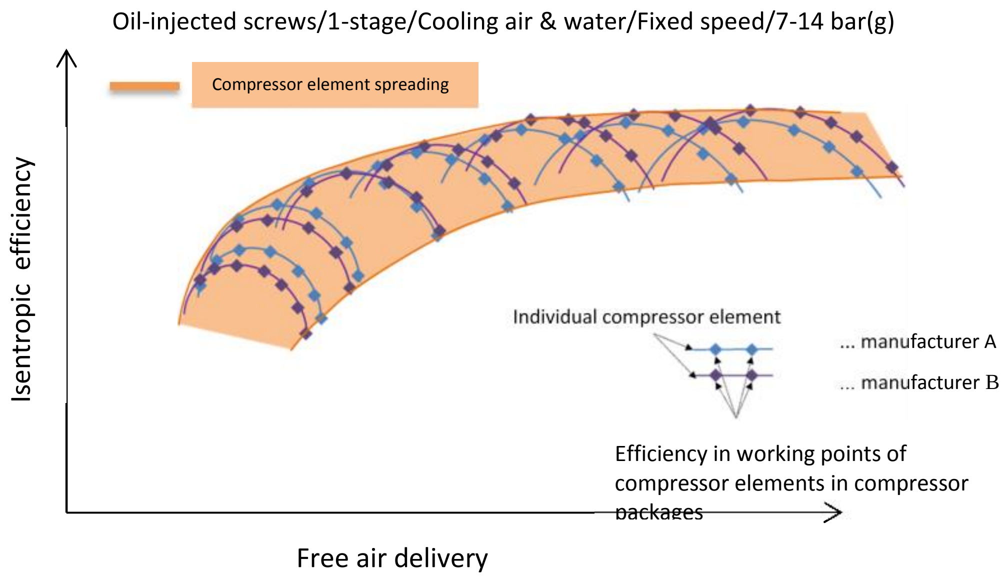


Figure 1-7: Isentropic efficiency cloud with compressor elements spreading (only illustrative no quantitative data)

the previous figure depicts the efficiency spread of the compressor elements alone (not the compressor packages!) resulting from the aforementioned effects and circumstances, e.g.

- different manufacturers
  - with different design quality
  - with different manufacturing quality
  - different compressor element “generations”
  - different (reasonably justifiable) design choices
  - usage in different operating points, frame-sizes and/or configurations of different types of compressor packages
- the lower efficiency of the smaller air ends on the left side of the diagram is intrinsic and caused by the aforementioned inevitable technical reasons

1.3.6 Differences in package choices

The above sections explain the differences cause by differences in air ends. As the air end is ultimately placed on the market in a package, the package also introduces a spread in final energy efficiency of the package.

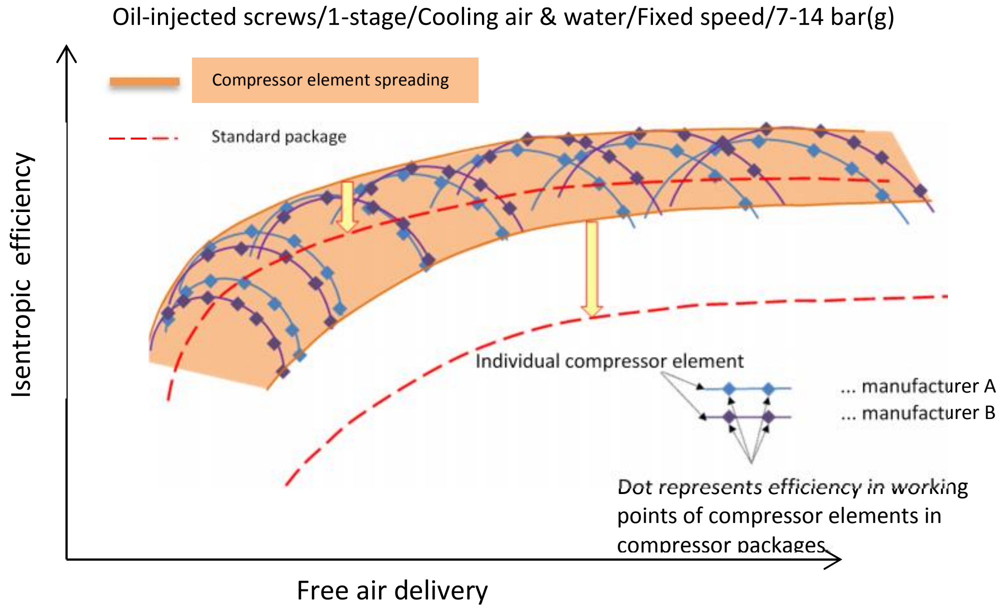


Figure 1-8: Isentropic efficiency cloud standard package compared to compressor element (only illustrative)

The above figure shows the “efficiency drop” (yellow arrows) from the compressor element level to the compressor package level, to be explained as follows:

1) the definition of “isentropic efficiency” for compressor elements and compressor packages is different (package efficiency includes additional ‘losses’ related to transmission, motor, drive, etc.):
    a) the isentropic efficiency on the compressor element level is related to:
        i) input shaft power (e.g. no motor included, no drive efficiency considered);
        ii) suction/discharge pressure at compressor element inlet/outlet;
    b) the isentropic efficiency on the compressor package level is related to:
        i) total electric input power of the package;
        ii) atmospheric ambient pressure;
        iii) discharge pressure at the compressor package discharge;
    c) the compressor package around the compressor element:
        i) is required to fulfil the primary function (compressed air production) and;
        ii) inevitably reduces the (differently defined) numerical value of isentropic efficiency on the compressor package level compared to the compressor element level.

The efficiency of the compressor package is influenced by

1) the efficiency of the compressor element:
    a) in its respective operating point;
    b) in the respective compressor package;
2) the efficiency impact of the package design, e.g.:
    a) internal pressure losses in:
        i) inlet filter(s);

   ii) inlet valve;
   iii) air piping;
   iv) oil separator vessel;
   v) oil separator cartridge;
   vi) minimum pressure check valve;
   vii) compressed air after-cooler;

b) main drive system efficiency:
   i) electric motor efficiency (not all possible motors give a good match to compressors
   ii) transmission (the transfer of motor shaft power to compressor element may take many forms. Gears and belts are most common methods, each with different losses);
   iii) the losses of the motor drive system (variable speed drives introduce electric losses and therefore less efficient when operating at single speed. If operated at variable speeds, higher efficiencies are attainable at part load conditions);

c) power consumption of auxiliary equipment, e.g.:
   i) main cooling fan(s) (influenced by type, characteristic, flow, differential pressure, fan drive/motor…);
   ii) control cabinet cooling fan(s) etc.;

d) dimensioning of the internal oil injection circuit in combination with cooling system efficiency and sizing;

e) …. many other design choices regarding the compressor package…

It is then conceivable that compressor packages differ in losses introduced. The figure below depicts a package design with lower losses.

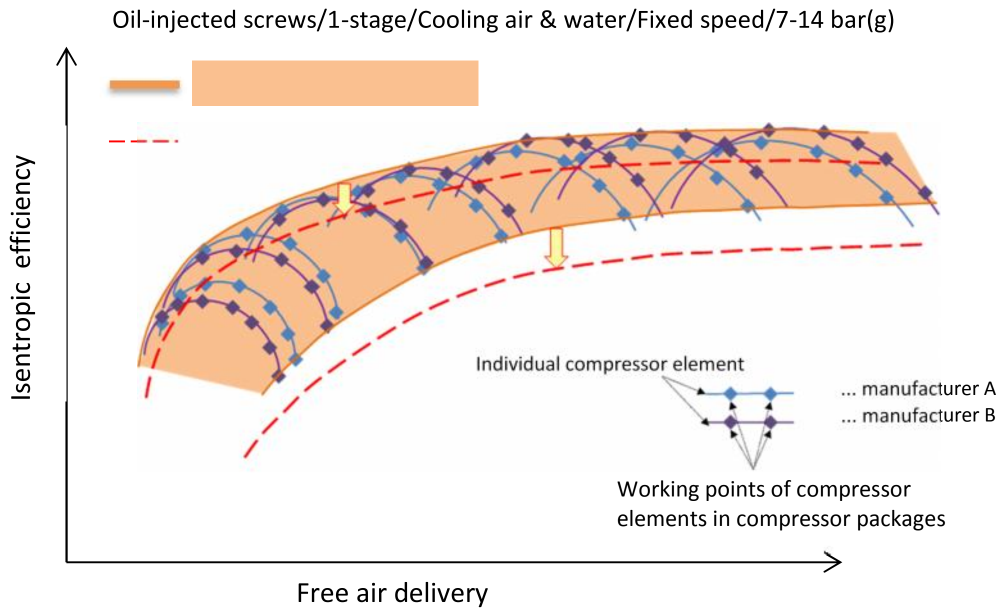
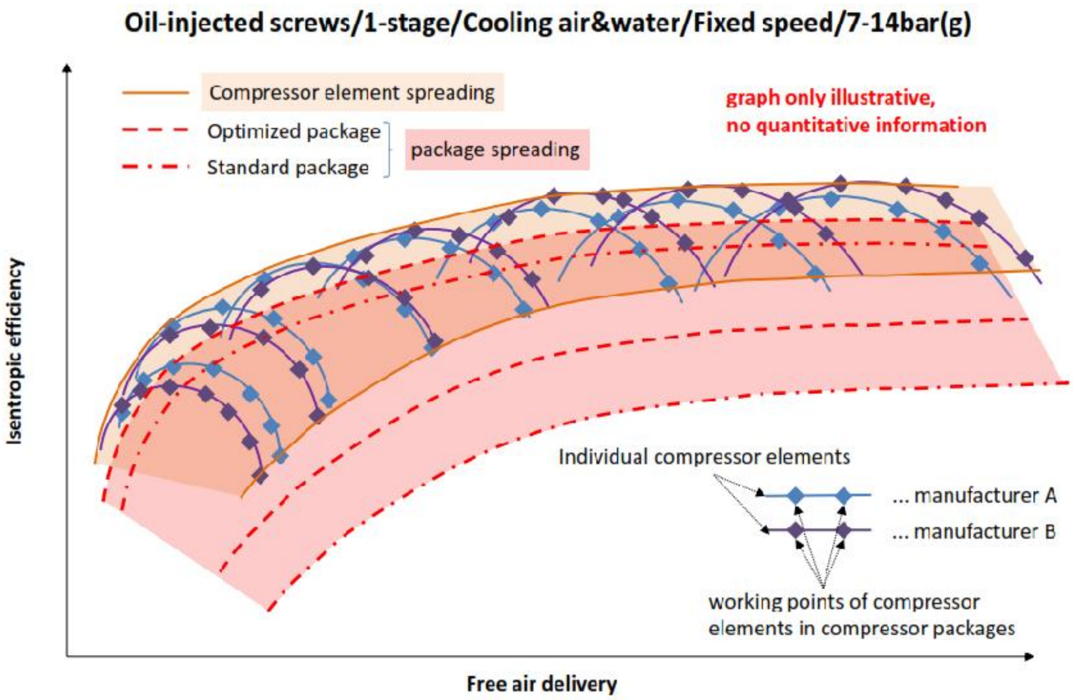


Figure 1-9: Isentropic efficiency cloud optimised package compared to compressor element (Only illustrative no quantitative data)

The relatively larger “efficiency drop” in standard compressor packages compared to the relatively smaller “efficiency drop” in optimized compressor packages further increases the total spread.



The spread of compressor package efficiency is larger than the spread of compressor element efficiency and is caused by a sequence of many design choices such as:

1) the decision for a basic design concept,
2) the compression element size selection, design point for the intended operation range, selection of materials, machining (micron accurate meshing screw rotors) and transmission,
3) sizing and matching of other components, the internal ventilation and ducting, measures to
   a) control vibration and noise, oil separation etc.,
   b) the contribution of some design changes depends on the level of efficiency already achieved
   c) some options do have a significant impact on the energy efficiency of the OIS package, but are not selected on that basis only , e.g. water cooling or air cooling;
   d) other choices like variable speed control are made for reason of energy efficiency, but this is made on basis of flow control requirements of a specific application;

The individual factors contributing to compressor package efficiency cannot be expressed as “energy efficiency options”, neither would it be easy to determine the related price increases.

1.3.7 Piston compressors: Trends and options to improve efficiency

Reciprocating piston compressors are considered a mature technology in the standard air application. They are designed for applications that require intermittent or sporadic use. These applications are mainly concentrated in the power segment between 1.1 and 11 kW and some of them are listed below (non exhaustive overview):

- Tyres shops (inflation of tyres and operation of pneumatic tools like impact wrenches)
- Car repair workshops (inflation, blowing and operation of pneumatic tools like impact and ratchet wrenches)
- Car body shops (painting and blowing)
- Petrol stations and car washing (inflating and blowing)
- Agriculture (pruning, milking)
- Craftsmen (wood workers, carpenters, plumbers, contractors etc…)
- Small workshops (mechanical workshops, laundries, printing shops, fire extinguishing devices etc…)

In these applications the running hours per working day are normally low (from 0,5 up to 4 hours) with light duty cycles (running time on total time from 10% to 50%), with limited overall energy consumption (from Pneurop data collection, piston compressors represent about 2.6% of the overall standard air category energy consumption).

Therefore, historically, customer focus on piston compressors has been more on reliability and purchasing price than on efficiency, since energy cost is not perceived as important. In spite of all that, during the last 20 years, manufacturers have improved the efficiency of the reciprocating piston compressor working specifically to increase the volumetric efficiency (defined in para. 1.4.3.3 of Inception Report ENER Lot 31).

This has been done by concentrating efforts on:

- improved cooling, through use of die cast aluminium components rather than cast iron components, with reduced wall thickness which provides improved heat exchange between compressed air and cooling air flow. The benefit, in addition to the reduced wall thickness, is in the better thermal conductivity of aluminium versus cast iron (+400%).
- improved design of the spokes of the compressor pulley, that acts also as cooling fan.

Figure 1-10 Pulley for belt drive

Figure 1-11 Reed valve

Reduction of the losses by improving the design of the intake/exhaust valve systems. This has been achieved by redesigning the valve reeds, increasing the available surface for the air flow (+30-50%).

A further improvement , having a reduced contribution to increasing the efficiency was the use of piston rings with lower friction coefficient.

The sum of these improvements can be assessed at 3-6 point of isentropic efficiency over last 20 years.

As already stated above, piston compressors are very mature products and the steps taken in the past to increase their isentropic efficiency cannot be repeated with the same magnitude in the future. The optimization of these products follows, as for the oil injected screw and vane compressors, a learning curve with asymptotic behaviour, requiring ever longer development times that result in ever decreasing improvements.

1.3.8 Compressors in other application ranges

The preceding sections focus on technologies for rotary positive displacement compressor technology (screw, vane) and reciprocating positive displacement technology.

The general conclusions on how compressor efficiency can be improved can be considered to apply to other types of positive displacement technology as well - in very general terms such as: improvement of shape of moving elements, improved machining tolerances, reduced losses in package, etc.

It has not been possible to develop the same approach of describing efficiency improvement options for turbo compressors. For this an exhaustive description of turbo compressor efficiency and their actual application constraints needs to be developed.

Improvement options for turbo compressors focus on:

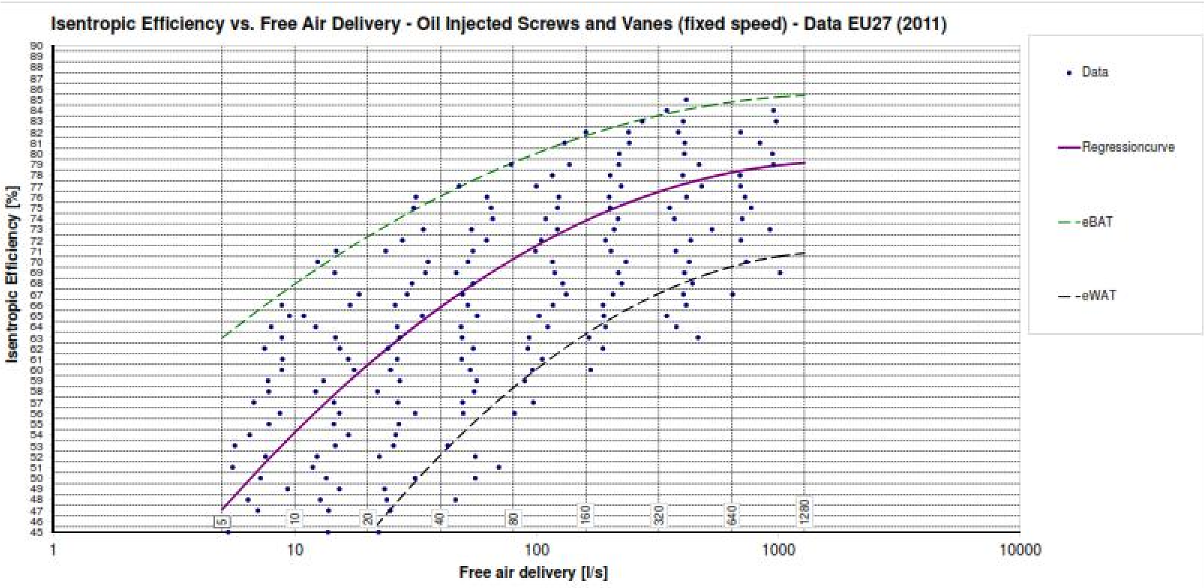
1) design of impellers (rotors) and diffusors (a.o. blade shapes, reduction of slip);
    a) reduction of rotor losses focus on reduction of incidence losses, disk friction losses, diffusion blading losses, clearance losses, skin friction losses, shock losses, etc.;
    b) reduction of stator losses focus on reduction of recirculating losses, wake mixing losses, vane less diffusor losses, vaned diffusor losses, exit losses, etc.
2) design and application of inlet guide vanes (a.o. reduction surge effects) and diffusor guide vanes;
3) staged operation: single or multi-stage designs
4) transmission: integrally geared;
5) bearings, seals with reduced losses;

However, it is difficult to state the improvement potential of such options without a comparative assessment based on an analysis of the full spectrum of products placed on the market, their intended applications and their performance assessed on basis of standardized test methods. Such an analysis has proven to be beyond the capabilities of the study, as the time and resources needed for such an analysis exceed the time and resources allocated to the study.

1.3.9 Efficiency of fixed speed oil-injected screw and vane compressors

The data collection resulted in the following data points for fixed speed OIS+OIV compressors. The horizontal axis is the volume flow (at free air delivery), the vertical axis is the isentropic efficiency (at full load).

Figure 1-1 Data cloud for fixed speed efficiency (EU 27, Pneurop 2014)



The regression parameters are shown in the table below.

Table 1-1 fixed speed OIS+OIV regression parameters

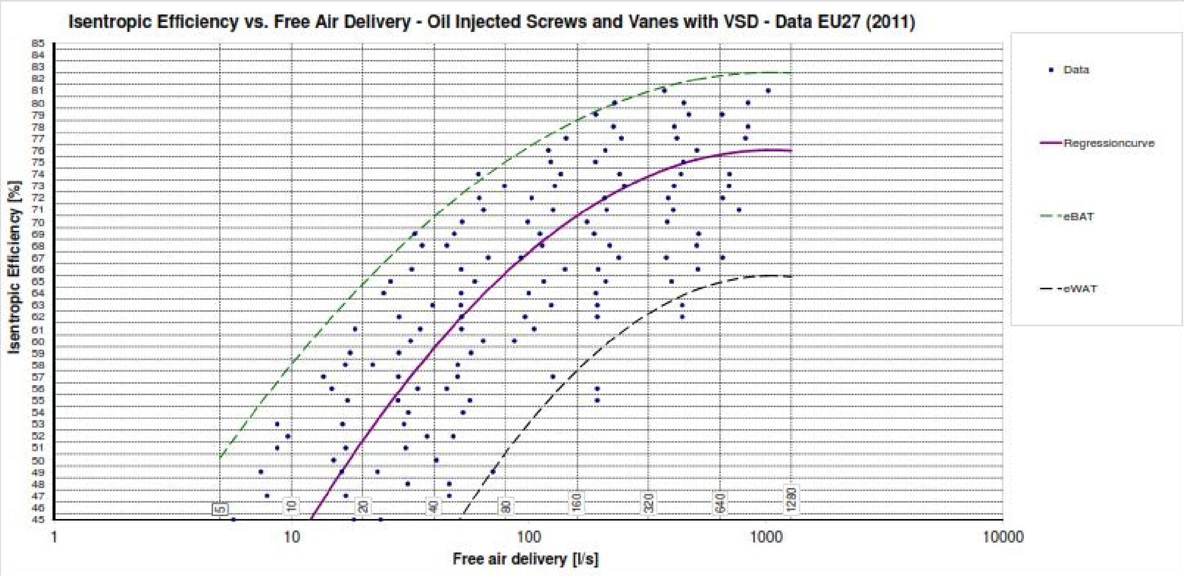
regression parameters	
-0,928	ln(x)^2
13,911	ln(x)
27,110	c

Table 1-2 Average, highest and lowest isentropic efficiencies per volume flow segment of fixed speed OIS+OIV compressors

Fixed speed OIS+OIV			
Volume flow segment	Lowest efficiency	Average efficiency	Highest efficiency
7.5	40	53.1	66
15	40	58.8	71
30	44	62.6	76
60	48	67.6	79
120	56	73.0	82
240	60	74.7	83
480	63	78.0	85
960	67	76.5	84
average			
59 l/s	63 %		

1.3.10 Efficiency of variable speed oil-injected screw and vane compressors

Figure 1-2 Data cloud variable speed efficiency (EU 27, Pneurop 2014)



The regression parameters are shown in the table below.

Table 1-3 Variable speed OIS+OIV regression parameters

regression	
parameters	
-1,549	ln(x)^2
21,573	ln(x)
0,905	c

Table 1-4 Average, highest and lowest isentropic efficiencies per volume flow segment of variable speed OIS+OIV compressors

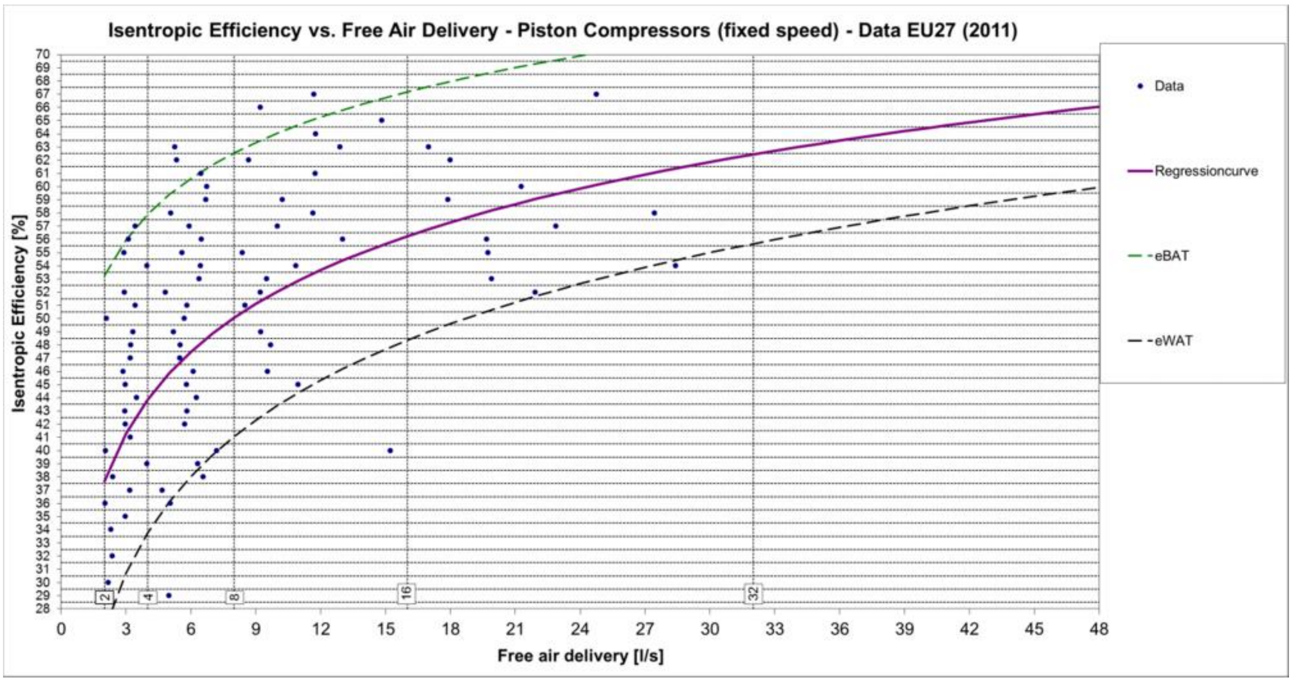
Variable speed OIS+OIV			
Volume flow segment	Lowest efficiency	Average efficiency	Highest efficiency
7.5	45	50.2	53
15	41	52.1	61
30	40	56.1	69
60	47	63.1	74
120	57	69.2	77
240	77	71.8	80
480	62	74.6	81
960	67	76.6	81
average			
123 l/s	65%		

1.3.11 Efficiency of piston compressors

The statistical approach applied on piston compressors resulted in a dataset as presented below together with the regression line and worst ("eWAT") and best ("eBAT") curves.

The regression is valid only for the volume flow classes for which data has been collected (from 2 to 32 l/s), since for higher volume flows piston compressors are rarely used (for average outlet pressure 8-9 bar(g)).

Figure 1-3: data cloud piston compressors (EU 27, Pneurop 2014)



The regression parameters are shown in the table below.

Table 1-5: Piston regression parameters

regression	
parameters	
0	ln(x)^2
8.931	ln(x)
31.477	c

The average, highest and lowest efficiencies are also presented in the table below.

Table 1-6: Average, highest and lowest isentropic efficiencies per volume flow segment of piston compressors

Piston compressor			
Volume flow segment	Lowest efficiency	Average efficiency	Highest efficiency
3	30	42.2	57
6	29	46.5	63

12	40	52.6	67
24	52	58.9	67
average			
6.7 l/s	47%		

1.3.12 Best available technology

Best Available Technology point (BAT), representing the best commercially available product with the lowest resources use and/or emissions

According the methodology (MEErP 2011) the assessment of the best available technology (BAT) takes place on purely technical grounds, i.e. the product with the lowest environmental impact, but it should be clear that in terms of functional performance, quality and durability it should be a product that is at least equivalent to the Base Case (representative of the average product placed on the market).

As the energy efficiency has been identified to be the single most important environmental parameter (see Task 5) the BAT products are those with the highest energy efficiencies.

For the three sub-base cases these BAT products have been identified in the preceding sections, in the tables showing the highest efficiencies achieved by products. Although a direct comparison of the highest efficiencies for fixed speed and variable speed OIS+OIV shows the first achieves higher efficiencies, a direct comparison is not meaningful because the highest efficiencies do not (and cannot) reflect the operational behaviour of both compressor types, which is also influenced by circumstances and aspects outside/beyond the product boundaries. It does not show the efficiency gain of variable speed in part load over fixed speed compressors in part load (that may include idle mode or even turn off/on in certain operating conditions).

For compressors in the other application ranges no BAT could be identified as no such information could be presented within the boundaries of this study.

1.3.13 Best not yet available technology

Best Not yet Available Technology point (BNAT), representing an experimentally proven technology that is not yet brought to market, e.g. it is still at the stage of field-tests or official approval.

According the methodology (MEErP 2011) the assessment of BNAT indicates the potential for future innovation and product-differentiation after the introduction of (possible) measures.

Industry stakeholders have stated on several occasions that the improvement of energy efficiency of most compressor application ranges follows an evolutionary path, rather than a revolutionary path. New disruptive technologies, offering significant better energy efficiency have not been identified. Instead, the market has shown and is expected to continue to show, an incremental improvement in highest efficiencies. Further improvement of efficiency becomes increasingly difficult, an effect also known as the 'learning curve'.

Still, compressor technology, being part of a wide 'fluid dynamics' technology field that stretches out from fan applications to combustion engines, including vacuum technology, is vast and varied and innovation has not reached a standstill.

A possible example of the difficulties in dealing with Best Not Yet Available Technology, may be the "Lontra Blade Compressor" by British inventor Lindsey, announced in 2010 [3]. This invention is

[3] Various sources, such as: http://www.lontra.co.uk/technologies/the_bladecompressor.htm
http://www.theengineer.co.uk/news/air-compressor-could-help-industry-slash-energy-costs/1002454.article

presented as breakthrough technology (for the application range 'low pressure') and reportedly delivers "efficiency savings of between 15-20 per cent over competing technologies". However, the actual design and efficiency of this or other competing technologies, to be used as reference or yardstick for the claims on savings, have not been reported. A claim whether a new compressor is more efficient than other technologies currently placed on the market should be supported by clear evidence, preferably a comparative assessment with a competing state-of-the-art technology on the basis of standardized test methods. For low pressure applications such as waste water treatment this would more often be rotary displacement compressors using lobes and centrifugal turbo compressors rather than piston compressors (mentioned in articles as 'competing technology')[4].

Having said that, it could very well be that BNAT may also originate from unexpected angles such as Peltier-devices that harvest thermal losses and convert these to electric power. Ongoing research shows gradual improvement in conversion efficiency and application (temperature) range.

Other incremental improvements may be related to motor technology (permanent magnet motors are now considered commonplace, and alternatives exists with even higher efficiencies, or with a better 'environmental' performance, using less critical raw materials).

Also lubricant technology should be mentioned, in particular in the standard air application range, which could help improving thermal lubricating and shearing properties.

1.3.14 Use of critical raw materials

Although not identified as main environmental parameter of compressors, the use of critical raw materials is addressed in this section.

As improving efficiency can be achieved by improving electric motor efficiency, for instance by using permanent magnet motors, the use of critical raw materials may increase as a result of this.

The effect could however not be quantified as relevant data is lacking (see Task 4), but certain improvement options that reduce the environmental burden can be mentioned.

First, the use of critical raw materials per high efficiency motor can be reduced by an optimal placement of substances, at positions where they are most effective, and avoiding use at positions less effective.

Another possible way of achieving sustainable utilization of rare-earth elements is to recycle these materials from electric motors. But so far there are no practical methods for doing so[5]. Instead, electric motors usually wind up in smelters: “It’s true the material is recycled, but the rare earths get mixed in with the rest and are simply lost”. With this in mind, Siemens researchers have begun to develop a process that begins with removal of magnets from motors and comprises several phases of recycling[6]. As direct re-use wouldn’t always work because the magnets usually don’t fit, efforts are underway to design products from the very start in a way that will make it possible to remove permanent magnets from a motor with relative ease for recycling. For this project, which is supported by the German Ministry of Research, partnerships with institutions and companies are also used to develop processes for selectively concentrating magnetic materials from smelters in slag, and for recovering rare-earth metals from it. Researchers estimate this process will be ready for industrial use in a few years.

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[4] http://www.worldpumps.com/view/37760/massive-cost-savings-found-through-technical-innovation/
http://eandt.theiet.org/contribute/design-production/sewage-treatment.cfm
[5] Of course methods exist, but what is meant by 'practical' is that for a recycling route to become attractive and common place not only technological aspects, but also economic aspects and environmental need to be addressed and solved.
[6] http://www.siemens.com/innovation/en/news/2011/e_inno_1137_2.htm

1.4 Options for heat recovery

The following section is an excerpt from the Improving Compressed Air System Performance - a sourcebook for industry, by the U.S. Department of Energy Efficiency and Renewable Energy[7].

As much as 80 to 93 percent of the electrical energy used by an industrial air compressor is converted into heat. In many cases, a properly designed heat recovery unit can recover anywhere from 50 to 90 percent of this available thermal energy and put it to useful work heating air or water.

Typical uses for recovered heat include supplemental space heating, industrial process heating, water heating, makeup air heating, and boiler makeup water preheating. Recoverable heat from a compressed air system however, is usually not hot enough to produce steam directly.

Heat recovery systems are available for both air and water-cooled compressors.

1.4.1 Heat Recovery with Air-Cooled, Rotary Screw Compressors

Heating Air

Air-cooled, packaged, rotary screw compressors are very amenable to heat recovery for space heating or other hot air uses. Ambient atmospheric air is heated by passing it across the system's after cooler and lubricant cooler, where it extracts heat from both the compressed air and the lubricant that is used to lubricate and cool the compressor.

Because packaged compressors are typically enclosed in cabinets and already include heat exchangers and fans, the only system modifications needed are the addition of ducting and possibly another fan to handle the duct loading and to eliminate any back pressure on the compressor cooling fan. These heat recovery systems can be modulated with a simple, thermostatically controlled hinged vent. When heating is not required —such as in the summer months—the hot air can be ducted outside the building. The vent can also be thermostatically regulated to provide a constant temperature for a heated area. Recovery efficiencies of 80 to 90 percent are common.

Heating Water

Using a heat exchanger, it is also possible to extract waste heat from the lubricant coolers found in packaged water-cooled, reciprocating or rotary screw compressors and produce hot water.

Depending on design, heat exchangers can heat non-potable (grey) or potable water. When hot water is not required, the lubricant is routed to the standard lubricant cooler.

1.4.2 Heat Recovery with Water-Cooled Compressors

Heat recovery for space heating is not as common with water-cooled compressors because an extra stage of heat exchange is required and the temperature of the available heat is lower. Because many water-cooled compressors are quite large, however, heat recovery for space heating can be an attractive opportunity. Recovery efficiencies of 50 to 60 percent are typical.

[7] Freely available from: http://www1.eere.energy.gov/industry/bestpractices/pdfs/compressed_air_sourcebook.pdf

2 Task 7: Life cycle costing calculations

2.1 Introduction to Task 7

This is the final report of Task 7 of the preparatory study on electric motor systems/compressors in the context of the Ecodesign Directive: **'ENER Lot 31 – Products in motor systems outside the scope of the Lot 30 and the Regulation 640/209 on electric motors, in particular compressors, including small compressors, and their possible drives'.**

This study is being carried out for the European Commission (DG ENER). The consultant responsible for the study is Van Holsteijn en Kemna B.V. (VHK).

2.1.1 Aim of Task 7

The aim of Task 7

The aim of this task is to identify design options, their monetary consequences in terms of Life Cycle Cost for the consumer, their environmental costs and benefits and pinpointing the solution with the Least Life Cycle Costs (LLCC) and the Best Available Technology (BAT).

The assessment of monetary Life Cycle Costs is relevant to indicate whether design solutions might negatively or positively impact the total ED consumer's expenditure over the total product life (purchase, running costs, etc.). The distance between the LLCC and the BAT indicates -in a case a

LLCC solution is set as a minimum target- the remaining space for product-differentiation (competition). The BAT indicates a medium-term target that would probably more subject to promotion measures than restrictive action. The BNAT (subtask 7.5) indicates long-term possibilities and helps to define the exact scope and definition of possible measures.

2.1.2 Subtasks Task 7

The technical tender specifications for the Task 7 subtasks are:

Subtask 7.1 Options

- Identification and description of individual design options for environmental improvement

Subtask 7.2 Impacts

- Quantitative assessment of the environmental improvement per option (using EuP EcoReport)

Subtask 7.3 Costs

- Estimate of price increase due to implementation of design options, either by looking at prices of products on the market and/or by applying a production cost model with sector specific margins

Subtask 7.4 Analysis LLCC and BAT

- Ranking of the individual design options by LCC (e.g. option 1, option 2, option 3, etc.)
- Determination / estimation of possible or negative ('rebound') side effects of the individual design measures;
- Estimating the accumulative improvement and cost effect of implementing the ranked options simultaneously (e.g. option 1, option 1+2, option 1+2+3, etc.), also taking into account the above side-effects;

- Ranking of the accumulative design options, drawing of a LCC-curve (Y-axis= LLCC, X¬ axis= options) and identifying the Least Life Cycle Cost (LLCC) point and the point with the Best Available Technology (BAT).

Subtask 7.5 - Long-term targets (BNAT) and systems analysis

- Discussion of long-term technical potential on the basis of outcomes of applied and fundamental research, but still in the context of the present product archetype;
- Discussion of long-term potential on the basis of changes of the total system to which the present archetype product belongs: Societal transitions, product-services substitution, dematerialisation etc.

2.1.3 Task 7 report structure

The subtasks required for task 7 are covered in this report according the structure below.

Figure 2-1: (Sub)tasks for Report Task 6 & 7

Subtask required	Included in report Task 6/7
Subtask 7.1 - Options	The options to improve efficiency have been described in section 3.2 (see explanation d-value).
Subtask 7.2 - Impacts	The life cycle impacts of the average product and the improved (BAT) product have been described in section 3.8
Subtask 7.3 - Costs	The cost implications of increased efficiency have been assessed in section 3.4 (purchase costs) and sections 3.5 + 3.6 (energy and other costs).
Subtask 7.4 - Analysis LLCC & BAT	Ranking of options by LCC is included in section 3.7, including identification of LLCC (BAT was defined in section 2.3)
Subtask 7.5 - Long term targets	The long-term potential is discussed in section 3.9

2.2 Design options for improvement (subtask 7.1)

The previous chapter Task 6 showed that improvement of the environmental (mainly energy) performance of the products is not achieved by simply applying certain individual design options ("replacing part X by a better performing part Y") but achieved by combining an array of design decisions, often bound by manufacturing constraints, into the best market proposition.

The improvement is achieved more through an **evolutionary change** in aspects that influence the overall performance, as opposed to a 'drop-in' replacement of certain components. Of course one can identify very specific design options such as replacing a standard motor or transmission with a more efficient motor or a transmission with less losses, but it is the overall design of the package, of all its components combined, that determine the overall package efficiency.

As no specific individual design option could be identified to link an improved efficiency to, this section introduces a metric that represents the change (increase or decrease) of efficiency and which can be used to express both average and BAT products. The metric is based upon the isentropic efficiency of the compressor package. This metric can also be used as basis for proposals for future regulation of the products.

As it is preferred to develop a **parametric** approach to identifying targets (as opposed to specific target values that apply to specific products and volume flow classes, possibly introducing threshold barrier effects) the change in efficiency is to be expressed using a formula, a so-called regulation curve.

2.2.1 Improvement options expressed as "d-value" (also relevant for the Regulation curve)

Potential regulation curves (i.e. curves defining efficiency thresholds) are derived from the regression curve with respect to the distance of the regression curve to the 100%-isentropic efficiency line. The difference between the individual efficiency and 100% can be roughly considered as being representative for "losses".

The assumption to generate regulation curves from the regression curve is that the relative change in losses shall be the same for all volume flow rates ("relative adjustment"). This takes into account that compressors having a high efficiency only provide a small potential for additional improvement.

This leads to the following formula to generate regulation curves:

regulation curve = regression curve + (100 - regression curve) * d_ / 100

Where d_ = relative change of losses

This d-factor or d-value is very important for the following sections in Task 7 and Task 8, as it represents the improvement of the product (improvement expressed as reduction of losses going from average (regression curve) to 100% efficiency(theoretical).

In Chapter Task 8 it is assumed that all compressors with efficiencies lower than the regulation curve will be replaced by such compressors that fulfil the requirement.

This chapter Task 7 will use the same approach to calculate life cycle costs and identify the least life cycle cost point.

2.3 General LCC approach

2.3.1 Life cycle costs

The analysis uses the definition of Life Cycle Costs (LCC) as given in MEErP 2011. With respect of the MEEuP 2005, the definition is extended, amongst others, with the notion of 'escalation rate' e. The escalation rate is the real (above inflation) growth rate of the price components, e.g. the energy costs. Whereas in the previous methodology it could be assumed that all price components show the growth rate of the inflation (escalation rate=0), the latest figures show that in particular energy prices show a nominal annual growth rate of around 6%, which results – at an inflation rate of around 2% - in an escalation rate of 4% for the electricity and fossil fuel prices that are used in the underlying report.

The basic LCC formula is:
LCC = PP + PWF * OE + EoL,
where
LCC is Life Cycle Costs to end-users in €,
PP is the purchase price (including installation costs) in €,
OE is the annual operating expense in €
PWF (Present Worth Factor) is

$$PWF = 1 - \left(\frac{1+e}{1+d}\right) * \left[1 - \left(\frac{1+e}{1+d}\right)^N\right] \; (d \neq e)$$

In which:

N is the product service life in years;

d is the discount rate in % (by definition 4%[8])

e is the aggregated annual growth rate of the operating expense (a.k.a 'escalation rate', in €)

If d=e then **PWF = N and** the LCC formula can be simplified to:

LCC = PP + N * OE + EoL

The value of *EoL* for compressors is assumed to be negligible.[9]

2.3.2 Simple payback period

The fact that the escalation rate of the running costs more or less equals the discount rate also means that the discounted payback period equals the simple payback period (SPP). This is the time period it takes for an investor to recuperate the extra investment in purchase price *dPP* through the reduction in annual operating expense *dOE*.

The equation for comparing two alternatives 'A' and 'B' is then

$\boldsymbol{SPP_{AB} = dPP_{AB} / dOE_{AB}}$ (in years)

Where

> $\boldsymbol{SPP_{AB}}$ is the Simple Payback Period of a higher acquisition cost of a product B over product A (in years)
>
> $\boldsymbol{dPP_{AB}}$ is the extra Purchase Price of product B over A (in €)

[8] In accordance with the European Commission Impact Assessment Guidelines 2009.
[9] Meaning that, given the fact that the units consist largely of metals representing a value for recycling, there will be no net disposal costs.

dOE_{AB} is the saving in annual Operating Expense of Product B over A (in €/year)

This formula can only be used to judge the payback period for products that roughly have the same product service life. This is assumed to be the case for the compressors considered.

2.4 Purchase costs

The purchase costs are to be established for products with varying efficiencies, in order to establish a price-efficiency relation.

Information on cost price of compressors has been collected by VHK by sending questionnaires to individual manufacturers directly. The collection of all pricing information was done outside the structure set up by Pneurop for the 'statistical approach' and is covered solely by agreements between VHK and individual manufacturers.

2.4.1 Complications in cost price assessment

The cost assessment has proven to be quite difficult in this study for several reasons:

- Data combining efficiencies of models and their actuals number or share in sales is considered extremely confidential - for this reason all cost data depicted in this report is not sales-weighted and based on a very limited amount of data entries;
- All cost data is based on list prices only. The transition to sales ('street') prices has been done by applying a discount factor (for final customers) and mark-up factors (for distributors and/or dealers). These discount and mark-up factors differ quite significantly between manufacturers, type of products, size of products, (geographical) markets, as they are very relevant for positioning on the market and dealing with competitors. More specifically:;
    - Prices may be the average of the countries in which sales take place. Compressors for a manufacturer's domestic market may be sold on the basis of general list prices, but compressors exported to the rest of Europe are sold to "resellers". In this case country specific list prices may exist (prices depend per country, sales quantities, and various other aspects) and the final prices to the end users are not known;
    - Prices are influenced by specific market segments and strategies (ie. premium brand versus low cost brand) and therefore do not only reflect cost effects related to volume flow class and/or efficiency;
- Cost data does not include all manufacturers, neither all models available;
- Cost data is confined to basic packages only. Packages with additional features, such as 'active cooling' has been omitted as it would complicate the cost analysis;
    - For piston compressors in particular. the basic package does not include the receiver (storage tank) as it doesn't affect energy efficiency. But many list prices of manufacturers usually include this item. The tank may comprise 30% of the list price of the product. Therefore it proved to be pretty difficult to provide list prices of units defined as basic packages because they normally do not exist, or, if existing, they are sold in very small quantity and their cost and price could be even higher than similar tank mounted units due to market considerations.
- Prices of packages that are in the same volume flow class, but deliver air at different pressures are quite different, as packages for higher pressures have larger motors (which are one of multiple reasons the equipment is more expensive). This effect could not properly be reflected in the approach that tries to link energy efficiency (isentropic efficiency) to price. List prices are assumed to apply to equipment in primarily the 8-9 bar(g) range, as these form

the largest market segment. Compressors with higher rated pressures (e.g. 10…15 bar(g)) have significantly higher prices than compressors with rated pressure of e.g. 8 bar(g).

- The flow classes are quite coarse and therefore the mix of compressors can be rather diverse, which impacts on the prices;
- In certain cases manufacturers responded that certain combinations of compressor elements and motors, may give comparable volume flow and comparable energy input, but are very different in pricing levels. Differences in outlet pressure is one of the most often cited reasons. This is not directly visible when comparing the performance or prices at the level of isentropic efficiency.:
- In screw compressors in particular, the efficiency is also related to the discharge pressure (low pressure --> more efficient), but price is only in a few cases differing between them.
- Equipment designed with standard features like water cooling may reach higher efficiencies with comparatively lower list price, but the list price does not include/consider the higher efforts and costs related to installation (material, commissioning and water usage).
- As stated list prices do not perfectly reflect the product costs, and pricing mechanisms (discount structures) are not equal for all machines. Also there are some machines more expensive in comparison to others not for technology reasons but for having not the same scale effects due to lower sales quantity.
- Some basic packages provide more opportunities to upgrade functions in future and are more expensive for having space and material for further installation.
- Especially in the larger flow area the class width (example: between 480 to 960 l/s) is that big, that very different machines are located in one flow class. For example a 180hp machine is in the same flow class as a 340 hp machine but the price is very different.
- Larger compressors are more often assembled and sold not 'from the shelf' but 'to order'. This means that only after an order for a compressor is received, the manufacturing of the product commences. Only in case of products that are generally sold in relatively large volumes, the fabrication takes place using as much standardised components as possible. Special products may contain parts that are produced for that specific product. This also affects the pricing of compressors.

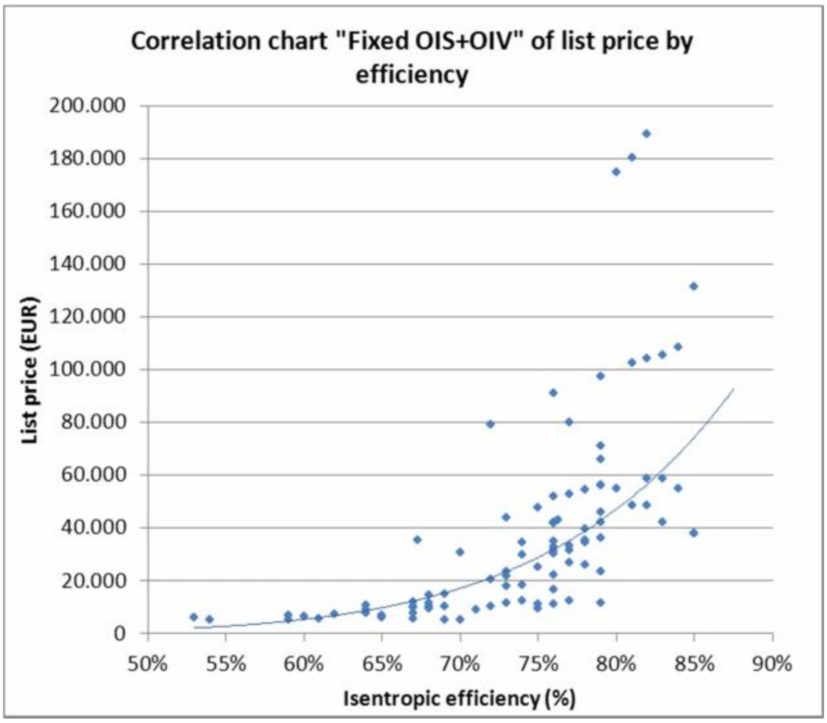
Determining the dependency of the list price on the efficiency for each manufacturer independently, and then make an average of those values, could not be performed due to lack of data points.

Still, the questionnaire resulted in pricing information that allowed an initial assessment of price versus efficiency. These results were discussed with industry experts and modified to better reflect actual list prices. The following sections shows this for fixed, variable speed and piston compressors.

2.4.2 Fixed speed OIS+OIV

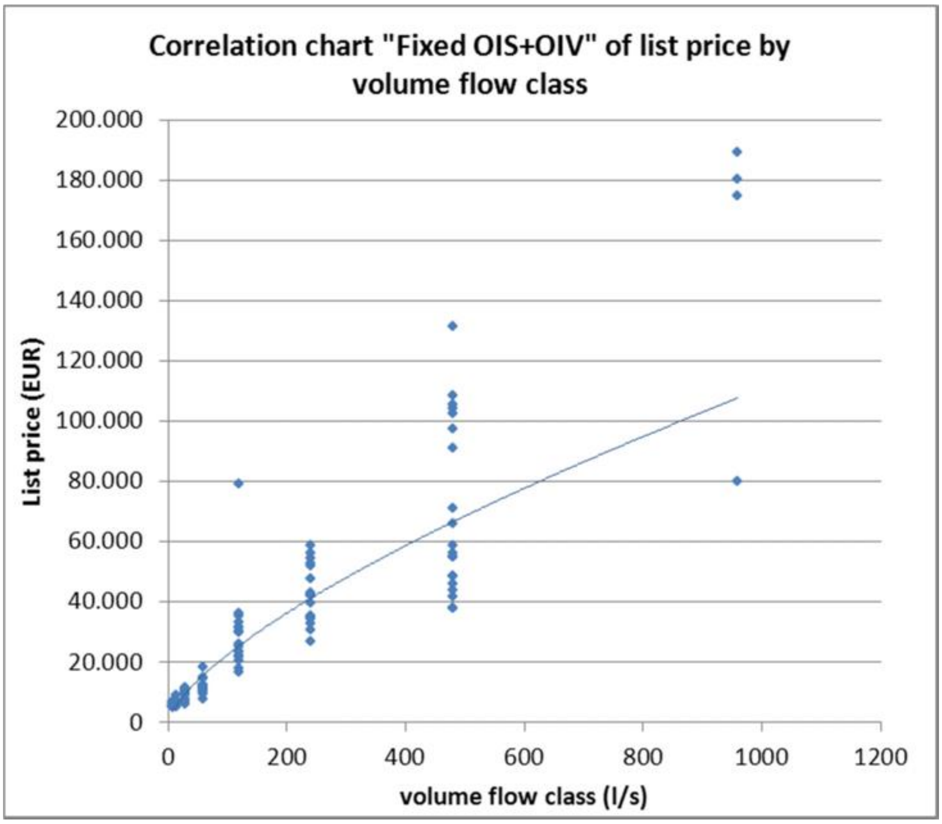
The questionnaire regarding list prices returned the following data-cloud for fixed speed OIS+OIV.

Figure 2-2 Fixed speed list prices by efficiency(Source: VHK 2014)



The below chart shows that there is also a relation of list price to volume flow class.

Figure 2-3 Fixed speed list prices by volume flow (Source: VHK 2014)



Combining both efficiency and volume flow in a single 'surface' chart reveals a trend of increasing list prices for increasing efficiency and increasing flow class.

On the basis of the above information VHK established the following relation:

Fixed speed List price=((10*flow)+2500)+((290*flow) + 10000)*(eff^3)

where:

flow = volume flow class in l/s

eff = isentropic efficiency in percentage points (e.g. 50, 60, etc.)

The above relation is intended to describe list prices of only the equipment of which the pressure at outlet is between 8-9 bar(g). Other equipment, providing higher pressures up to 14 bar(g), are expected to follow different list price curves, but the current calculation model can only be tuned towards the most often sold equipment, which is between 8-9 bar(g).

Table 2-1 List price fixed speed (Source: VHK 2014)

d-value \ (l/s)	-10	0	5	10	15	20	price factor best/ worst
7,5	€ 3.800	€ 4.226	€ 4.471	€ 4.740	€ 5.033	€ 5.352	1,41
15	€ 4.881	€ 5.446	€ 5.762	€ 6.100	€ 6.461	€ 6.847	1,40
30	€ 6.851	€ 7.631	€ 8.056	€ 8.505	€ 8.979	€ 9.479	1,38
60	€ 10.751	€ 11.911	€ 12.532	€ 13.182	€ 13.862	€ 14.571	1,36
120	€ 18.859	€ 20.729	€ 21.720	€ 22.748	€ 23.815	€ 24.920	1,32
240	€ 35.897	€ 39.125	€ 40.821	€ 42.571	€ 44.377	€ 46.241	1,29
480	€ 71.216	€ 77.079	€ 80.140	€ 83.290	€ 86.529	€ 89.858	1,26
960	€ 142.554	€ 153.623	€ 159.385	€ 165.301	€ 171.373	€ 177.604	1,25

The purchase price or end customer price is calculated on the basis of the list price, by applying a discount and a mark-up factor.

The discount factor may vary per type of equipment and market, and is possibly unique for each compressor sold (even within the same manufacturer discount factors vary per region and model, etc.). The discount can vary between 20% to 40% to 60%. We will assume an average of 45% discount (price factor 0.55).

This average discount is assumed to take into account discounts applied to end customer through both direct sales and through retail channels such as dealers or distributors that apply a mark-up factor for the turnover to be realised by them.

Table 2-2 End customer / Purchase prices fixed speed (incl. discount) (Source: VHK 2014)

d-value \ (l/s)	-10	0	5	10	15	20
7,5	€ 2.090	€ 2.324	€ 2.459	€ 2.607	€ 2.768	€ 2.943
15	€ 2.685	€ 2.996	€ 3.169	€ 3.355	€ 3.554	€ 3.766
30	€ 3.768	€ 4.197	€ 4.431	€ 4.678	€ 4.939	€ 5.214
60	€ 5.913	€ 6.551	€ 6.893	€ 7.250	€ 7.624	€ 8.014
120	€ 10.372	€ 11.401	€ 11.946	€ 12.511	€ 13.098	€ 13.706
240	€ 19.743	€ 21.519	€ 22.451	€ 23.414	€ 24.408	€ 25.432
480	€ 39.169	€ 42.393	€ 44.077	€ 45.809	€ 47.591	€ 49.422
960	€ 78.405	€ 84.493	€ 87.662	€ 90.915	€ 94.255	€ 97.682

2.4.3 Variable speed OIS+OIV

The questionnaire regarding list prices returned the following data-cloud for variable speed OIS+OIV compressors.

Note that the efficiencies presented here are NOT the result of the statistical analysis, but of the cost price survey.

Figure 2-4 Variable speed list price by efficiency (Source: VHK 2014)

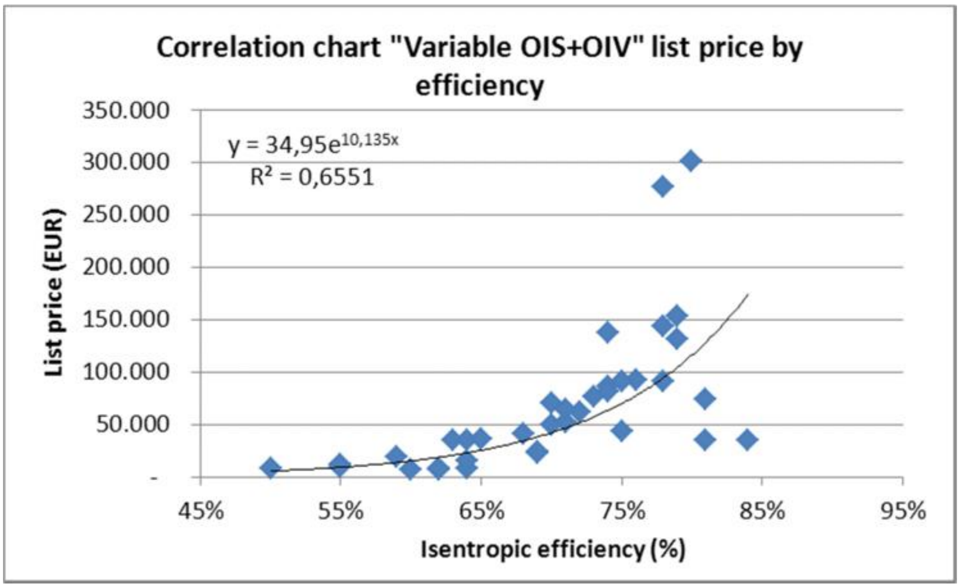
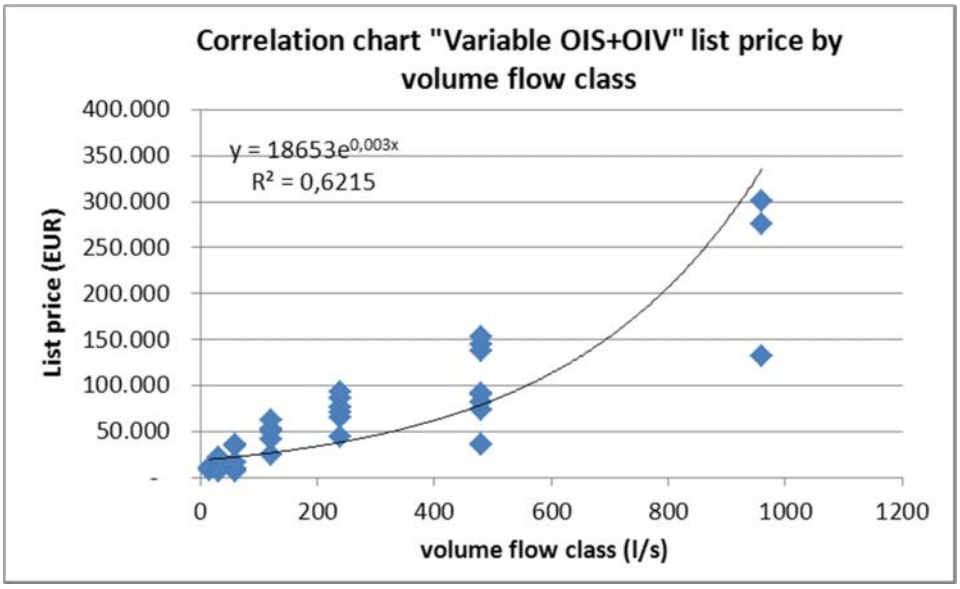
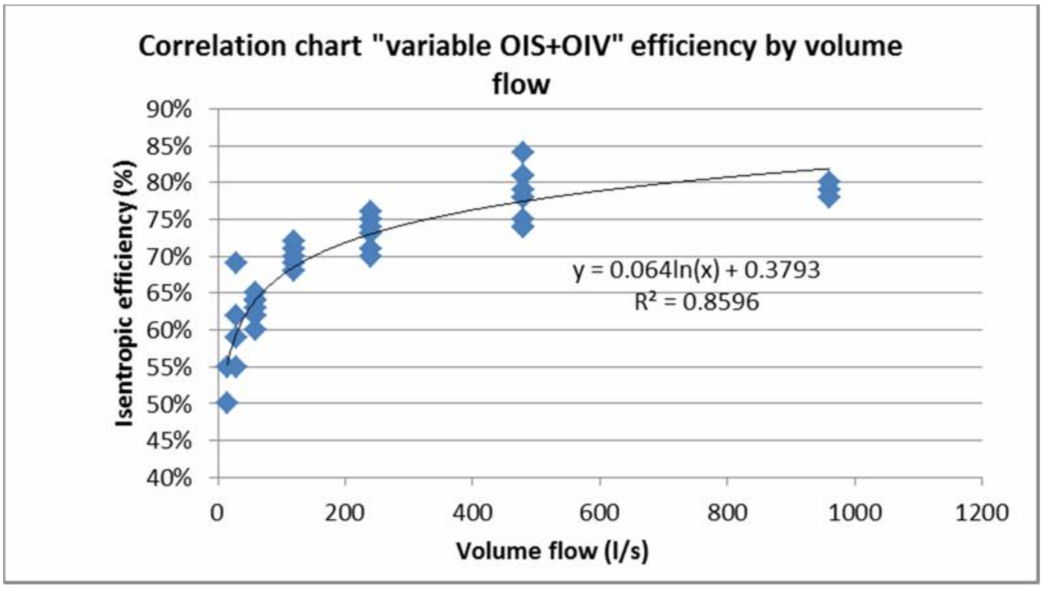


Figure 2-5 Variable speed list price by volume flow (Source: VHK 2014)



The above figure shows the presence of smaller volume flow models in the lower efficiency and the lower price segment, and vice versa for the higher volume flow models. This is consistent with the data for efficiency per volume flow class.

Figure 2-6 Variable speed efficiency by volume flow (Source: VHK 2014)



The above chart shows there is a correlation between volume flow and efficiency (as already shown in the analysis of the statistical approach data collection – note that the above graph is based on a different survey, related to costs).

On the basis of comparing the above information, and taking into account the parametric approach developed for fixed speed OIS+OIVVHK established the following relation, which follows the relation for fixed speed products, but applies a mark=up factor of 1.5 (average price difference fixed versus variable speed at list price level):

Variable speed list price (EUR) =((10*flow)+2500)+((290*flow) + 10000)*(eff^3) * 1.5

where:

flow = volume flow class in l/s

eff = isentropic efficiency in percentage points (e.g. 50, 60, etc.)

The above relation is intended to describe list prices of only the equipment of which the pressure at outlet is between 8-9 bar(g). Other equipment, providing higher pressures up to 14 bar(g), are expected to follow different list price curves, but the current calculation model can only be tuned towards the most often sold equipment, which is between 8-9 bar(g).

Table 2-3 List price variable speed (Source: VHK 2014)

d-value \ (l/s)	-10	0	5	10	15	20	price factor best/worst
7,5	€ 4.455	€ 4.871	€ 5.138	€ 5.448	€ 5.804	€ 6.210	1,39
15	€ 5.658	€ 6.350	€ 6.758	€ 7.210	€ 7.709	€ 8.256	1,46
30	€ 8.143	€ 9.221	€ 9.828	€ 10.481	€ 11.182	€ 11.934	1,47
60	€ 13.347	€ 15.057	€ 15.990	€ 16.977	€ 18.020	€ 19.120	1,43
120	€ 24.477	€ 27.321	€ 28.845	€ 30.437	€ 32.101	€ 33.838	1,38
240	€ 48.077	€ 53.057	€ 55.693	€ 58.428	€ 61.264	€ 64.203	1,34
480	€ 96.428	€ 105.553	€ 110.349	€ 115.305	€ 120.423	€ 125.706	1,30
960	€ 190.630	€ 208.058	€ 217.196	€ 226.623	€ 236.342	€ 246.359	1,29

The discount factor may vary per type of equipment and market, and is possibly unique for each compressor sold (even within the same manufacturer discount factors vary per region and model, etc.). The discount can vary between 20% to 40% to 60%. We will assume an average of 45% discount (price factor 0.55).

This average discount is assumed to take into account discounts applied to end customer through both direct sales and through retail channels such as dealers or distributors that apply a mark-up factor for the turnover to be realised by them.

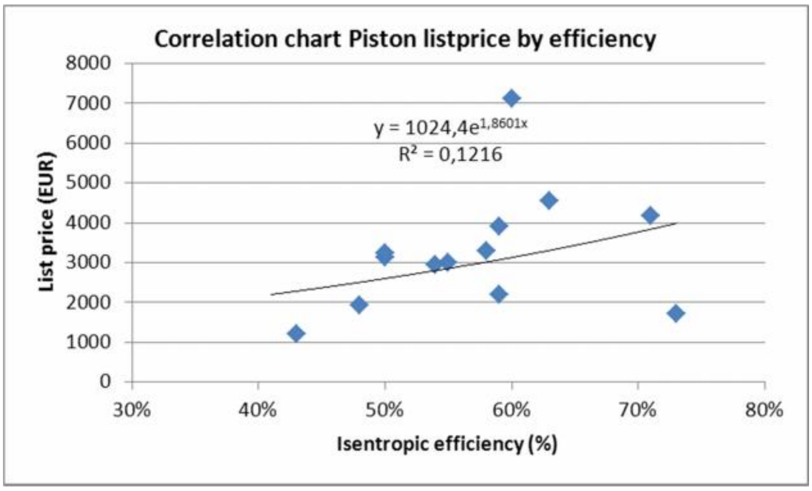
Table 2-4 Purchase price variable speed (incl. discount) (Source: VHK 2014)

d-value \ (l/s)	-10	0	5	10	15	20
7,5	€ 2.450	€ 2.679	€ 2.826	€ 2.996	€ 3.192	€ 3.415
15	€ 3.112	€ 3.493	€ 3.717	€ 3.966	€ 4.240	€ 4.541
30	€ 4.479	€ 5.072	€ 5.405	€ 5.764	€ 6.150	€ 6.564
60	€ 7.341	€ 8.281	€ 8.794	€ 9.337	€ 9.911	€ 10.516
120	€ 13.462	€ 15.027	€ 15.865	€ 16.741	€ 17.656	€ 18.611
240	€ 26.443	€ 29.182	€ 30.631	€ 32.135	€ 33.695	€ 35.312
480	€ 53.035	€ 58.054	€ 60.692	€ 63.418	€ 66.233	€ 69.138
960	€ 104.847	€ 114.432	€ 119.458	€ 124.643	€ 129.988	€ 135.498

2.4.4 Pistons

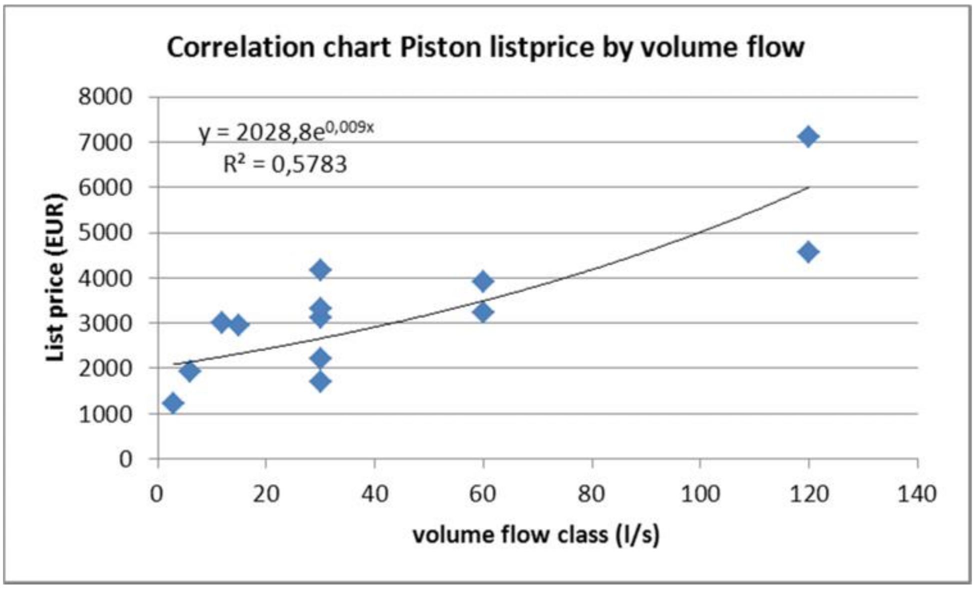
The questionnaire regarding list prices returned the following data-cloud for piston compressors. The data cloud shows only a weak correlation with energy efficiency. This is probably the result of the limited number of data entries received.

Figure 2-7 Piston list price by efficiency (Source: VHK 2014)



The below chart shows that there is a stronger relation of list price to volume flow class[10].

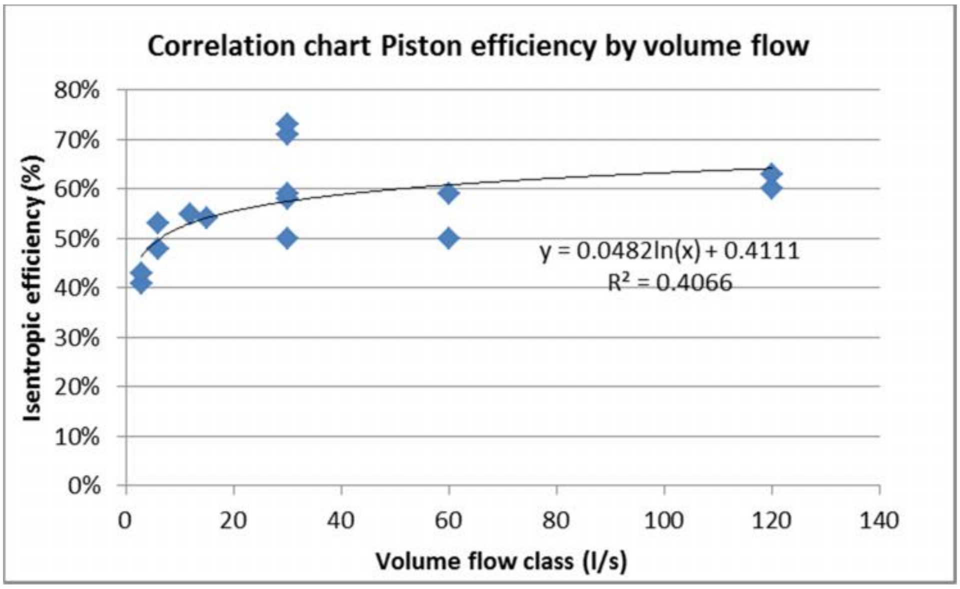
Figure 2-8 Piston list price by volume flow (Source: VHK 2014)



Efficiency and volume flow shows only a weak link.

[10] Although the statistical approach (regarding sales and efficiency) was limited up to 24 l/s class ((16-32 l/s segment), list prices were received for equipment up to 120 l/s.

Figure 2-9 Piston efficiency by volume flow (Source: VHK 2014)



Note that the above graph is based on data collected in the cost survey and does not match the data collected in the statistical approach.

On the basis of the above information VHK established the following relation:

Piston list price=(3500*LN(flow) + 38000)*(eff^3.4)

where:

flow = volume flow class in l/s

eff = isentropic efficiency in percentage points (e.g. 50, 60, etc.)

The above relation is intended to describe list prices of only the equipment of which the pressure at outlet is between 8-9 bar(g). Other equipment, providing higher pressures up to 14 bar(g), are expected to follow different list price curves, but the current calculation model can only be tuned towards the most often sold equipment, which is between 8-9 bar(g).

Table 2-5 List price pistons (Source: VHK 2014)

d-value \ (l/s)	-5	0	5	10	15	25	price factor best/worst
3	€ 1.609	€ 2.068	€ 2.612	€ 3.249	€ 3.990	€ 4.842	3,01
6	€ 2.899	€ 3.517	€ 4.224	€ 5.025	€ 5.928	€ 6.940	2,39
12	€ 4.844	€ 5.628	€ 6.498	€ 7.458	€ 8.515	€ 9.673	2,00
24	€ 7.642	€ 8.581	€ 9.600	€ 10.700	€ 11.887	€ 13.164	1,72

The discount factor may vary per type of equipment and market, and is possibly unique for each compressor sold (even within the same manufacturer discount factors vary per region and model, etc.). The discount can vary between 20% to 40% to 60%. We will assume an average of 45% discount (price factor 0.55).

This average discount is assumed to take into account discounts applied to end customer through both direct sales and through retail channels such as dealers or distributors that apply a mark-up factor for the turnover to be realised by them.

Table 2-6 Purchase price pistons (incl. discount) (Source: VHK 2014)

d-value \ (l/s)	-5	0	5	10	15	25
3	€ 885	€ 1.137	€ 1.436	€ 1.787	€ 2.194	€ 2.663
6	€ 1.594	€ 1.935	€ 2.323	€ 2.764	€ 3.260	€ 3.817
12	€ 2.664	€ 3.096	€ 3.574	€ 4.102	€ 4.683	€ 5.320
24	€ 4.203	€ 4.720	€ 5.280	€ 5.885	€ 6.538	€ 7.240

2.5 Energy costs

Energy prices

Electricity prices are based on the latest available Eurostat data, as the electricity prices presented in the MEErP report (see Task 2) are not provided in sufficient detail.

The analysis in Task 7 shows that the smallest compressor in the standard air application range consumes some 670 kWh (d=20 for smallest piston compressor) to 1.369.815 kWh (for largest variable speed OIS/OIV with d=-5). This is a ratio of around 1:2000, which is very much larger than the average product assessed using the MEErP.

Therefore the electricity prices are based on the prices identified for industrial consumers ranging from less than 20 000 kWh to maximum 2 000 000 kWh per annum.

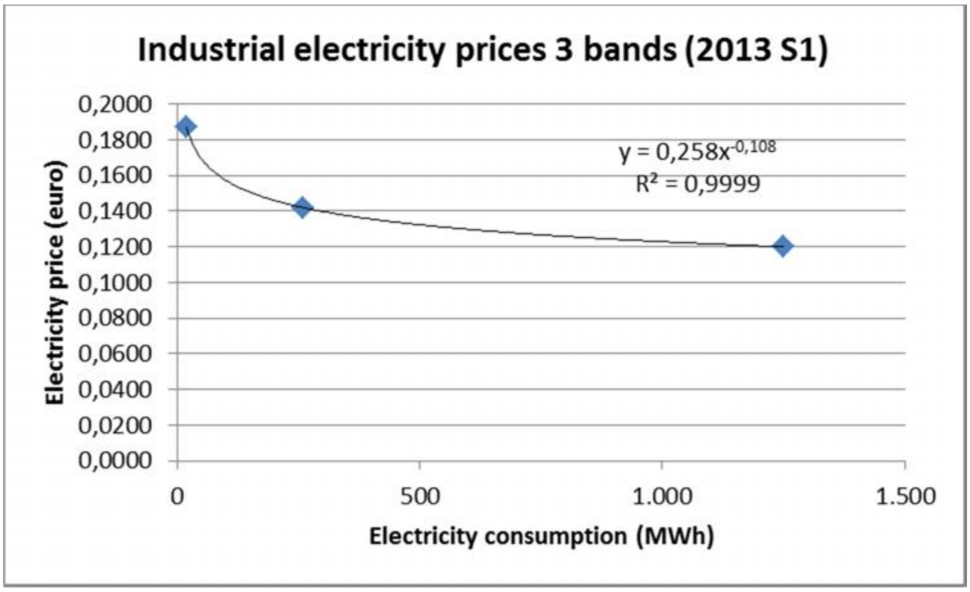
Table 2-7 Electricity prices for industrial consumers (Source: Eurostat 2014)

Electricity prices for industrial consumers, from 2007 onwards - bi-annual data [nrg_pc_205]										
Last update	20.12.13									
Extracted on	09.01.14									
Source of data	Eurostat									
CONSOM	2008S2	2009S1	2009S2	2010S1	2010S2	2011S1	2011S2	2012S1	2012S2	2013S1
Band IA : Consumption < 20 MWh	**0.1566**	**0.1588**	**0.1620**	**0.1635**	**0.1723**	**0.1692**	**0.1766**	**0.1747**	**0.1849**	**0.1871**
Band IB : 20 MWh < Consumption < 500 MWh	**0.1194**	**0.1225**	**0.1199**	**0.1221**	**0.1231**	**0.1298**	**0.1316**	**0.1346**	**0.1380**	**0.1416**
Band IC : 500 MWh < Consumption < 2 000 MWh	**0.1027**	**0.1067**	**0.1025**	**0.1039**	**0.1052**	**0.1102**	**0.1116**	**0.1153**	**0.1187**	**0.1200**
GEO	European Union (28 countries									
PRODUCT	Electrical energy									
UNIT	Kilowatt/hour									
TAX	Excluding VAT and other recoverable taxes and levies									
CURRENCY	Euro (from 1.1.1999)/ECU (up to 31.12.1998)									

Source: http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_pc_205&lang=en --> further aggregation by Eurostat/VHK

By plotting the average of the bands (MWh) together with the price a parametric relationship is established. This relation is used for the calculation of electricity costs.

Figure 2-10 Industrial electricity prices (Source Eurostat 2014)



Average electric input power

The average input power (sales weighted) is presented in the table below.

Table 2-8 Average input power (Source: VHK 2014, based on Pneurop data)

Average power (2011)	(kW)
fixed speed OIS+OIV	24.7
variable speed OIS+OIV	35.4
Pistons	4.3

Operating hours

For fixed speed machines the operating hours (or running hours) include both the hours that the compressor is running loaded and the hours that the compressor is idling or running unload.

There is no “rule of thumb” for the time slice in which a fixed speed machine is in “idle” or ”unloaded” operation. In a correctly sized compressor installation both the frequency of the unload cycles and the total idling time should be limited (see further below).

In the data collection scheme for variable speed compressors a 25/50/25% weighting of total electric input power at 100/70/40% volume flow was introduced to be consistent with the definition of “averaged weighted isentropic efficiency”, which itself is an attempt to define an average efficiency in a reasonable (meaningful) operating range of a VS compressor. Using the very rough approximation that input power reduces in proportion with flow the result of the formal calculation

25% x 100% P + 50%x70% P + 25%x40% P = 0.7 P (P: rated input power)

can be interpreted as a “load factor” of 0.7 in the JWG calculation scheme, but in the data collection scheme this factor is already included in the weighted average input power. Therefore the JWG used the virtual “load factor” of 1,0.

Energy costs

Energy costs are calculated by calculating the energy consumption and multiplication with energy prices.

Table 2-9 Fixed speed energy cost calculation

Flow	Power	Load factor	Operating hrs	Energy consumption for d=				
l/s	kW	[-]	hr/yr	kWh/yr				
				-10	0	5	10	15
7,5	5,1	0,85	900	4.290	3.884	3.709	3.548	3.401
15	8,2	0,85	1500	11.251	10.435	10.070	9.730	9.412
30	14,9	0,85	2000	26.864	25.333	24.631	23.966	23.337
60	25,9	0,85	2600	60.023	57.264	55.978	54.748	53.571
120	49,5	0,85	3200	139.855	134.534	132.022	129.603	127.271
240	91,0	0,85	3800	303.848	293.976	289.276	284.725	280.314
480	171,8	0,85	4300	646.562	627.922	618.999	610.326	601.893
960	318,8	0,85	4900	1.364.283	1.327.745	1.310.201	1.293.114	1.276.467

Table 2-10 Fixed speed energy costs (Source VHK 2014)

Flow	Energy costs				
l/s	-10	0	5	10	15	20
	EUR/yr					
7,5	€ 449	€ 449	€ 410	€ 394	€ 379	€ 365
15	€ 1.060	€ 1.060	€ 991	€ 960	€ 931	€ 904
30	€ 2.304	€ 2.304	€ 2.186	€ 2.132	€ 2.081	€ 2.032
60	€ 4.719	€ 4.719	€ 4.525	€ 4.435	€ 4.348	€ 4.264
120	€ 10.036	€ 10.036	€ 9.695	€ 9.533	€ 9.377	€ 9.226
240	€ 20.052	€ 20.052	€ 19.469	€ 19.192	€ 18.922	€ 18.660
480	€ 39.326	€ 39.326	€ 38.313	€ 37.827	€ 37.354	€ 36.894
960	€ 76.552	€ 76.552	€ 74.720	€ 73.839	€ 72.979	€ 72.141

Table 2-11 Variable speed energy cost calculation

Flow	Power	Load factor	Operatin g hrs	Energy consumption for d=					
l/s	kW	[-]	hr/yr	kWh/yr					
				-10	0	5	10	15	20
7,5	4,4	1,00	1100	5.726	4.795	4.435	4.125	3.855	3.619
15	6,9	1,00	1800	13.878	12.373	11.736	11.162	10.641	10.167
30	11,7	1,00	2400	30.561	28.195	27.144	26.168	25.260	24.414
60	20,2	1,00	3200	68.711	64.721	62.895	61.170	59.536	57.987

120	35,4	1,00	3900	144.589	137.996	134.920	131.978	129.161	126.463
240	65,7	1,00	4600	314.005	302.160	296.566	291.176	285.978	280.962
480	121,2	1,00	5200	652.056	630.379	620.071	610.096	600.436	591.077
960	221,1	1,00	6000	1.369.815	1.326.560	1.305.941	1.285.954	1.266.568	1.247.759

Table 2-12 Variable speed energy costs (Source VHK 2014)

Energy costs					
-10	0	5	10	15	20
EUR/yr					
€ 580	€ 580	€ 495	€ 462	€ 433	€ 408
€ 1.278	€ 1.278	€ 1.154	€ 1.101	€ 1.052	€ 1.009
€ 2.585	€ 2.585	€ 2.405	€ 2.325	€ 2.250	€ 2.181
€ 5.324	€ 5.324	€ 5.047	€ 4.920	€ 4.800	€ 4.685
€ 10.339	€ 10.339	€ 9.917	€ 9.720	€ 9.530	€ 9.349
€ 20.648	€ 20.648	€ 19.952	€ 19.622	€ 19.304	€ 18.996
€ 39.624	€ 39.624	€ 38.447	€ 37.886	€ 37.342	€ 36.814
€ 76.828	€ 76.828	€ 74.661	€ 73.625	€ 72.619	€ 71.641

Table 2-13 Piston energy cost calculation

Flow	Power	Load factor	Operating hrs	Energy consumption for d=					
l/s	kW	[-]	hr/yr	kWh/yr					
				-5	0	5	10	15	20
3	2,3	1,00	400	977	908	848	795	748	670
6	4,4	1,00	600	2.790	2.636	2.498	2.373	2.261	2.065
12	6,4	1,00	800	5.376	5.144	4.931	4.735	4.554	4.231
24	12,9	1,00	800	10.639	10.282	9.949	9.636	9.342	8.806

Table 2-14 Fixed speed energy costs (Source VHK 2014)

Energy costs					
-5	0	5	10	15	25
EUR/yr					
€ 120	€ 120	€ 112	€ 106	€ 100	€ 94
€ 306	€ 306	€ 290	€ 277	€ 265	€ 253
€ 549	€ 549	€ 527	€ 508	€ 490	€ 473
€ 1.008	€ 1.008	€ 978	€ 950	€ 923	€ 898

2.6 Additional costs

Other costs than purchase and energy, contributing to life cycle costs are installation costs (once per product life) and operational costs such as maintenance costs (over total product life) and air filter costs. Oil replenishment and oil filter costs are assumed to be covered under 'maintenance'.

End-of-life costs are assumed to be negligible or even positive given the value of scrap metal toe be recovered. In this analysis a zero end-of-life cost is assumed.

2.6.1 Installation costs

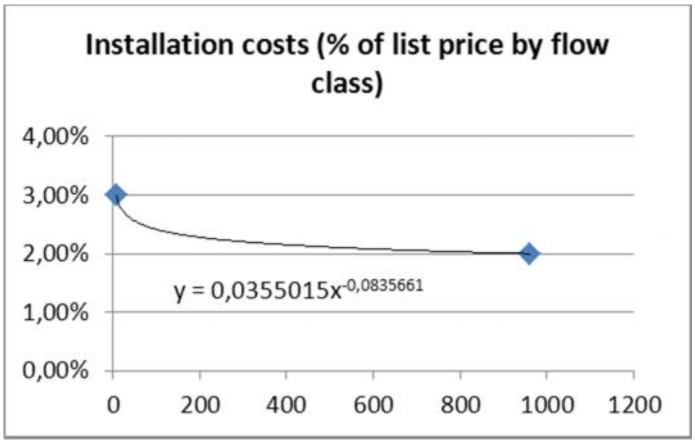
According manufacturers estimates the installation costs are between some 2-3% of the list prices, whereby the smaller value applies to larger products and the higher value to smaller products.

By plotting the limits, 3% of the list price for the small and 2% of the list price for the large flow class, together with the list price, a parametric relationship is established.

Fixed and variable OIS+OIV

For OIS+OIV (fixed and variable) this relation is shown in the figure below.

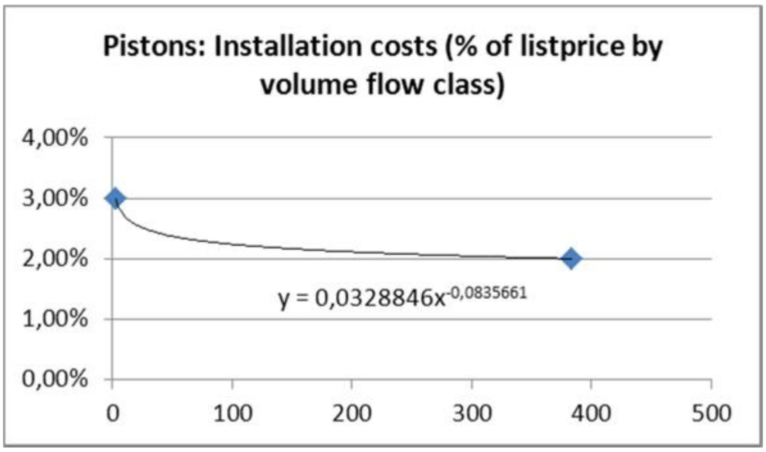
Figure 2-11 Fixed-variable speed installation costs (Source VHK 2014)



Pistons

For piston compressors the relation is slightly different as the range of flow classes considered is much smaller. The following relation is established for piston compressors.

Figure 2-12 Piston installation costs (Source VHK 2014)



Following the above described parametric relation, the installation costs for the compressors are:

Table 2-15 Installation costs (Source VHK 2014)

OIS/OIV fixed and variable speed				Piston compressors		
l/s	Percentage of list price	Installation costs		l/s	Percentage of list price	Installation costs
		Fixed	Variable			
7,5	3,0%	€ 127	€ 146	**3**	3%	€ 62
15	2,8%	€ 154	€ 180	**6**	3,1%	€ 108
30	2,7%	€ 204	€ 246	**12**	2,9%	€ 162
60	2,5%	€ 300	€ 380	**24**	2,7%	€ 234
120	2,4%	€ 493	€ 650			
240	2,2%	€ 879	€ 1.191			
480	2,1%	€ 1.634	€ 2.237			
960	2,0%	€ 3.072	€ 4.161			

2.6.2 Maintenance costs

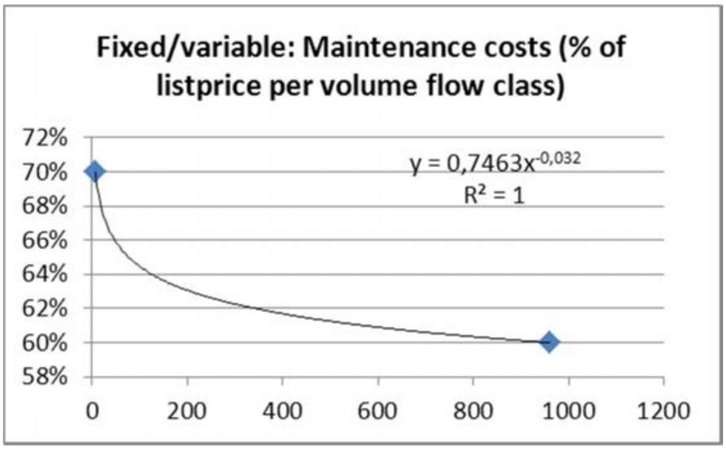
Similar to the installation costs a parametric relationship has been established in order to calculate the maintenance costs for the different flow classes.

Maintenance costs are costs for repair and maintenance and includes costs for oil replenishment and oil cartridge (oil filter) replacement. It also includes costs for spares.

Fixed and variable OIS+OIV

For the fixed speed and variable speed the same relationship is calculated.

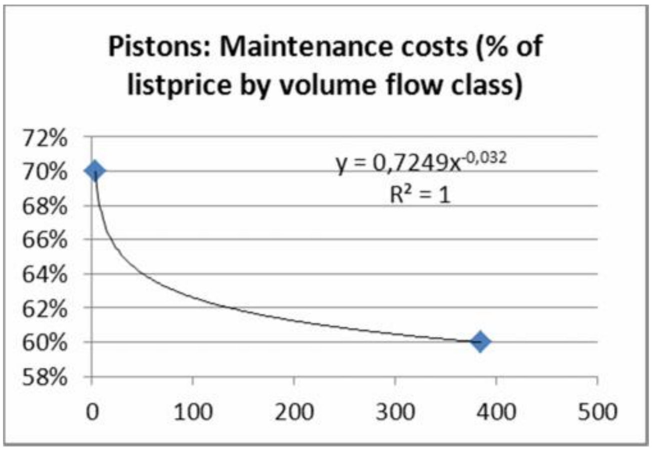
Figure 2-13 Fixed-variable speed maintenance costs (Source VHK 2014)



Pistons

For pistons the relation is again different as the range in flow classes considered is much smaller.

Figure 2-14 Piston maintenance costs (Source VHK 2014)



Following the above described parametric relation, the maintenance costs for the compressors are:

Table 2-16 Maintenance costs (Source VHK 2014)

OIS/OIV fixed and variable speed				Piston compressors		
l/s	Percentage of list price	fixed	variable	l/s	Percentage of list price	pistons
7,5	70%	€ 2.958	€ 3.410	**3**	70%	€ 1.447
15	68%	€ 3.727	€ 4.346	**6**	70%	€ 2.479
30	67%	€ 5.108	€ 6.172	**12**	69%	€ 3.879
60	65%	€ 7.797	€ 9.857	**24**	67%	€ 5.785
120	64%	€ 13.273	€ 17.494			
240	63%	€ 24.502	€ 33.227			
480	61%	€ 47.212	€ 64.652			
960	60%	€ 92.174	€ 124.835			

2.6.3 Air filter costs

Fixed and variable OIS+OIV

For **operational** costs related to **paper air filters** for fixed and variable speed OIS+OIV we will assume annual costs between 1 to 4 euro/yr per m^3/hr capacity unit, using 1 euro m^3/hr per year for the high volume categories to 4 euro for the smallest categories. The table shows our calculation for filter costs for the flow classes.

Table 2-17 Fixed/Variable speed air filter costs (Source VHK 2014)

Volume flow (l/s)	Filter costs (m^3/hr)	EUR/(m^3/hr/yr)	Filter: EUR/yr	Product life	Filter costs over life
7,5	27	4,00	108	10	€ 1.079
15	54	3,28	177	11	€ 1.947
30	108	2,69	290	12	€ 3.339
60	216	2,20	476	12	€ 5.715
120	432	1,81	781	13	€ 9.765
240	864	1,48	1281	13	€ 16.658
480	1728	1,22	2102	14	€ 29.428
960	3456	1,00	3448	15	€ 49.995

Pistons

Piston compressors have only one filter for the air intake, whose replacement cost is pretty low and, in terms of LCC, can be considered almost negligible. Filter costs over compressor life are estimated to be 10% of the compressors end customer price.

Table 2-18 Piston air filter costs (Source VHK 2014)

Volume flow (l/s)	Filter costs over life
3	€ 114
6	€ 193
12	€ 310
24	€ 472

2.7 Ranking of options by LCC

Although the tender terms of reference for this study call for a comparison (ranking on basis of LCC) of individual and accumulative improvement options separately, the preceding sections have made clear that in case of compressors for standard air applications, this is not preferred.

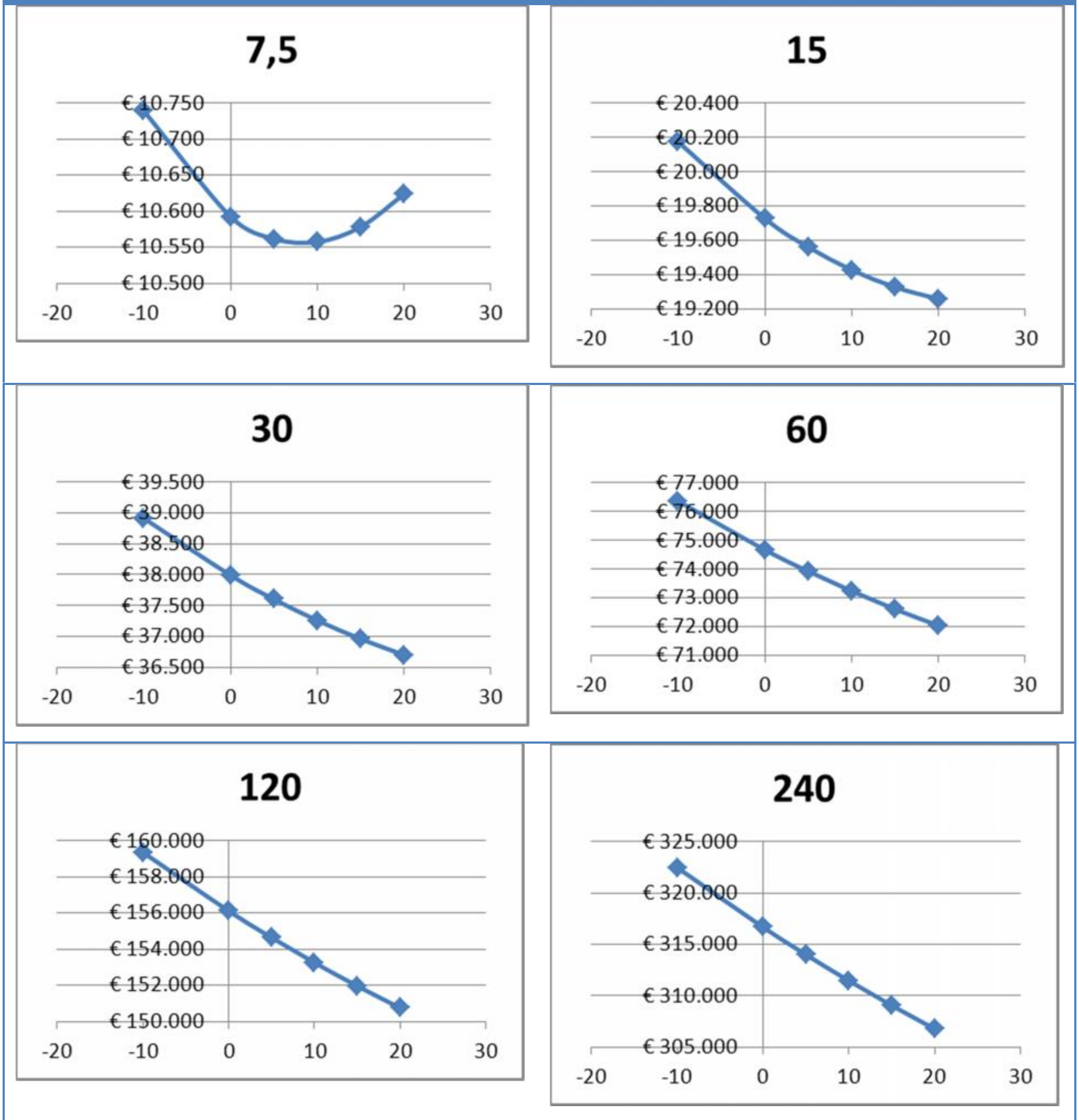
This sections therefore deals with accumulative “options” only, expressed as improvements in isentropic efficiency of the package.

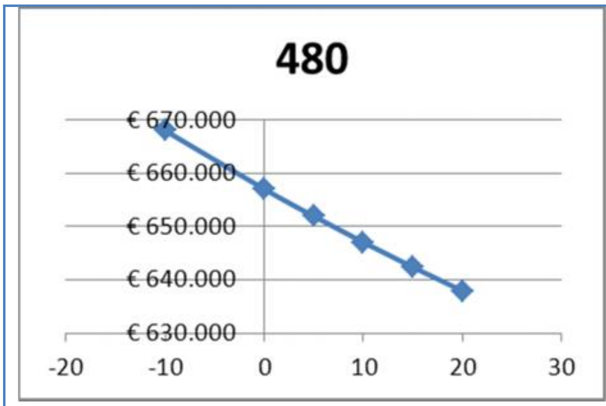
2.7.1 LCC of fixed speed OIS+OIV

The information above led to the following calculation of life cycle costs.

Table 2-19: LCC curves for Fixed speed OIS+OIV

LCC curves for Fixed speed OIS+OIV





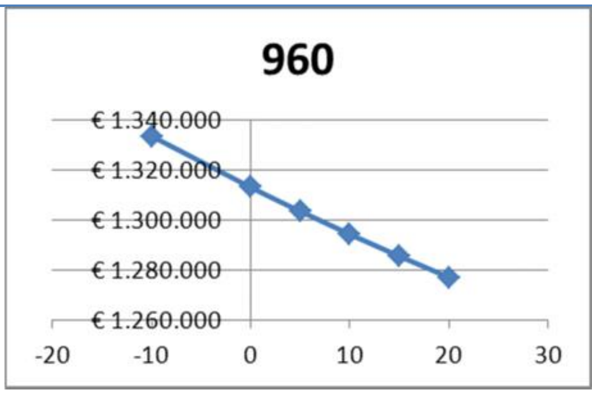


Table 2-20 Total LCC Fixed speed OIS+OIV

d-value (l/s)		base case (avg.)	impr. 1	impr. 2	impr. 3	best eff.
	-10	0	5	10	15	20
7,5	€ 10.739	€ 10.593	€ 10.562	€ 10.557	€ 10.578	€ 10.624
15	€ 20.172	€ 19.726	€ 19.559	€ 19.426	€ 19.326	€ 19.257
30	€ 38.912	€ 37.990	€ 37.601	€ 37.257	€ 36.957	€ 36.698
60	€ 76.357	€ 74.667	€ 73.920	€ 73.233	€ 72.605	€ 72.033
120	€ 159.354	€ 156.117	€ 154.642	€ 153.257	€ 151.960	€ 150.748
240	€ 322.454	€ 316.661	€ 313.981	€ 311.439	€ 309.031	€ 306.752
480	€ 668.011	€ 657.055	€ 651.934	€ 647.043	€ 642.374	€ 637.922
960	€ 1.333.645	€ 1.313.177	€ 1.303.567	€ 1.294.357	€ 1.285.537	€ 1.277.096

Table 2-21 Relative change in TOTAL life cycle costs (compared to d=0)

l/s	-10	0	5	10	15	20
7,5	101%	100%	100%	100%	100%	100%
15	102%	100%	99%	98%	98%	98%
30	102%	100%	99%	98%	97%	97%
60	102%	100%	99%	98%	97%	96%
120	102%	100%	99%	98%	97%	97%
240	102%	100%	99%	98%	98%	97%
480	102%	100%	99%	98%	98%	97%
960	102%	100%	99%	99%	98%	97%

Table 2-22 Life cycle costs split up by purchase/energy/other (% of total)

d-value l/s			base case (avg.)	impr. 1	impr. 2	impr. 3	best eff.
		-10	0	5	10	15	20
7,5	of which purchase	19%	22%	23%	25%	26%	28%
	of which energy	42%	39%	37%	36%	34%	33%
	of which installation & maintenance	39%	39%	39%	39%	39%	39%

15	of which purchase	13%	15%	16%	17%	18%	20%
	of which energy	58%	55%	54%	53%	51%	50%
	of which installation & maintenance	29%	30%	30%	30%	30%	30%
30	of which purchase	10%	11%	12%	13%	13%	14%
	of which energy	68%	66%	65%	64%	63%	62%
	of which installation & maintenance	22%	23%	23%	23%	23%	24%
60	of which purchase	8%	8,8%	9%	10%	11%	11%
	of which energy	74%	73%	72%	71%	70%	70%
	of which installation & maintenance	18%	18,5%	19%	19%	19%	19%
120	of which purchase	7%	7,3%	8%	8%	9%	9%
	of which energy	79%	78%	77%	76%	76%	75%
	of which installation & maintenance	15%	15,1%	15%	15%	15%	16%
240	of which purchase	6%	6,8%	7%	8%	8%	8%
	of which energy	81%	80%	79%	79%	78%	78%
	of which installation & maintenance	13%	13,3%	13%	13%	14%	14%
480	of which purchase	6%	6,5%	7%	7%	7%	8%
	of which energy	82%	82%	81%	81%	80%	80%
	of which installation & maintenance	12%	11,9%	12%	12%	12%	12%
960	of which purchase	6%	6,4%	7%	7%	7%	8%
	of which energy	83%	83%	82%	82%	81%	81%
	of which installation & maintenance	11%	11,1%	11%	11%	11%	11%

Table 2-23 Simple payback period (years)

d-value (l/s)		base case (avg.)	impr. 1	impr. 2	impr. 3	best eff.
	-10	0	5	10	15	20
7,5	6,2	ref.	8,1	8,9	9,7	10,5
15	4,5	ref.	5,6	6,0	6,4	6,8
30	3,7	ref.	4,3	4,6	4,8	5,1
60	3,3	ref.	3,8	3,9	4,1	4,3
120	3,0	ref.	3,4	3,5	3,6	3,8
240	3,1	ref.	3,4	3,5	3,6	3,7
480	3,2	ref.	3,5	3,6	3,7	3,8
960	3,3	ref.	3,6	3,7	3,8	3,9

Conclusion LCC Fixed speed compressors

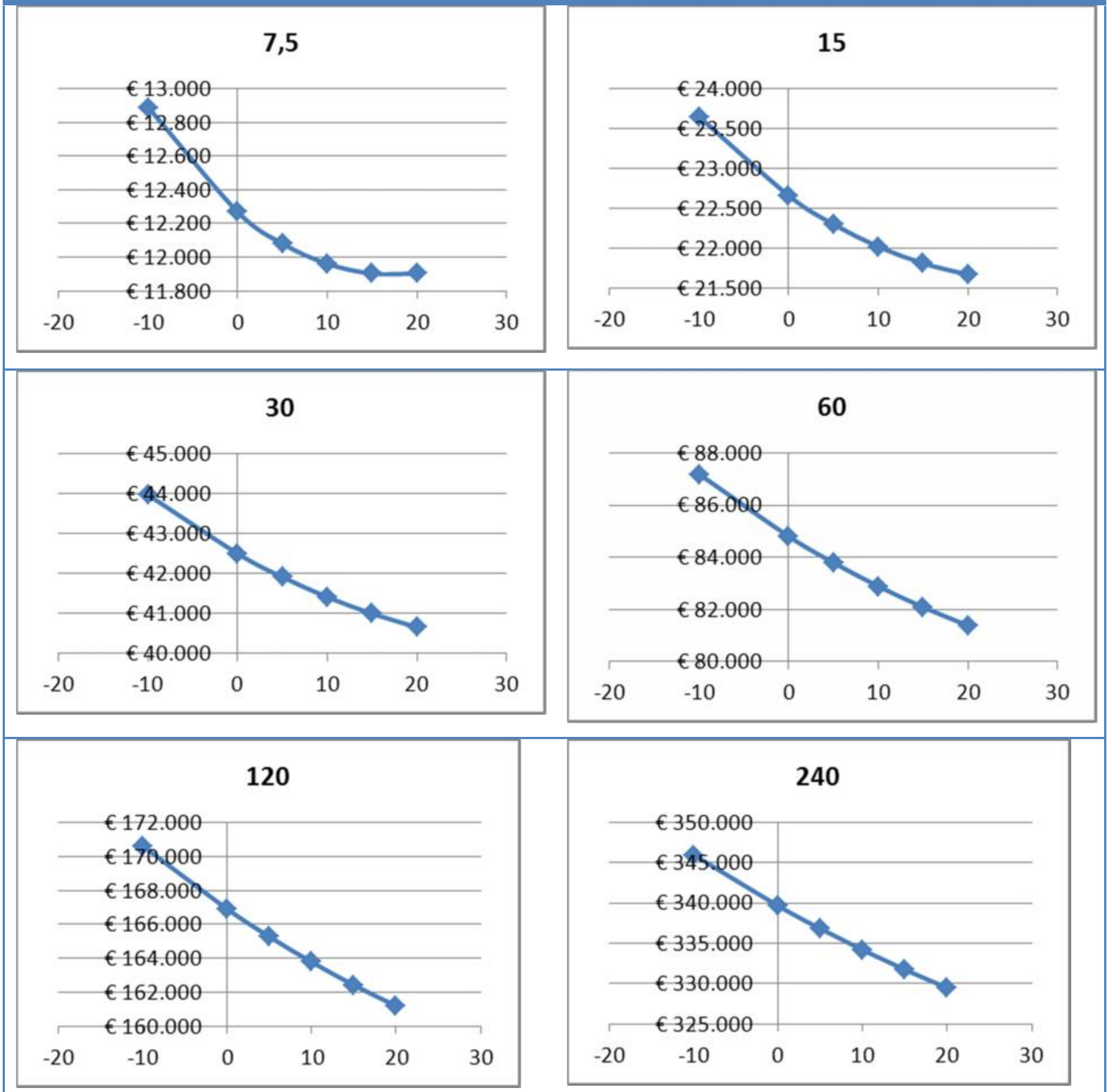
The least life cycle costs (LLCC) points is reached for fixed speed compressors at d-values larger than 10 for all volume flow classes. For the highest volume flow classes d-values beyond 10 still result in lower life cycle costs.

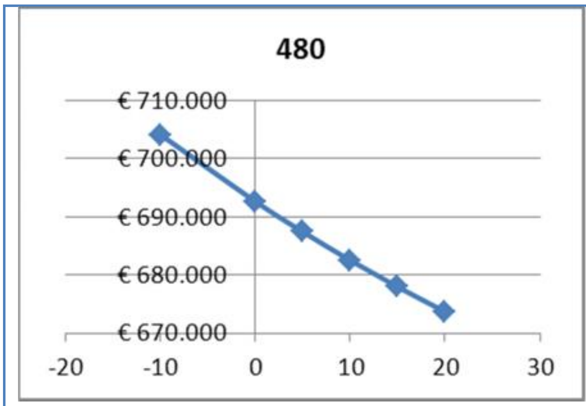
2.7.2 LCC of variable speed OIS+OIV

The information above led to the following calculation of life cycle costs.

Table 2-24: LCC curves for Variable speed OIS+OIV

LCC curves for Variable speed OIS+OIV





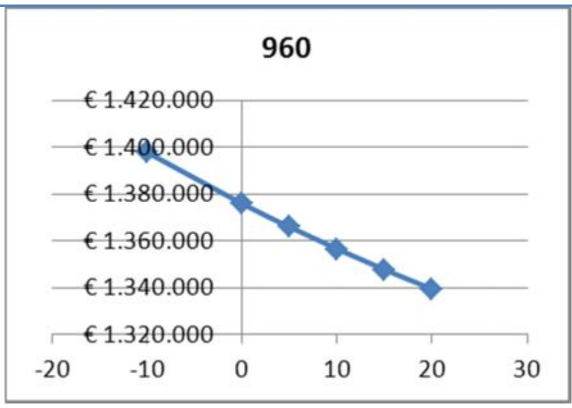


Table 2-25 Total LCC Variable speed OIS+OIV

		base case (avg.)	impr. 1	impr. 2	impr. 3	best eff.
d-value (l/s)	-10	0	5	10	15	20
7,5	€ 12.888	€ 12.267	€ 12.080	€ 11.962	€ 11.904	€ 11.904
15	€ 23.644	€ 22.656	€ 22.296	€ 22.015	€ 21.806	€ 21.665
30	€ 43.959	€ 42.490	€ 41.902	€ 41.402	€ 40.986	€ 40.648
60	€ 87.182	€ 84.803	€ 83.789	€ 82.885	€ 82.084	€ 81.383
120	€ 170.603	€ 166.898	€ 165.268	€ 163.778	€ 162.423	€ 161.197
240	€ 345.949	€ 339.637	€ 336.799	€ 334.164	€ 331.724	€ 329.473
480	€ 704.093	€ 692.631	€ 687.411	€ 682.519	€ 677.944	€ 673.678
960	€ 1.397.851	€ 1.376.004	€ 1.366.008	€ 1.356.606	€ 1.347.781	€ 1.339.518

Table 2-26 Relative change in TOTAL life cycle costs (compared to d=0)

l/s	-10	0	5	10	15	20
7,5	105%	100%	98%	98%	97%	97%
15	104%	100%	98%	97%	96%	96%
30	103%	100%	99%	97%	96%	96%
60	103%	100%	99%	98%	97%	96%
120	102%	100%	99%	98%	97%	97%
240	102%	100%	99%	98%	98%	97%
480	102%	100%	99%	99%	98%	97%
960	102%	100%	99%	99%	98%	97%

Table 2-27 Life cycle costs split up by purchase/energy/other (% of total)

d-value l/s		-10	0	5	10	15	20
			base case (avg.)	impr. 1	impr. 2	impr. 3	best eff.
7,5	of which purchase	19%	22%	23%	25%	27%	29%
	of which energy	45%	40%	38%	36%	34%	32%
	of which installation & maintenance	36%	38%	38%	39%	39%	39%
15	of which purchase	13%	15%	17%	18%	19%	21%
	of which energy	59%	56%	54%	53%	51%	49%
	of which installation & maintenance	27%	29%	29%	29%	30%	30%

30	of which purchase	10%	12%	13%	14%	15%	16%
	of which energy	68%	65%	64%	63%	61%	60%
	of which installation & maintenance	22%	23%	23%	24%	24%	24%
60	of which purchase	8%	9,8%	10%	11%	12%	13%
	of which energy	73%	71%	70%	69%	68%	67%
	of which installation & maintenance	18%	18,8%	19%	19%	19%	20%
120	of which purchase	8%	9,0%	10%	10%	11%	12%
	of which energy	76%	74%	74%	73%	72%	71%
	of which installation & maintenance	16%	16,7%	17%	17%	17%	17%
240	of which purchase	8%	8,6%	9%	10%	10%	11%
	of which energy	78%	76%	76%	75%	74%	74%
	of which installation & maintenance	15%	15,0%	15%	15%	15%	16%
480	of which purchase	8%	8,4%	9%	9%	10%	10%
	of which energy	79%	78%	77%	77%	76%	75%
	of which installation & maintenance	14%	13,9%	14%	14%	14%	14%
960	of which purchase	8%	8,3%	9%	9%	10%	10%
	of which energy	80%	79%	78%	78%	77%	77%
	of which installation & maintenance	13%	13,0%	13%	13%	13%	13%

Table 2-28 Simple payback period (years)

d-value (l/s)		base case (avg.)	impr. 1	impr. 2	impr. 3	best eff.
	-10	0	5	10	15	20
7,5	2,7	ref.	4,4	5,1	5,9	6,7
15	3,1	ref.	4,2	4,7	5,1	5,7
30	3,3	ref.	4,2	4,5	4,8	5,1
60	3,4	ref.	4,0	4,3	4,5	4,7
120	3,7	ref.	4,2	4,4	4,6	4,8
240	3,9	ref.	4,4	4,6	4,7	4,9
480	4,3	ref.	4,7	4,9	5,0	5,2
960	4,4	ref.	4,9	5,0	5,2	5,3

Conclusion LCC Variable speed compressors

The least life cycle costs (LLCC) points is reached for variable speed compressors at d-values larger than 15 for all volume flow classes. For the highest volume flow classes d-values beyond 15 still result in lower life cycle costs.

2.7.3 LCC of Pistons

The information above led to the following calculation of life cycle costs.

Table 2-29: LCC curves for Pistons

LCC curves for Pistons

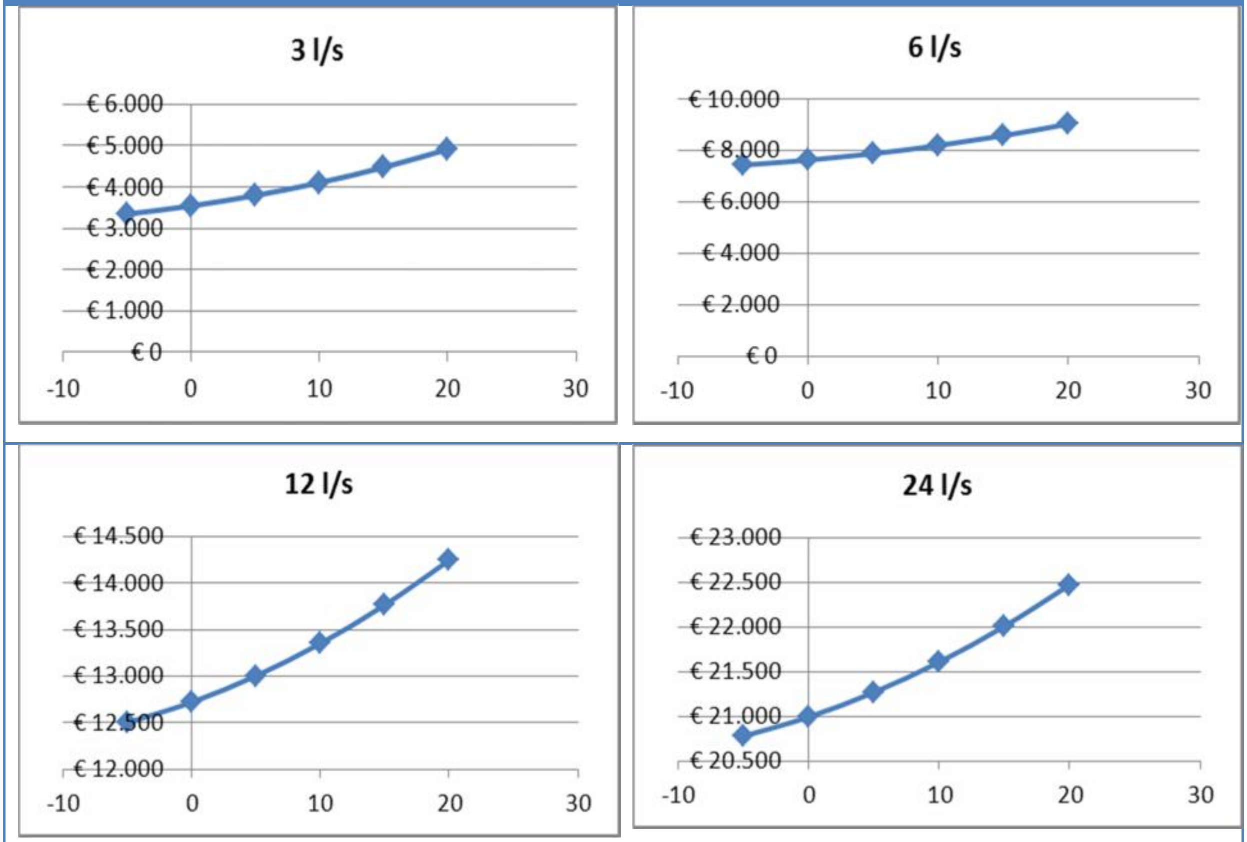


Table 2-30 Total LCC Piston compressors

		base case (avg.)	impr. 1	impr. 2	impr. 3	best eff.
d-value (l/s)	-5	0	5	10	15	20
3	€ 3.347	€ 3.546	€ 3.799	€ 4.108	€ 4.479	€ 4.915
6	€ 7.430	€ 7.619	€ 7.872	€ 8.189	€ 8.573	€ 9.027
12	€ 12.501	€ 12.720	€ 13.004	€ 13.351	€ 13.765	€ 14.246
24	€ 20.777	€ 20.992	€ 21.268	€ 21.607	€ 22.008	€ 22.473

Table 2-31 Relative change in TOTAL life cycle costs (compared to d=0)

d-value (l/s)		base case (avg.)	impr. 1	impr. 2	impr. 3	best eff.
	-5	0	5	10	15	25
3	94%	100%	107%	116%	126%	139%
6	98%	100%	103%	107%	113%	118%
12	98%	100%	102%	105%	108%	112%
24	99%	100%	101%	103%	105%	107%

Table 2-32 Life cycle costs split up by purchase/energy/other (% of total)

d-value \ l/s			base case (avg.)	impr. 1	impr. 2	impr. 3	best eff.
		-5	0	5	10	15	25
3	of which purchase	26%	32%	38%	44%	49%	54%
	of which energy	25%	22%	19%	17%	15%	13%
	of which installation & maintenance	48%	46%	43%	40%	36%	33%
6	of which purchase	21%	25%	30%	34%	38%	42%
	of which energy	41%	38%	35%	32%	30%	27%
	of which installation & maintenance	37%	36%	35%	34%	32%	31%
12	of which purchase	21%	24%	27%	31%	34%	37%
	of which energy	44%	41%	39%	37%	34%	32%
	of which installation & maintenance	35%	34%	33%	33%	32%	31%
24	of which purchase	20%	22%	25%	27%	30%	32%
	of which energy	49%	47%	45%	43%	41%	39%
	of which installation & maintenance	31%	31%	31%	30%	29%	29%

Table 2-33 Simple payback period (years)

d-value (l/s)		base case (avg.)	impr. 1	impr. 2	impr. 3	best eff.
	-5	0	5	10	15	25
3	33,0	ref.	44,8	51,8	59,5	67,9
6	22,5	ref.	28,5	32,0	35,7	39,7
12	20,4	ref.	24,5	26,8	29,2	31,8
24	17,1	ref.	19,8	21,2	22,7	24,3

Conclusion LCC Piston compressors

The least life cycle costs (LLCC) points is reached for piston compressors (up to max 32 l/s, which is the "24 l/s volume flow class) at d-values less than average (d=0) for all volume flow classes.

However, the calculation of LCC for pistons is also very susceptive to changes in the assumptions for the main parameters. Please look at section 3.8 of Task 8 (Sensitivity analysis) as well.

2.8 Sensitivity analysis

The analysis in this section investigates the sensitivity of the main outcomes for changes in the main calculation parameters. Selected as these main calculation parameters are the discount factor and the product life:

- The average discount factor applied in the general LCC calculations has been discussed with individual compressor specialists. From these discussions VHK learned that no agreement on a single value would be probably. In order to proceed with the calculations a single value was ultimately selected, but this section allows scrutiny of the results in case the value is higher. The sensitivity calculations are based on a discount of 1, as this presents the extreme and will result in street prices identical to list prices (higher prices). It will increase the sensitivity to cost price increases, thus increasing LCC and reducing the effect of energy saving options on LCC.
- The second parameter that is subject to sensitivity analysis is the product life which governs the period in which investments can be recuperated at maximum. For the analysis the product life will be set to 50% of the original value. The payback period will not change, but that payback period will more quickly surpass the technical product life.

The resulting calculations are shown below.

2.8.1 Sensitivity to discount factor

2.8.1.1 Fixed speed and discount factor

The table below presents the LCC findings for a discount factor of '1'.

Table 2-34 Sensitivity discount factor LCC fixed speed OIS/OIV

l/s	d-value: -10	0	5	10	15	20
7.5	€ 12,449	€ 12,494	€ 12,574	€ 12,690	€ 12,843	€ 13,032
15	€ 22,369	€ 22,177	€ 22,152	€ 22,171	€ 22,233	€ 22,338
30	€ 41,995	€ 41,424	€ 41,226	€ 41,085	€ 40,998	€ 40,963
60	€ 81,195	€ 80,027	€ 79,559	€ 79,165	€ 78,843	€ 78,590
120	€ 167,841	€ 165,445	€ 164,416	€ 163,494	€ 162,677	€ 161,962
240	€ 338,607	€ 334,268	€ 332,351	€ 330,596	€ 329,001	€ 327,560
480	€ 700,058	€ 691,740	€ 687,997	€ 684,523	€ 681,312	€ 678,358
960	€ 1,397,794	€ 1,382,308	€ 1,375,290	€ 1,368,742	€ 1,362,654	€ 1,357,018

The table below shows that the smaller compressors more easily reach higher than reference LCC values. Slightly larger compressors however still result in lower LCC.

Table 2-35 Sensitivity discount factor relative LCC fixed speed OIS/OIV

l/s	d-value: -10	0	5	10	15	20
7.5	100%	100%	101%	102%	103%	104%
15	101%	100%	100%	100%	100%	101%
30	101%	100%	100%	99%	99%	99%
60	101%	100%	99%	99%	99%	98%
120	101%	100%	99%	99%	98%	98%
240	101%	100%	99%	99%	98%	98%
480	101%	100%	99%	99%	98%	98%
960	101%	100%	99%	99%	99%	98%

The table below shows the purchase, energy and other costs as share of the overall life cycle costs.

Table 2-36 Sensitivity discount factor shares of total fixed speed OIS/OIV

l/s	LCC		base case (avg.)	impr. 1	impr. 2	impr. 3	best eff.
	d-value	-10	0	5	10	15	20
7.5	of which purchase	31%	34%	36%	37%	39%	41%
	of which energy	36%	33%	31%	30%	28%	27%
	of which installation & maintenance	33%	33%	33%	33%	32%	32%
15	of which purchase	22%	25%	26%	28%	29%	31%
	of which energy	52%	49%	48%	46%	45%	43%
	of which installation & maintenance	26%	26%	26%	26%	26%	26%
30	of which purchase	16%	18%	20%	21%	22%	23%
	of which energy	63%	61%	59%	58%	57%	56%
	of which installation & maintenance	21%	21%	21%	21%	21%	21%
60	of which purchase	13%	14.9%	16%	17%	18%	19%
	of which energy	70%	68%	67%	66%	65%	64%
	of which installation & maintenance	17%	17.3%	17%	17%	18%	18%
120	of which purchase	11%	12.5%	13%	14%	15%	15%
	of which energy	75%	73%	72%	72%	71%	70%
	of which installation & maintenance	14%	14.2%	14%	14%	14%	15%
240	of which purchase	11%	11.7%	12%	13%	13%	14%
	of which energy	77%	76%	75%	74%	74%	73%
	of which installation & maintenance	12%	12.6%	13%	13%	13%	13%
480	of which purchase	10%	11.1%	12%	12%	13%	13%
	of which energy	79%	78%	77%	76%	76%	75%
	of which installation & maintenance	11%	11.3%	11%	11%	11%	12%
960	of which purchase	10%	11.1%	12%	12%	13%	13%
	of which energy	79%	78%	78%	77%	77%	76%
	of which installation & maintenance	10%	10.5%	11%	11%	11%	11%

2.8.1.2 Variable speed and discount factor

The table below presents the LCC findings for a discount factor of '1'.

Table 2-37 Sensitivity discount factor LCC variable speed OIS/OIV

l/s	d-value: -10	0	5	10	15	20
7.5	€ 14,893	€ 14,459	€ 14,392	€ 14,413	€ 14,516	€ 14,698
15	€ 26,190	€ 25,514	€ 25,338	€ 25,260	€ 25,275	€ 25,381
30	€ 47,623	€ 46,640	€ 46,324	€ 46,118	€ 46,018	€ 46,019
60	€ 93,188	€ 91,578	€ 90,985	€ 90,524	€ 90,193	€ 89,987
120	€ 181,618	€ 179,193	€ 178,248	€ 177,475	€ 176,868	€ 176,424
240	€ 367,584	€ 363,513	€ 361,861	€ 360,456	€ 359,292	€ 358,364
480	€ 747,485	€ 740,130	€ 737,069	€ 734,406	€ 732,135	€ 730,246
960	€ 1,483,635	€ 1,469,631	€ 1,463,746	€ 1,458,586	€ 1,454,135	€ 1,450,380

The table below shows that the smallest compressors more easily reach higher than reference LCC values. Slightly larger compressors however still result in lower LCC.

Table 2-38 Sensitivity discount factor relative LCC variable speed OIS/OIV

l/s	d-value: -10	0	5	10	15	20
7.5	103%	100%	100%	100%	100%	102%
15	103%	100%	99%	99%	99%	99%
30	102%	100%	99%	99%	99%	99%
60	102%	100%	99%	99%	98%	98%
120	101%	100%	99%	99%	99%	98%
240	101%	100%	100%	99%	99%	99%
480	101%	100%	100%	99%	99%	99%
960	101%	100%	100%	99%	99%	99%

The table below shows the purchase, energy and other costs as share of the overall life cycle costs.

Table 2-39 Sensitivity discount factor shares of total variable speed OIS/OIV

l/s			base case (avg.)	impr. 1	impr. 2	impr. 3	best eff.
	d-value	-10	0	5	10	15	20
7.5	of which purchase	30%	34%	36%	38%	40%	42%
	of which energy	39%	34%	32%	30%	28%	26%
	of which installation & maintenance	31%	32%	32%	32%	32%	32%
15	of which purchase	22%	25%	27%	29%	30%	33%
	of which energy	54%	50%	48%	46%	44%	42%
	of which installation & maintenance	25%	25%	26%	26%	26%	26%
30	of which purchase	17%	20%	21%	23%	24%	26%
	of which energy	62%	59%	58%	56%	54%	53%
	of which installation & maintenance	20%	21%	21%	21%	21%	21%
60	of which purchase	14%	16.4%	18%	19%	20%	21%
	of which energy	69%	66%	65%	64%	62%	61%
	of which installation & maintenance	17%	17.4%	18%	18%	18%	18%
120	of which purchase	13%	15.2%	16%	17%	18%	19%
	of which energy	71%	69%	68%	67%	66%	65%
	of which installation & maintenance	15%	15.6%	16%	16%	16%	16%
240	of which purchase	13%	14.6%	15%	16%	17%	18%
	of which energy	73%	71%	70%	70%	69%	68%
	of which installation & maintenance	14%	14.1%	14%	14%	14%	14%
480	of which purchase	13%	14.3%	15%	16%	16%	17%
	of which energy	74%	73%	72%	71%	70%	70%
	of which installation & maintenance	13%	13.0%	13%	13%	13%	13%
960	of which purchase	13%	14.2%	15%	16%	16%	17%
	of which energy	75%	74%	73%	72%	71%	71%
	of which installation & maintenance	12%	12.2%	12%	12%	12%	12%

2.8.1.3 Pistons and discount factor

The table below presents the LCC findings for a discount factor of '1'.

Table 2-40 Sensitivity discount factor LCC OL piston

l/s	d-value: -5	0	5	10	15	20
3	€ 4,164	€ 4,570	€ 5,067	€ 5,663	€ 6,367	€ 7,187
6	€ 8,893	€ 9,360	€ 9,931	€ 10,608	€ 11,399	€ 12,308
12	€ 14,934	€ 15,506	€ 16,181	€ 16,961	€ 17,850	€ 18,852
24	€ 24,602	€ 25,239	€ 25,974	€ 26,808	€ 27,744	€ 28,783

The table below shows that the smaller compressors more easily reach higher than reference LCC values. Slightly larger compressors however still result in lower LCC.

Table 2-41 Sensitivity discount factor relative LCC OL piston

l/s	d-value: -5	0	5	10	15	20
3 l/s	91%	100%	111%	124%	139%	157%
6 l/s	95%	100%	106%	113%	122%	131%
12 l/s	96%	100%	104%	109%	115%	122%
24 l/s	97%	100%	103%	106%	110%	114%

The table below shows the purchase, energy and other costs as share of the overall life cycle costs.

Table 2-42 Sensitivity discount factor shares of total OL piston

l/s			base case (avg.)	impr. 1	impr. 2	impr. 3	best eff.
	d-value	-5	0	5	10	15	20
3	of which purchase	39%	45%	52%	57%	63%	67%
	of which energy	20%	17%	15%	12%	10%	9%
	of which installation & maintenance	41%	38%	34%	30%	27%	24%
6	of which purchase	33%	38%	43%	47%	52%	56%
	of which energy	34%	31%	28%	25%	22%	20%
	of which installation & maintenance	33%	31%	30%	28%	26%	24%
12	of which purchase	32%	36%	40%	44%	48%	51%
	of which energy	37%	34%	31%	29%	27%	24%
	of which installation & maintenance	31%	30%	28%	27%	26%	24%
24	of which purchase	31%	34%	37%	40%	43%	46%
	of which energy	41%	39%	37%	34%	32%	30%
	of which installation & maintenance	28%	27%	26%	26%	25%	24%

2.8.1.4 Conclusions of reduced discount factor

The above analysis shows that although there is some shift in optimum d-value, the changes are not drastic and the conclusions for the most important classes remain valid. As the discount factor equal to 1 (purchase price equals list price) is an extreme value, the overall conclusions as regards the effect of d-value on prices and the conclusions regarding target values remain unaffected.

2.8.2 Sensitivity to product life

This analysis assumes a reduction of product life to 50% of the original value.

Table 2-43 Adjusted product life for LCC sensitivity analysis

Product life			
Fixed/variable OIS/OIV		**Piston**	
Volume flow class (l/s)	Adjusted Product life(yr)	**Volume flow class (l/s)**	Adjusted Product life(yr)
7.5	5	**3**	3.5
15	5.5	**6**	5
30	5.75	**12**	5
60	6	**24**	5
120	6.25		
240	6.5		
480	7		
960	7.25		

2.8.2.1 Fixed speed and product life

The table below presents the LCC findings for a product life which is 50% that of the original value.

Table 2-44 Sensitivity product life LCC fixed speed OIS/OIV

l/s	d-value: -10	0	5	10	15	20
7.5	€ 8,496	€ 8,540	€ 8,592	€ 8,664	€ 8,755	€ 8,865
15	€ 14,343	€ 14,275	€ 14,278	€ 14,305	€ 14,354	€ 14,426
30	€ 25,665	€ 25,419	€ 25,341	€ 25,293	€ 25,273	€ 25,281
60	€ 48,041	€ 47,516	€ 47,313	€ 47,148	€ 47,021	€ 46,930
120	€ 96,629	€ 95,525	€ 95,059	€ 94,650	€ 94,295	€ 93,993
240	€ 192,118	€ 190,110	€ 189,236	€ 188,446	€ 187,739	€ 187,112
480	€ 392,726	€ 388,860	€ 387,142	€ 385,562	€ 384,119	€ 382,808
960	€ 778,646	€ 771,456	€ 768,235	€ 765,257	€ 762,517	€ 760,010

For the fixed speed compressors, where the lowest volume flow class already shows a saddle shape LCC curve, the change causes a more extreme saddle shape. As for classes 15 and 30 l/s the continuous decrease trend in LCC changes to a saddle curve with an optimum close to d=0/5/10.

Table 2-45 Sensitivity product life relative LCC fixed speed OIS/OIV

l/s	d-value: -10	0	5	10	15	20
7.5	99%	100%	101%	101%	103%	104%
15	100%	100%	100%	100%	101%	101%
30	101%	100%	100%	100%	99%	99%
60	101%	100%	100%	99%	99%	99%
120	101%	100%	100%	99%	99%	98%
240	101%	100%	100%	99%	99%	98%
480	101%	100%	100%	99%	99%	98%
960	101%	100%	100%	99%	99%	99%

The share of purchase price in the overall LCC increases but not drastically and moves from 28% to 8% (from smallest to largest flow class, for d=20) to 33% to 13%.

Table 2-46 Sensitivity product life shares of total fixed speed OIS/OIV

l/s	LCC		base case (avg.)	impr. 1	impr. 2	impr. 3	best eff.
		-10	0	5	10	15	20
7.5	of which purchase	25%	27%	29%	30%	32%	33%
	of which energy	26%	24%	23%	22%	21%	20%
	of which installation & maintenance	49%	49%	48%	48%	48%	47%
15	of which purchase	19%	21%	22%	23%	25%	26%
	of which energy	41%	38%	37%	36%	35%	33%
	of which installation & maintenance	41%	41%	41%	41%	41%	40%
30	of which purchase	15%	17%	17%	18%	20%	21%
	of which energy	52%	49%	48%	47%	46%	45%
	of which installation & maintenance	34%	34%	34%	34%	34%	34%
60	of which purchase	12%	13.8%	15%	15%	16%	17%
	of which energy	59%	57%	56%	55%	54%	53%
	of which installation & maintenance	29%	29.1%	29%	29%	29%	29%
120	of which purchase	11%	11.9%	13%	13%	14%	15%
	of which energy	65%	63%	63%	62%	61%	60%
	of which installation & maintenance	24%	24.6%	25%	25%	25%	25%
240	of which purchase	10%	11.3%	12%	12%	13%	14%
	of which energy	68%	67%	66%	65%	65%	64%
	of which installation & maintenance	22%	22.1%	22%	22%	22%	22%
480	of which purchase	10%	10.9%	11%	12%	12%	13%
	of which energy	70%	69%	68%	68%	67%	67%
	of which installation & maintenance	20%	20.1%	20%	20%	20%	20%
960	of which purchase	10%	11.0%	11%	12%	12%	13%
	of which energy	71%	70%	70%	69%	69%	68%
	of which installation & maintenance	19%	18.8%	19%	19%	19%	19%

2.8.2.2 *Variable speed and product life*

The table below presents the LCC findings for a product life which is 50% that of the original value.

Table 2-47 Sensitivity product life LCC variable speed OIS/OIV

l/s	d-value: -10	0	5	10	15	20
7.5	€ 9,986	€ 9,791	€ 9,771	€ 9,796	€ 9,866	€ 9,977
15	€ 16,614	€ 16,311	€ 16,243	€ 16,227	€ 16,259	€ 16,339
30	€ 29,097	€ 28,660	€ 28,532	€ 28,462	€ 28,447	€ 28,485
60	€ 55,237	€ 54,518	€ 54,268	€ 54,087	€ 53,973	€ 53,925
120	€ 105,987	€ 104,917	€ 104,521	€ 104,214	€ 103,994	€ 103,858
240	€ 211,734	€ 209,948	€ 209,254	€ 208,688	€ 208,248	€ 207,931
480	€ 426,722	€ 423,501	€ 422,210	€ 421,127	€ 420,247	€ 419,567
960	€ 840,845	€ 834,714	€ 832,229	€ 830,120	€ 828,380	€ 827,004

The sensitivity to product life is visible for the smallest volume flow classes. When the product life is reduced to 50% of its original value, the LCC curve for the volume flow class 7.5 and 15 l/s change from a steady decrease to a saddle curve. This is visible in the table below, where at d=20 the lowest volume flow classes exhibit higher LCC.

Table 2-48 Sensitivity product life relative LCC variable speed OIS/OIV

l/s	d-value: -10	0	5	10	15	20
7.5	102%	100%	100%	100%	101%	102%
15	102%	100%	100%	99%	100%	100%
30	102%	100%	100%	99%	99%	99%
60	101%	100%	100%	99%	99%	99%
120	101%	100%	100%	99%	99%	99%
240	101%	100%	100%	99%	99%	99%
480	101%	100%	100%	99%	99%	99%
960	101%	100%	100%	99%	99%	99%

The share of purchase price in the overall LCC increases but not drastically and moves from 29% to 10% (from smallest to largest flow class, for d=20) to 34% to 16%.

Table 2-49 Sensitivity product life shares of total variable speed OIS/OIV

l/s	LCC		base case (avg.)	impr. 1	impr. 2	impr. 3	best eff.
	d-value	-10	0	5	10	15	20
7.5	of which purchase	25%	27%	29%	31%	32%	34%
	of which energy	29%	25%	24%	22%	21%	19%
	of which installation & maintenance	46%	47%	47%	47%	47%	46%
15	of which purchase	19%	21%	23%	24%	26%	28%
	of which energy	42%	39%	37%	36%	34%	33%
	of which installation & maintenance	39%	40%	40%	40%	40%	40%
30	of which purchase	15%	18%	19%	20%	22%	23%
	of which energy	51%	48%	47%	45%	44%	43%
	of which installation & maintenance	34%	34%	34%	34%	34%	34%
60	of which purchase	13%	15.2%	16%	17%	18%	20%
	of which energy	58%	56%	54%	53%	52%	51%
	of which installation & maintenance	29%	29.3%	29%	29%	30%	30%
120	of which purchase	13%	14.3%	15%	16%	17%	18%
	of which energy	61%	59%	58%	57%	56%	55%
	of which installation & maintenance	26%	26.6%	27%	27%	27%	27%
240	of which purchase	12%	13.9%	15%	15%	16%	17%
	of which energy	63%	62%	61%	60%	59%	58%
	of which installation & maintenance	24%	24.3%	24%	24%	25%	25%
480	of which purchase	12%	13.7%	14%	15%	16%	16%
	of which energy	65%	64%	63%	62%	61%	61%
	of which installation & maintenance	23%	22.7%	23%	23%	23%	23%
960	of which purchase	12%	13.7%	14%	15%	16%	16%
	of which energy	66%	65%	64%	63%	63%	62%
	of which installation & maintenance	21%	21.4%	22%	22%	22%	22%

2.8.2.3 *Pistons and product life*

The table below presents the LCC findings for a product life which is 50% that of the original value.

Table 2-50 Sensitivity product life LCC OL piston

l/s	d-value: -5	0	5	10	15	20
3	€ 2,928	€ 3,153	€ 3,429	€ 3,759	€ 4,148	€ 4,601
6	€ 5,902	€ 6,167	€ 6,487	€ 6,866	€ 7,307	€ 7,812
12	€ 9,758	€ 10,084	€ 10,464	€ 10,902	€ 11,400	€ 11,959
24	€ 15,735	€ 16,101	€ 16,519	€ 16,991	€ 17,518	€ 18,102

With product life 50% of original values, the absolute values for LCC are reduced but the relative difference between efficiency levels remains. The shapes of the LCC curves remain the same.

Table 2-51 Sensitivity product life relative LCC OL piston

l/s	d-value: -5	0	5	10	15	20
3 l/s	93%	100%	109%	119%	132%	146%
6 l/s	96%	100%	105%	111%	118%	127%
12 l/s	97%	100%	104%	108%	113%	119%
24 l/s	98%	100%	103%	106%	109%	112%

The share of purchase price in the overall LCC increases but not drastically.

Table 2-52 Sensitivity product life shares of total OL piston

l/s			base case (avg.)	impr. 1	impr. 2	impr. 3	best eff.
	d-value	-5	0	5	10	15	20
3	of which purchase	30%	36%	42%	48%	53%	58%
	of which energy	14%	12%	11%	9%	8%	7%
	of which installation & maintenance	55%	51%	47%	43%	39%	35%
6	of which purchase	27%	31%	36%	40%	45%	49%
	of which energy	26%	24%	21%	19%	17%	16%
	of which installation & maintenance	47%	45%	43%	40%	38%	36%
12	of which purchase	27%	31%	34%	38%	41%	44%
	of which energy	28%	26%	24%	22%	21%	19%
	of which installation & maintenance	45%	43%	42%	40%	38%	36%
24	of which purchase	27%	29%	32%	35%	37%	40%
	of which energy	32%	30%	29%	27%	26%	24%
	of which installation & maintenance	41%	40%	39%	38%	37%	36%

2.8.2.4 *Conclusions of reduced product life*

The above analysis shows that although there is some shift in optimum d-value, the changes are not drastic and the conclusions for the most important classes remain valid. As the 50% product life is an extreme value, the overall conclusions as regards the effect of d-value on prices and the conclusions regarding target values remain unaffected.

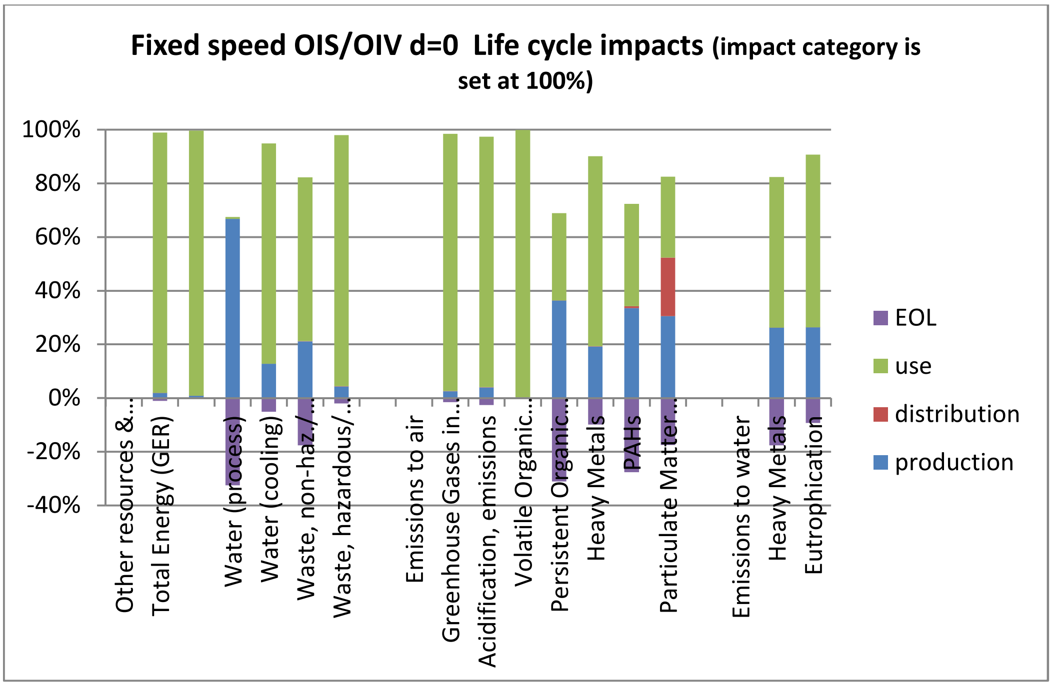
2.9 Environmental impact per improvement option (subtask 7.2)

The effects of the change in energy efficiency on the overall environmental life cycle impacts needs to be considered in order to signal other significant environmental effects of increasing energy efficiency.

The analysis of the improvement options however has not resulted in identification of improvement options that significantly alter the environmental profile as calculated by the MEErP Ecoreport.

In order to demonstrate this, the Ecoreport results for the average product and a product with maximum efficiency have been calculated and presented in the following paragraphs.

Figure 2-15 Fixed- speed ecoreport results (Source VHK 2014)



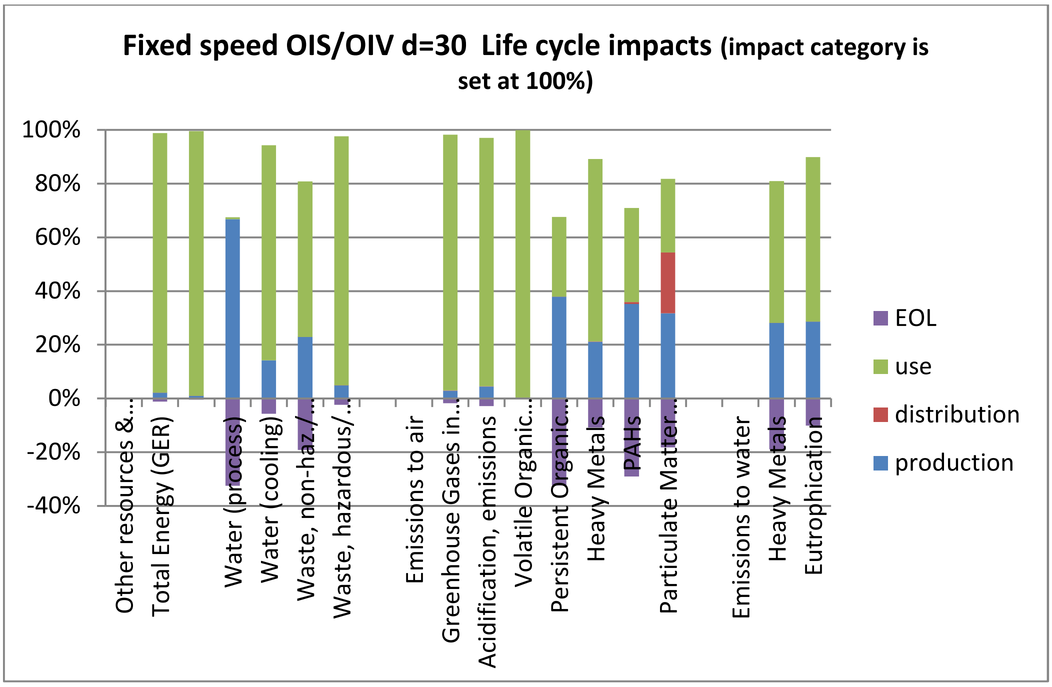
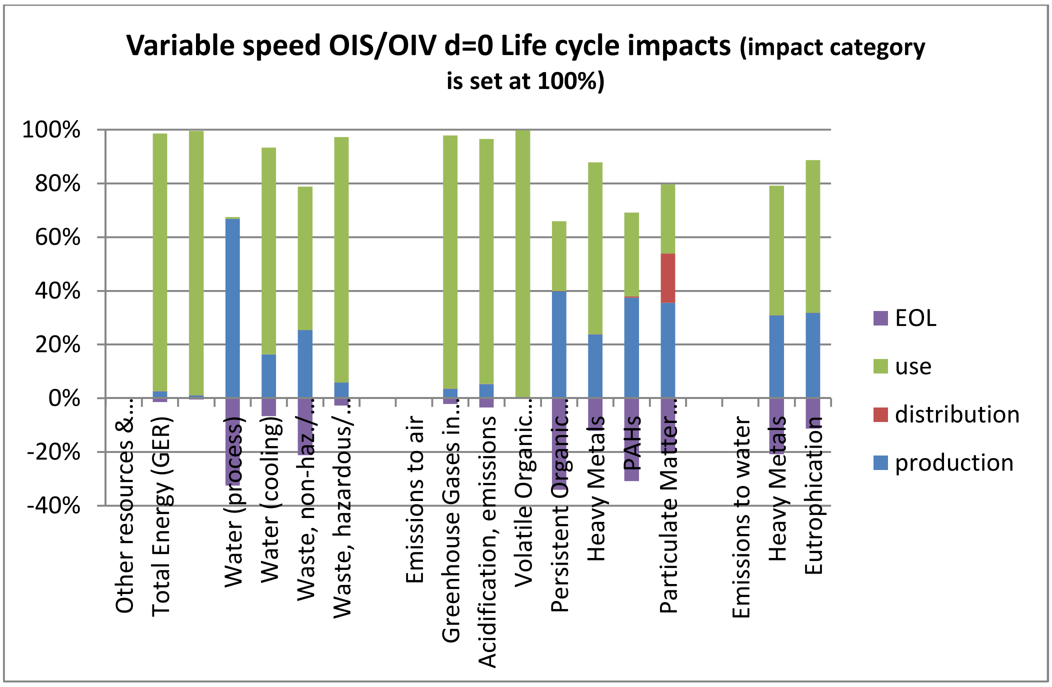


Figure 2-16 Variable- speed ecoreport results (Source VHK 2014)



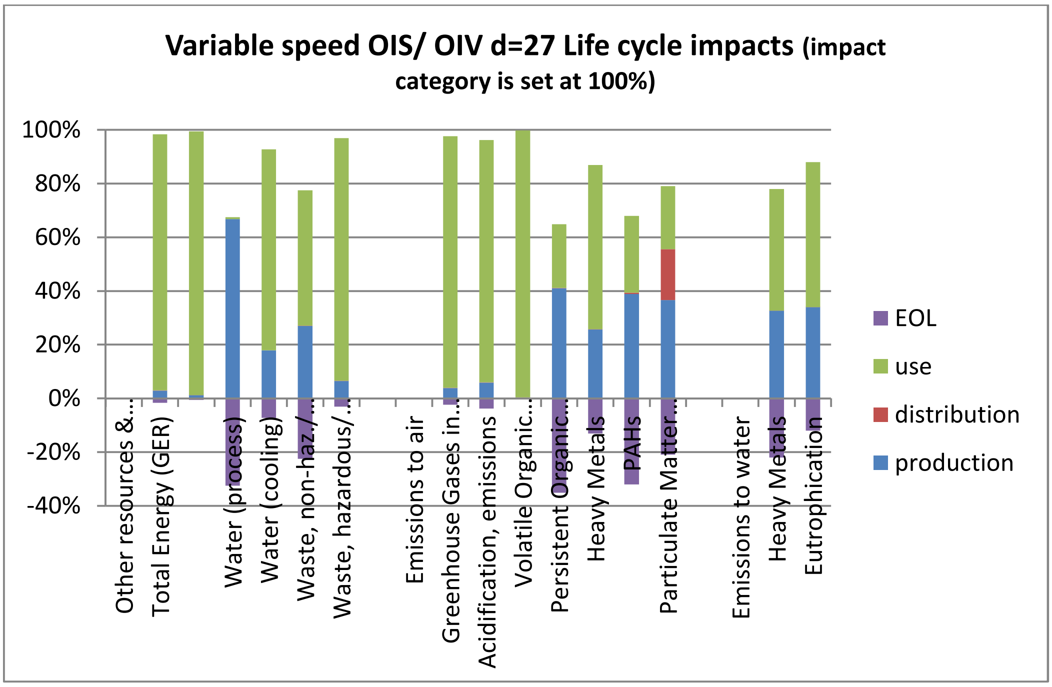
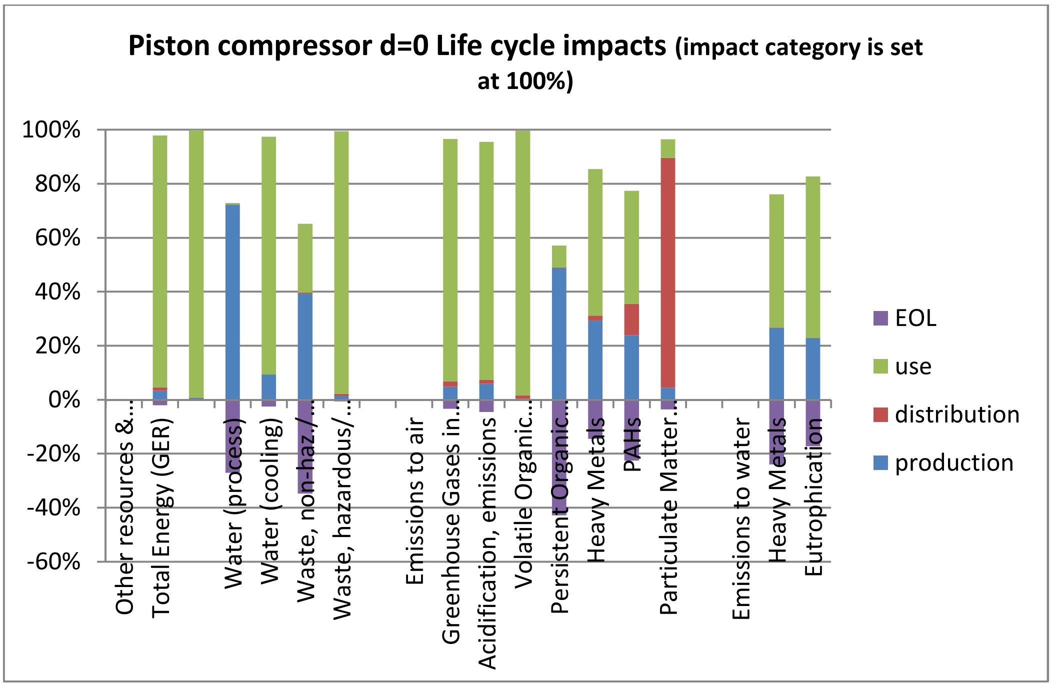
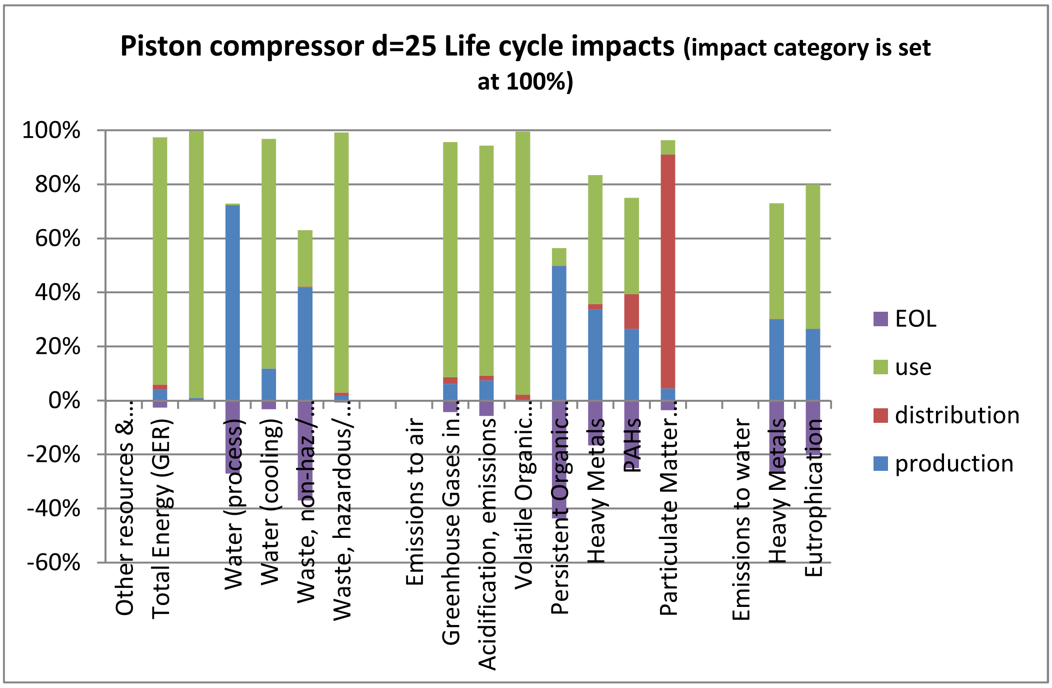


Figure 2-17 Piston ecoreport results (Source VHK 2014)





In addition to the above it could be that certain design options make use of electric motors with improved energy efficiency (such as by using permanent magnets). This could have an effect on the use of critical raw materials such as neodymium (used for magnets). The effect however could not be quantified.

2.10 Long-term targets and system analysis

This section is to discuss the long-term technical potential on the basis of outcomes of the research, in the context of the present product archetype;

Additionally a discussion of long-term potential on the basis of changes of the total system to which the present archetype product belongs is required: Societal transitions, product-services substitution, dematerialisation etc.

In certain studies the increase of (energy) efficiency has led to a change in consumer behaviour, which may introduce adverse effects. This is often referred to as a 'rebound' effect.

For industrial air applications this rebound effect is assumed to be negligible. The authors have not come across any reference to such effects in available literature on compressor usage.

2.10.1 Long term technical potential

The change in compressor efficiency is mainly evolutionary in nature, not revolutionary. The physical principles are largely known, as well as the boundaries, both technical and economical.

The long term potential is most likely similar to that of Best Available technology today.

2.10.2 Long term system potential

Discussion of system potential

In Task 3 it is mentioned that studies have shown that the energy losses due to leakage in the pressurised air system can be significant.

Therefore, this study would not be complete if it did not mention the option to reduce these 'leakage' losses and through this achieve energy savings that exceed the estimated savings on the compressor package alone. A section on indicative savings has been added to Task 8.

3 Task 8: Scenario-, policy-, impact- and sensitivity analysis

3.1 Introduction

This is the final report of Task 8 of the preparatory study on electric motor systems/compressors in the context of the Ecodesign Directive: **'ENER Lot 31 – Products in motor systems outside the scope of the Lot 30 and the Regulation 640/209 on electric motors, in particular compressors, including small compressors, and their possible drives'.**

This study is being carried out for the European Commission (DG ENER). The consultant responsible for the study is Van Holsteijn en Kemna B.V. (VHK).

3.1.1 Aim of Task 8

This task summarizes and totals the outcomes of all previous tasks. It looks at suitable policy means to achieve the potential e.g. implementing LLCC as a minimum and BAT as a promotional target, using legislative or voluntary agreements, labelling and promotion. It draws up scenarios 1990 - 2020 quantifying the improvements that can be achieved vs. a Business-as-Usual scenario and compares the outcomes with ED environmental targets, the societal costs if the environmental impact reduction would have to be achieved in another way, etc.

It makes an estimate of the impact on consumers (purchasing power, societal costs) and industry (employment, profitability, competitiveness, investment level, etc.) as described in Annex 2 of the Directive, explicitly describing and taking into account the typical design cycle (platform change) in a product sector as well as the cost of redesign necessary to apply the policy recommendations. Finally, in a sensitivity analysis of the main parameters it studies the robustness of the outcome.

In addition the contractor should provide an analysis of which significant impacts may have to be measured under possible implementing measures, and what measurement methods would need to be developed or adapted.

3.1.2 Subtasks Task 8

Subtask 8.1 - Policy- and scenario analysis

As part of their scenario analysis contractors should in addition provide a simple tool (e.g. in Excel), allowing estimates of the impacts on different scenarios and, to the extent possible, the estimation of Member State specific impacts.

On the basis of the results of the analysis and the relation of the product studied with product groups already regulated under the Ecodesign and/or Energy Labelling Directives, or with product groups currently studied, contractors should suggest, if relevant, with adequate analysis, amending existing regulations or integrating new product groups into existing Regulations or similar action (e.g. amending the scope of the Regulation 640/2009 with the inclusion of products from LOT 31) with the objective of keeping the ED legislation as clear as possible for operators.

Subtask 8.2 - Impact analysis - economic, social and environmental

Each policy option identified in Task 8 should be accompanied by an assessment of the associated economic, social and environmental impacts. The analysis should be both quantitative and qualitative. The policy options should be compared and weighted in what regards the positive and negative impacts of each identified policy option in terms of effectiveness, efficiency and consistency; the aggregated and disaggregated results should be displayed. The analysis should also include a consideration of risks and uncertainties in the policy options including obstacles to compliance or enforcement of compliance by market surveillance authorities.

Subtask 8.3 - Sensitivity analysis of the main parameters.

In this task the sensitivity of the identification of policy options for its main parameters will be assessed.

3.1.3 Task 8 report structure

The subtasks required for task 8 are covered in this report according the structure below.

Figure 3-1: (Sub)tasks for Report Task 6 & 7

Subtask required	Included in report Task 8
Subtask 8.1 - Policy- and scenario analysis	Section 3.2
Subtask 8.2 - Impact analysis	Section 3.3
Subtask 8.3 - Sensitivity analysis	Section 3.4

3.2 Policy- and scenario analysis

3.2.1 Policy analysis

In about every process leading up to regulations or measures, the Commission will decide on the appropriate policy option to take for the product group considered. These are – within the scope of improving energy efficiency of products – usually the following five options:

1) Business-as-usual;
2) Voluntary agreement;
3) Energy labelling;
4) Ecodesign;
5) A combination of the above.

Business-as-usual

Business-as-usual (BAU) means "do not change the regulatory framework". If no regulations are present, such as in the cuurent case, this options comes down to that the companies are driven by competition only to develop more efficient machines. BAU means savings by competition included.

For the product groups compressors for standard air applications, this would mean that no savings enforced by legislation would be achieved (policy option = baseline).

BAU is used as the baseline to compare all other scenarios with.

> ***Freeze***
>
> Not an policy option but calculated for the purpose of reference only is the so-called "Freeze" scenario: This scenario assumes that product energy efficiencies remain unchanged after 2011, assuming zero improvements. The sales volumes and replacement of machines evolves as in other scenarios.

Voluntary agreement

The Ecodesign directive 2009/125/EC states that the preferred options should be a voluntary agreement with relevant industries as this allows (in most cases) a faster delivery of savings, provided certain conditions are met. It is required that the relevant industries support such an approach.

In the case of compressors for standard air application the industries have discussed within the context of this study this option and came to the conclusion that the risk of free-rider behaviour was too large (manufacturers and importers that do not sign the agreement and continue to place products on the market that do not meet the agreed requirements, whereas the signatories of the agreement are voluntary bound by it).

Therefore this option was not considered feasible.

Energy labelling requirements

Energy labelling regulates, in the form of delegated regulations, the information to be provided on the product **at the point of sale**. It addresses responsibilities of suppliers and retailers.

It also specifies the content of this information, be it in the form of labels, and the scope of products to which the mandatory information requirement applies.

It is known from the previous tasks that especially larger equipment is bought by professionals who – in general - are very much knowledgeable about the product. For these products energy costs are usually over 75% of total life cycle costs. Additional information requirements in the form of a mandatory energy label, are not expected to change the existing situation as the information available is already considered by purchasers.

This may not be the case for smaller equipment, where more often the buyer is not a (compressed air) specialist. This mainly applies to sales of especially low volume flow piston compressors, which have low duty cycles and are purchased/sold together with a storage tank for compressed air. Such units do not require extensive knowledge of air compressors and compressed air systems. For this specific product group an approach involving energy labelling, providing simple and relatively easy-to-understand information on its relative performance, could be imagined to be of use.

However, in the grand scheme of things, the products that could benefit from energy labelling information do not represent much energy consumption (maximum 5.5% of overall 'standard air' energy consumption).

This is because of the reasons already stated in preceding chapters: the combination of a low average power and relatively smaller annual operating hours result in a small contribution to the overall energy consumption. The extra efficiency possibly to be gained by energy labelling is expected to be limited.

***

However, the mere introduction of a harmonised product performance metric has shown in other market segments, to carry the potential of a 'game changer'. Up to date only a few typically commercial or industrial products are (or have been) subject to mandatory energy labelling. A well-known example is the energy label for circulators in the EU. The introduction of harmonised performance metrics for energy efficiency did boost competition in this area and led to a general increase of awareness regarding energy efficiency of products.

This means that, even if the most directly affected market segment represents only a small percentage of the overall energy consumption, it is imaginable (or not to be excluded) that the introduction of a useful energy efficiency metric leads to a transformation in buying behaviour in other segments (larger products) as well.

Quantifying these effects bears a certain risk as the market for compressors is distinctly different to that of average consumer products, and conclusions from the consumer market should not be directly transferred to the professional market. To date the study team is not aware of studies that evaluate the effectiveness of labelling in professional markets. But it is known that energy labelling provides a marketing tool of much power.

The Energy Labelling Directive 2010/30/EC leaves open the possibility to introduce other label formats that the well-known A-G label with coloured arrows. The main difference to ecodesign information requirements is that Energy labelling imposes measures upon retailers (at point of sales), which the Ecodesign Directive 2009/125/EC cannot.

Ecodesign requirements

Under the Ecodesign Directive 2009/125/EC two types of measures can be implemented:

1) Generic requirements, relating to information related to product environmental performance.
2) Specific requirements related to minimum requirements of environmental performance parameters.

The environmental assessment in Task 4 & 5 has shown that the most relevant environmental impact is energy consumption during use, which is governed by the energy efficiency (of the packaged product). This parameter therefore has to be addressed through a specific requirement(s).

By regulating the energy efficiency of the products the ecodesign option guarantees energy savings as the least efficient products are removed from the market.

The proposed parameters to regulate for the compressors in the standard air application are:

1. energy efficiency (to be expressed as parameter "d" representing a proportional shift in regression curve) at full load (for fixed speed and pistons) or deduced from a load distribution profile (for variable speed): 25% for 100% VF, 50% for 70% VF and 25% for 40% VF.
2. possibly to add: idle power consumption as % of the full load consumption for fixed speed compressors or as technical requirement on star/delta configuration of electric motor in idle-mode operation.

Table 3-1 Overview of possible measures

Typical compressor technology (other types are possible, but rare)	Typical use profile	Typical Individual Control Strategy	Proposal for Efficiency Requirements - Thresholds	Proposal for Efficiency Requirements - labelling / product information requirement
Fixed speed Oil injected rotary screw and vane compressors	Steady state use	Load / Unload	- minimum requirement for full load efficiency (function of max. FAD) - idle power consumption	- cycle energy requirement“ in terms of „full load equivalent (in seconds) - information regarding "appropriate usage"
Variable speed Oil injected rotary screw and vane compressors	Fluctuating use	Variable flow control	- minimum requirement for average efficiency	- information regarding "appropriate usage"
Reciprocating oil-lubricated piston compressors	Sporadic or intermittent use	Start / Stop	- minimum requirement for full load efficiency	- information regarding intermittent duty, like, for example, S3 for electric motors

The impacts of several combinations of timing and stringency are assessed in section 3.3 (see section 3.7.1. for a discussion of idle mode requirements and cycle energy requirement).

Additional information requirements could complement the energy efficiency requirements and could help to harmonise the method for expressing compressor efficiency in the European market place. The appropriateness of introducing such generic requirements shall be discussed under the section 3.7 Recommendations.

Combined Ecodesign and Energy Labelling requirements

This option will be further discussed in Section 3.7 Recommendations.

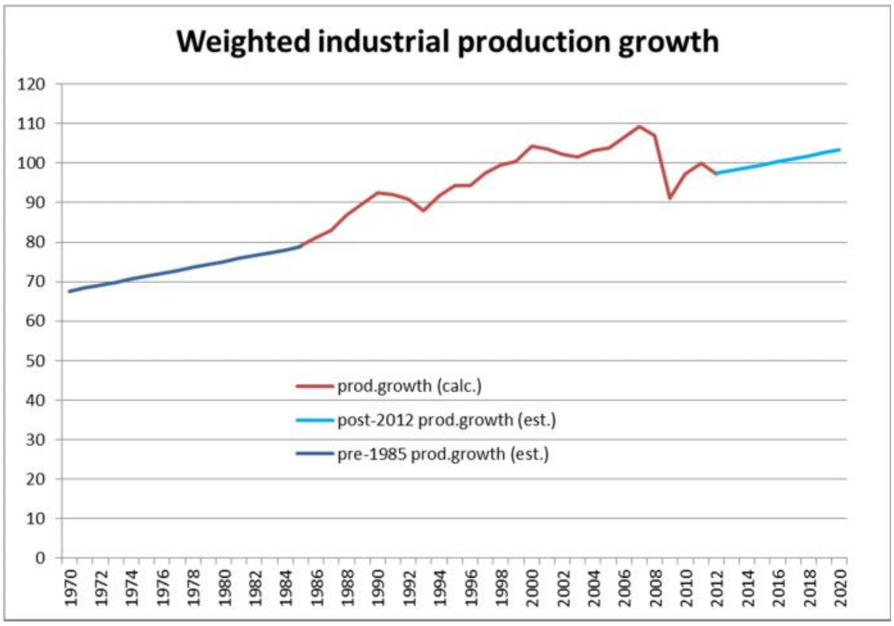
3.2.2 Scenario development

In order to assess the effects of possible ecodesign requirements a calculation model has been developed. This spreadsheet-based model allows the calculation of impacts (on resource use, such as primary energy consumption, overall EU expenditure and GHG emissions) depending on inputs on the level and timing of energy efficiency requirements.

3.2.2.1 Baseline / business-as-usual

All impacts and savings calculated will be referenced to a so-called baseline scenario (=BAU), which describes the historical and predicted resource consumption and impacts assuming no new legislation is introduced. The sales beyond 2011 are a forecast based on an economic growth being the average of preceding years in OECD countries[11].

Table 3-2 Sales growth 1970 – 2020 (extrapolation after 2020)



The sales, product life and resulting stock are in the tables below.

Table 3-3 Sales for all scenario's

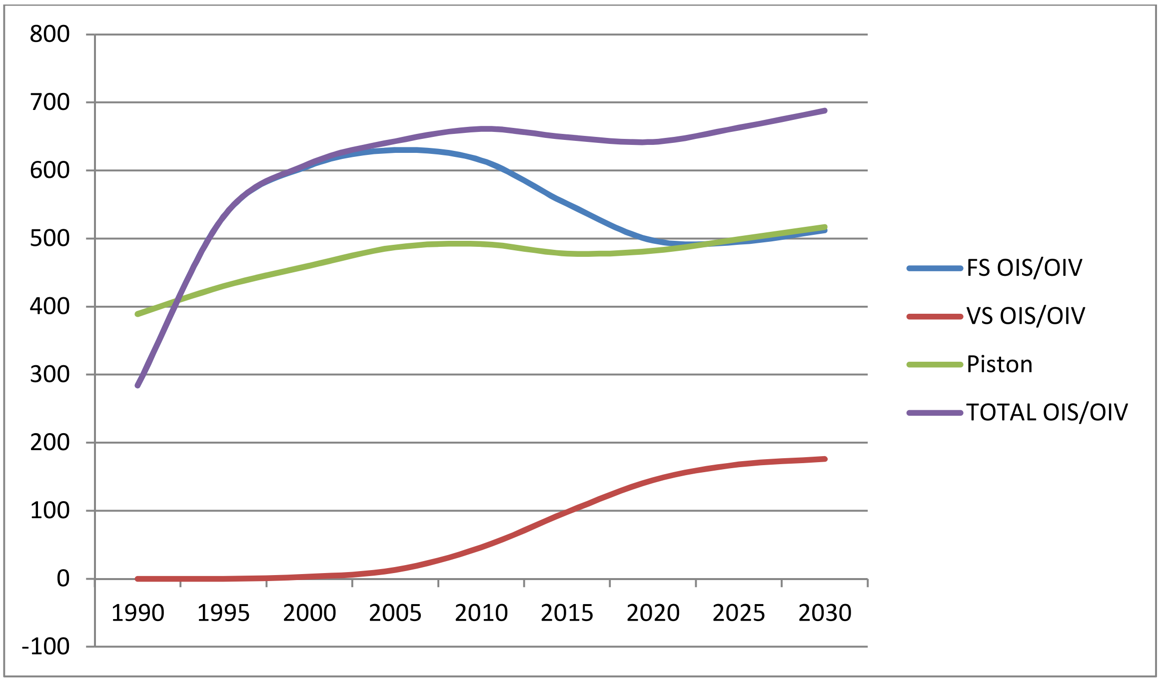
Sales ('000)									
	1990	1995	2000	2005	2010	2015	2020	2025	2030
fixed speed OIS+OIV	51,2	52,1	56,9	53,9	45,2	42,1	43,1	44,7	46,2
variable speed OIS+OIV	0,0	0,1	0,8	3,5	8,6	13,0	14,1	14,6	15,1
pistons	49,5	50,4	55,7	55,5	52,0	53,3	55,3	57,3	59,3

[11] Source: http://stats.oecd.org/OECDStat_Metadata/ShowMetadata.ashx?Dataset=KEI&ShowOnWeb=true&Lang=en

Table 3-4 Stock for all scenario's

Stock ('000)									
	1990	1995	2000	2005	2010	2015	2020	2025	2030
fixed speed OIS+OIV	284	532	607	630	615	551	497	495	512
variable speed OIS+OIV	0	0	3	13	46	98	145	168	176
pistons	389	430	460	487	492	478	482	499	517

Figure 3-2 Stock development of fixed speed, variable speed and pistons 1990-2030 ('000)



The product life is kept constant over the years, but does vary according the size of the equipment, whereby larger equipment has generally a longer product life.

Table 3-5 Product life of compressors

Product life (yrs)				
l/s	fixed speed OIS+OIV	variable speed OIS+OIV	**l/s**	Pistons
7.5	10	10	**3**	7
15	11	11	**6**	10
30	11,5	11,5	**12**	10
60	12	12	**24**	10
120	12,5	12,5		
240	13	13		
480	14	14		
960	14,5	14,5		

The average (sales weighted) efficiency of the products over the period 1990-2030 is expected to have developed / to develop as shown in the table below. These values more or less represent the expected increase of efficiency, driven by market demand and competition.

As a result of the sales weighting, it seems that the average efficiency of the variable speed compressor is decreasing after an initial increase. This is the result of increased sales of smaller equipment with relatively lower efficiencies. All equipment, when looking at flow class level, shows an increase in efficiency.

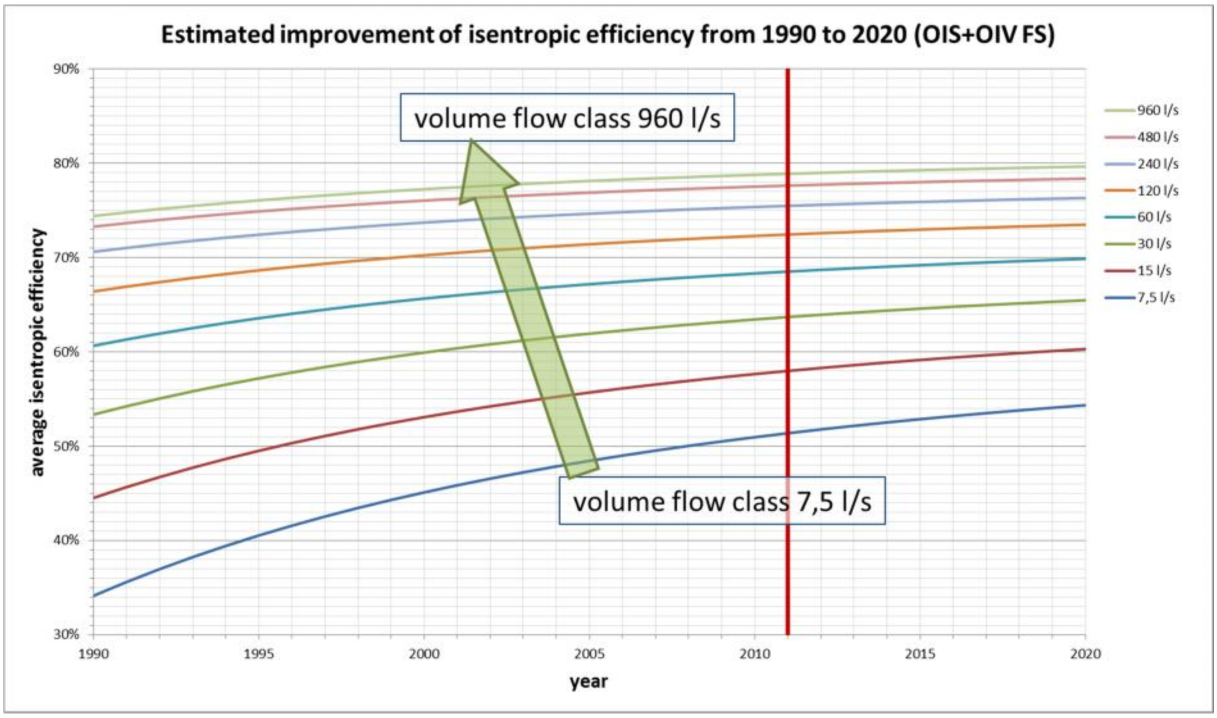
Table 3-6 Efficiency trend for baseline

Efficiency (isentropic) %									
	1990	1995	2000	2005	2010	2015	2020	2025	2030
fixed speed OIS+OIV	58,8%	60,8%	62,1%	62,8%	63,1%	63,5%	64,0%	64,4%	64,7%
variable speed OIS+OIV		60,8%	68,0%	67,5%	64,8%	64,1%	64,5%	65,0%	65,4%
pistons	43,8%	44,9%	45,8%	46,5%	47,0%	47,5%	47,8%	48,1%	48,3%

It should be emphasized that the improvement of energy efficiency correspond to the continuous efforts made by all manufacturers to put more competitive products on the market to ensure their growth and safeguard or increase their market share.

As stated before the change in average efficiencies is characterized by a learning curve consisting of tedious optimization of compressor screw elements and unit design features. This learning curve is presently levelling off to an asymptotic level, which means that improvement steps become smaller and take more and more time and effort to achieve.

Figure 3-3 Learning curve or estimated improvement from 1990 to 2020 (FS OIS+OIV)



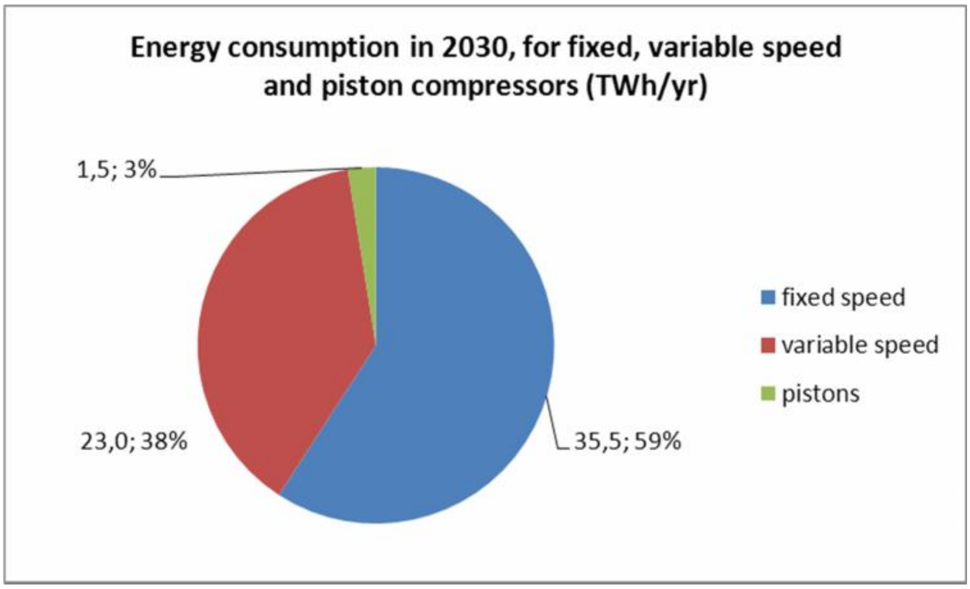
The baseline energy consumption is calculated on the basis of the average (sales weighted) input power is established for the year 2011, corrected for the previous and subsequent years by correcting for the relative change in efficiency. This results in higher and lower specific energy consumption per compressor model, depending on the change in efficiency.

The average power, operating hours and the load factor are given section 3.4. The baseline results in the following annual energy consumption of compressors.

Table 3-7 Baseline (BAU) Energy consumption (TWh/yr)

Energy consumption (TWh/yr)									
	1990	1995	2000	2005	2010	2015	2020	2025	2030
fixed speed OIS+OIV	23,6	44,0	53,3	52,7	48,4	40,8	35,4	34,6	35,5
variable speed OIS+OIV	0,0	0,1	0,6	3,3	8,9	15,7	20,2	22,2	23,0
pistons	1,28	1,38	1,44	1,50	1,50	1,44	1,43	1,47	1,51

Figure 3-4 Overall energy consumption for the three compressor categories



3.2.2.2 *Ecodesign scenario's*

The ecodesign scenarios differ from the baseline scenario with regard to the efficiency of models placed on the market. The change in efficiency is reflected in a change of the average input power used to calculate energy consumption. Annual sales volume, product life (and thus stock), running hours, load factors remain the same.

Replacement model

The average efficiency of models placed on the market is not identical to the target value for the efficiency imposed on these products, as only the least efficient are removed from the market. The remaining models already have efficiencies higher than required. The average efficiency will therefore be higher than the target efficiency.

The removal of the least efficiency appliances will result in a shift of sales in appliances still allowed on the market. It is however not known beforehand at which efficiency level the sales will take place. In order to account for some probability regarding this effect, two calculation models have been developed: a "limit" replacement model and an "average" replacement model.

- The "Limit" replacement model assumes that sales of models phased out will shift towards products that are just beyond the required minimum efficiency. The jump in average efficiency is therefore smallest for this replacement model.
- The "Average" replacement model assumes that the sales of models phased out will shift toward the level of the average efficiency of the remaining models. The jump in average efficiency is therefore highest for this replacement model.

As these models result in a slightly different average efficiency of products in the market, and also a different impact on the number of model affected by the measure, the model calculates two possible outcomes: a limit replacement outcome and an average replacement outcome.

Scenario's

As regards the setting of ecodesign requirements, more particularly energy efficiency targets from the Ecodesign Directive 2009/125/EC, Annex III states that targets should be at (or close to) the least life cycle point.

As the least life cycle point is reached at various levels of efficiency, depending on compressor type and volume flow class, there is no single target value that applies to all.

Therefore this assessment will introduce several scenarios, each with different target levels, to assess the possible savings and impacts of these targets.

As regards timing of measures: The study will be finalized before the summer of 2014. Assuming the Commission will continue with preparing Working Documents shortly after finalization, the final stages could be reached before the end of the year (unforeseen events could delay this). Assuming a smooth and easy policy process, the measure could be adopted in 2015.

The industries confronted with the measure will need time to prepare for the necessary arrangements and therefore the first tier is to be introduced not sooner than two years after entry into force. A second tier could enter into force some 4 years after entry into force, assuming this corresponds to an average design cycle of compressors.

A third tier, for long term target setting, is not modelled as this would unavoidably be at BAT level. Requiring BAT level of efficiency in an application range as wide and diverse as standard air applications is not recommended. Instead it is preferred to first gain experience and see whether tiers can be tightened during future revisions.

Note: the approach for defining a 'd-value' is described in section 2.2.1. The effects of very high d-values, close to or at BAT level, are described in scenario VI.

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Minimum energy efficiency requirements

The scenario's I-VI apply target values that can be expressed as for example "d-value = -5" or "= 0" or " or +10". The figures below show these "regulation curves" in the data point clouds for fixed speed OIS+OIV, variable speed OIS+OIV and piston compressors. The 'dots' below the respective lines are models, available in year 2011, that do not meet the requirements. The graphs do not show all the "d-values" used in the scenario's (this is not needed for comprehension of approach).

Figure 3-5 Fixed speed d=-5, d=0, d=+10

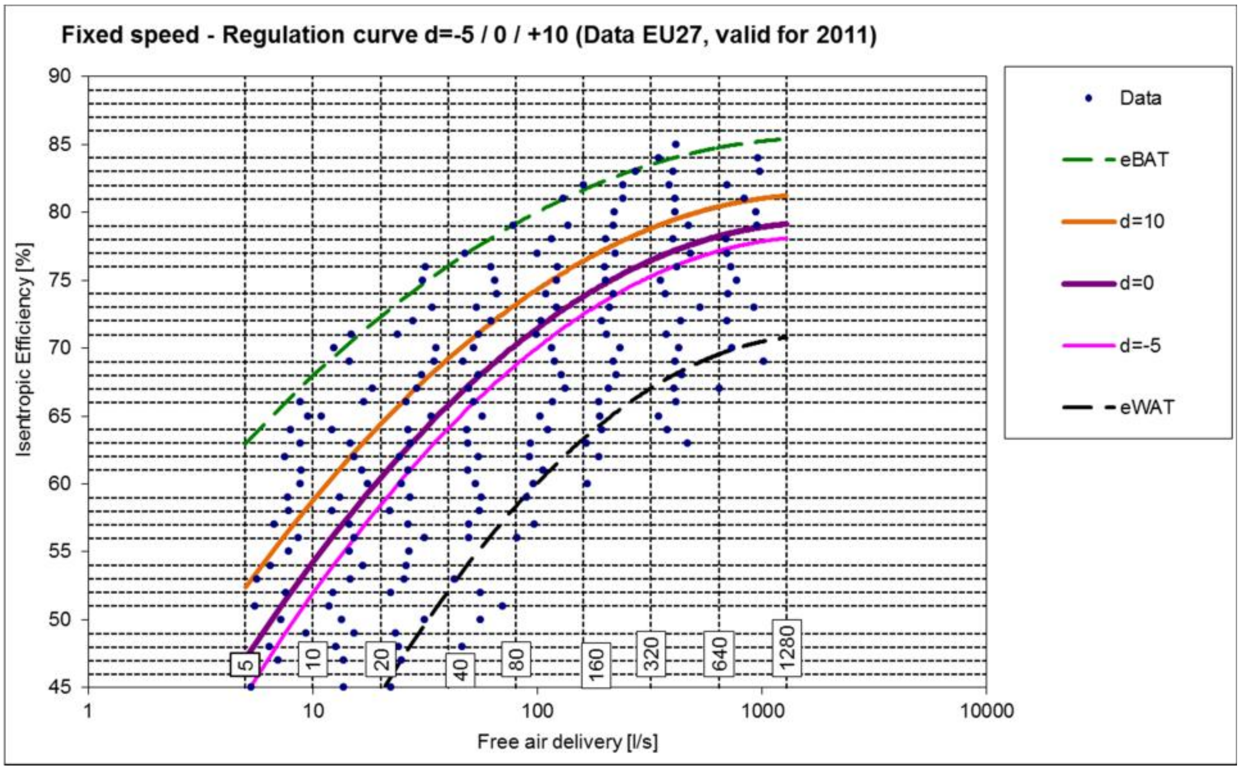


Figure 3-6 Variable speed d=-5, d=0, d=+10

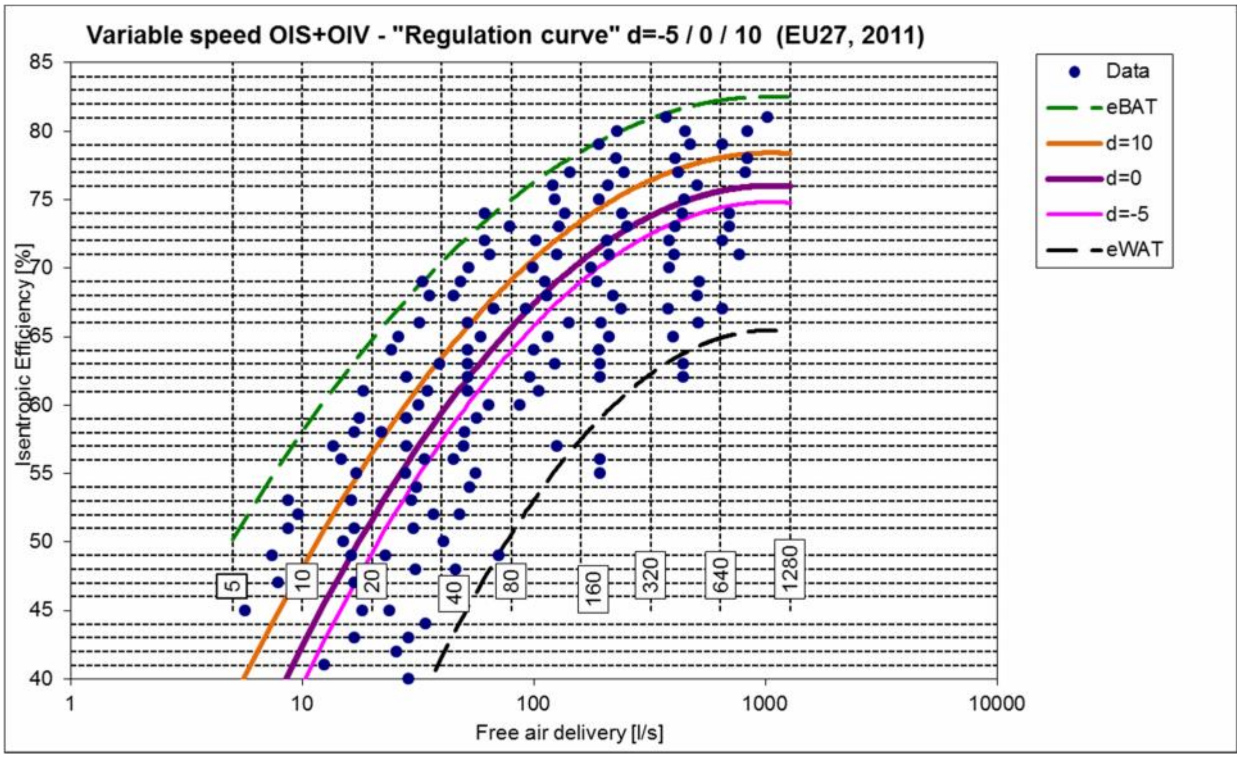
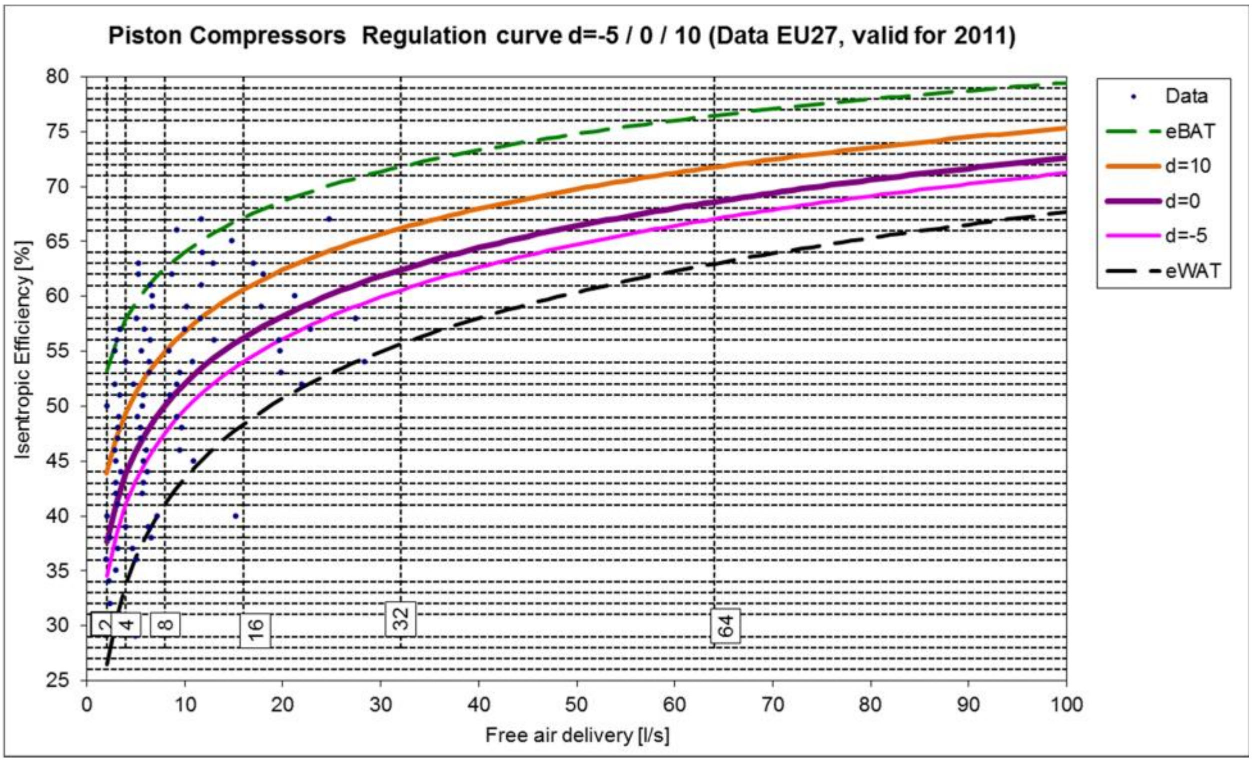


Figure 3-7 Piston d=-5, d=0, d=+10



3.3 Scenario and Impact analysis

This section presents the results of both the scenario analysis and the impact analysis.

3.3.1 Scenario I

Scenario I applies a d=-10 for the first tier and d=-5 for the second tier.

Table 3-8 Scenario I target table

TARGETS	Ecodesign option		
Year	2017	2021	2023
Ecodesign targets	Tier I	Tier II	Tier III
fixed speed OIS+OIV	-10	-5	-5
variable speed OIS+OIV	-10	-5	-5
pistons OL	-10	-5	-5

Savings compared to the baseline (BAU) are very close to zero or negative (depending on which replacement model is assumed) and also impact on sales (affected sales) is close to what is expected to happen assuming BAU (which assumes ongoing efforts to reduce energy).

Table 3-9 Scenario I overview table

Option with limit repl.	2010	2020	2030		Option with avg. repl.	2010	2020	2030	
ENERGY CONSUMPTION									
fixed speed OIS+OIV	48,4	35,3	35,4	TWh/yr	fixed speed OIS+OIV	48,4	35,0	34,8	TWh/yr
variable speed OIS+OIV	8,9	20,3	23,2	TWh/yr	variable speed OIS+OIV	8,9	20,2	22,9	TWh/yr
pistons OL	1,5	1,4	1,5	TWh/yr	pistons OL	1,5	1,4	1,5	TWh/yr
TOTALS	58,8	57,0	60,1	TWh/yr	TOTALS	58,8	56,6	59,2	TWh/yr
Abs. difference (Ecodesign-BAU)									
fixed speed OIS+OIV	(ref.)	-0,08	-0,15	TWh/yr	fixed speed OIS+OIV	(ref.)	-0,36	-0,76	TWh/yr
variable speed OIS+OIV	(ref.)	0,04	0,18	TWh/yr	variable speed OIS+OIV	(ref.)	-0,06	-0,12	TWh/yr
pistons OL	(ref.)	-0,00	0,01	TWh/yr	pistons OL	(ref.)	-0,02	-0,02	TWh/yr
TOTALS		-0,04	0,04	TWh/yr	TOTALS		-0,44	-0,91	TWh/yr
Rel. difference (Ecodesign-BAU)									
fixed speed OIS+OIV	(ref.)	-0,4%	-0,6%	% diff to BAU	fixed speed OIS+OIV	(ref.)	-1,8%	-3,3%	% diff to BAU
variable speed OIS+OIV	(ref.)	0,2%	0,8%	% diff to BAU	variable speed OIS+OIV	(ref.)	-0,3%	-0,5%	% diff to BAU
pistons OL	(ref.)	-0,1%	0,9%	% diff to BAU	pistons OL	(ref.)	-1,7%	-1,5%	% diff to BAU
TOTALS		-0,1%	0,1%	% diff to BAU	TOTALS		-0,8%	-1,5%	% diff to BAU
SALES AFFECTED									
related to 2011 models	2017	2021	2023						
fixed speed OIS+OIV	19%	27%	27%	% of models in 2011					
variable speed OIS+OIV	14%	22%	22%	% of models in 2011					
pistons OL	9%	26%	26%	% of models in 2011					
Related to Tier I/II models									
'Limit' replacement assumed for BAU					**'Average' replacement assumed for BAU**				

fixed speed OIS+OIV	4%	3%	0%		fixed speed OIS+OIV	16%	22%	20%	
variable speed OIS+OIV	0%	-5%	-17%		variable speed OIS+OIV	9%	11%	10%	
pistons OL	-12%	0%	-2%		pistons OL	4%	17%	-2%	
EXPENDITURE									
Option with limit repl.	2010	2020	2030		Option with avg. repl.	2010	2020	2030	
fixed speed OIS+OIV	4483	3404	3454	mln. EUR	fixed speed OIS+OIV	4483	3409	3436	mln. EUR
variable speed OIS+OIV	889	1929	2205	mln. EUR	variable speed OIS+OIV	889	1934	2198	mln. EUR
pistons OL	391	395	423	mln. EUR	pistons OL	391	404	431	mln. EUR
TOTALS	5763	5729	6082		TOTALS	5763	5746	6065	
Difference (Ecodesign-BAU)									
fixed speed OIS+OIV	(ref.)	1	-11	mln. EUR	fixed speed OIS+OIV	(ref.)	6	-28	mln. EUR
variable speed OIS+OIV	(ref.)	-1	-1	mln. EUR	variable speed OIS+OIV	(ref.)	4	-8	mln. EUR
pistons OL	(ref.)	-1	-4	mln. EUR	pistons OL	(ref.)	8	4	mln. EUR
TOTALS		0	-16		TOTALS		17	-33	
Rel. difference (Ecodesign-BAU)									
fixed speed OIS+OIV	(ref.)	0,0%	-0,3%		fixed speed OIS+OIV	(ref.)	0,2%	-0,8%	
variable speed OIS+OIV	(ref.)	0,0%	-0,1%		variable speed OIS+OIV	(ref.)	0,2%	-0,4%	
pistons OL	(ref.)	-0,1%	-0,9%		pistons OL	(ref.)	2,0%	0,9%	
		0,0%	-0,3%				0,3%	-0,5%	
GHG EMISSIONS									
fixed speed OIS+OIV	20	13	12	Mton/yr	fixed speed OIS+OIV	20	13	12	Mton/yr
variable speed OIS+OIV	4	8	8	Mton/yr	variable speed OIS+OIV	4	8	8	Mton/yr
pistons OL	1	1	1	Mton/yr	pistons OL	1	1	1	Mton/yr
TOTALS	24	22	20	Mton/yr	TOTALS	24	21	20	Mton/yr
Abs. difference (Ecodesign-BAU)									
fixed speed OIS+OIV	(ref.)	0,0	-0,1	Mton/yr	fixed speed OIS+OIV	(ref.)	-0,1	-0,3	Mton/yr
variable speed OIS+OIV	(ref.)	0,0	0,1	Mton/yr	variable speed OIS+OIV	(ref.)	0,0	0,0	Mton/yr
pistons OL	(ref.)	0,0	0,0	Mton/yr	pistons OL	(ref.)	0,0	0,0	Mton/yr
TOTALS		0,0	0,0	Mton/yr	TOTALS		-0,2	-0,3	Mton/yr
Rel.difference TOTALS		-0,1%	0,1%				-0,8%	-1,5%	

3.3.2 Scenario II

Scenario II applies a d=-7.5 for the first tier and d=-2.5 for the second tier. This scenario result in a phase out of approximately 15-22% of 2011 models in the first tier and about 1/3 (33-35%) of 2011 models in the second tier.

Table 3-10 Scenario II target table

TARGETS	Ecodesign option		
Year	2017	2021	2023
Ecodesign targets	Tier I	Tier II	Tier III
fixed speed OIS+OIV	-7,5	-2,5	-2,5
variable speed OIS+OIV	-7,5	-2,5	-2,5
pistons OL	-7,5	-2,5	-2,5

Savings are very close to zero or negative (depending on which replacement model is assumed) and also impact on sales (affected sales) is close to what would happen in BAU (which assumes ongoing efforts to reduce energy).

Table 3-11 Scenario II overview table

Option with limit repl.	2010	2020	2030		Option with avg. repl.	2010	2020	2030	
ENERGY CONSUMPTION									
fixed speed OIS+OIV	48,4	35,3	35,3	TWh/yr	fixed speed OIS+OIV	48,4	35,0	34,7	TWh/yr
variable speed OIS+OIV	8,9	20,2	23,1	TWh/yr	variable speed OIS+OIV	8,9	20,1	22,7	TWh/yr
pistons OL	1,5	1,4	1,5	TWh/yr	pistons OL	1,5	1,4	1,5	TWh/yr
TOTALS	58,8	56,9	60,0	TWh/yr	TOTALS	58,8	56,5	58,9	TWh/yr
Abs. difference (Ecodesign-BAU)									
fixed speed OIS+OIV	(ref.)	-0,12	-0,21	TWh/yr	fixed speed OIS+OIV	(ref.)	-0,39	-0,86	TWh/yr
variable speed OIS+OIV	(ref.)	0,00	0,07	TWh/yr	variable speed OIS+OIV	(ref.)	-0,12	-0,30	TWh/yr
pistons OL	(ref.)	-0,00	0,01	TWh/yr	pistons OL	(ref.)	-0,02	-0,02	TWh/yr
TOTALS		-0,12	-0,12	TWh/yr	TOTALS		-0,53	-1,18	TWh/yr
Rel. difference (Ecodesign-BAU)									
fixed speed OIS+OIV	(ref.)	-0,6%	-0,9%	% diff to BAU	fixed speed OIS+OIV	(ref.)	-1,9%	-3,7%	% diff to BAU
variable speed OIS+OIV	(ref.)	0,0%	0,3%	% diff to BAU	variable speed OIS+OIV	(ref.)	-0,6%	-1,3%	% diff to BAU
pistons OL	(ref.)	-0,1%	0,9%	% diff to BAU	pistons OL	(ref.)	-1,7%	-1,5%	% diff to BAU
TOTALS		-0,2%	-0,2%	% diff to BAU	TOTALS		-0,9%	-2,0%	% diff to BAU
SALES AFFECTED									
Sales affected by measure	2017	2021	2023						
fixed speed OIS+OIV	22%	35%	35%	% of models in 2011					
variable speed OIS+OIV	16%	33%	33%	% of models in 2011					
pistons OL	15%	35%	35%	% of models in					

				2011					
Related to Tier I/II models									
'Limit' replacement assumed for BAU					**'Average' replacement assumed for BAU**				
fixed speed OIS+OIV	7%	11%	8%	% of models in 2011	fixed speed OIS+OIV	19%	29%	28%	% of models in 2011
variable speed OIS+OIV	2%	6%	-6%	% of models in 2011	variable speed OIS+OIV	11%	22%	20%	% of models in 2011
pistons OL	-6%	9%	7%	% of models in 2011	pistons OL	10%	26%	7%	% of models in 2011
EXPENDITURE									
Option with limit repl.	2010	2020	2030		Option with avg. repl.	2010	2020	2030	
fixed speed OIS+OIV	4483	3404	3453	mln. EUR	fixed speed OIS+OIV	4483	3410	3434	mln. EUR
variable speed OIS+OIV	889	1930	2202	mln. EUR	variable speed OIS+OIV	889	1936	2194	mln. EUR
pistons OL	391	395	423	mln. EUR	pistons OL	391	404	431	mln. EUR
TOTALS	5763	5730	6078		TOTALS	5763	5750	6059	
Difference (Ecodesign-BAU)									
fixed speed OIS+OIV	(ref.)	2	-12	mln. EUR	fixed speed OIS+OIV	(ref.)	7	-31	mln. EUR
variable speed OIS+OIV	(ref.)	0	-4	mln. EUR	variable speed OIS+OIV	(ref.)	6	-12	mln. EUR
pistons OL	(ref.)	-1	-4	mln. EUR	pistons OL	(ref.)	8	4	mln. EUR
TOTALS		1	-20		TOTALS		21	-39	
Rel. difference (Ecodesign-BAU)									
fixed speed OIS+OIV	(ref.)	0,0%	-0,4%		fixed speed OIS+OIV	(ref.)	0,2%	-0,9%	
variable speed OIS+OIV	(ref.)	0,0%	-0,2%		variable speed OIS+OIV	(ref.)	0,3%	-0,6%	
pistons OL	(ref.)	-0,1%	-0,9%		pistons OL	(ref.)	2,0%	0,9%	
		0,0%	-0,3%				0,4%	-0,6%	
GHG EMISSIONS									
Ecodesign option A	2010	2020	2030		Ecodesign option A	2010	2020	2030	
fixed speed OIS+OIV	20	13	12	Mton/yr	fixed speed OIS+OIV	20	13	12	Mton/yr
variable speed OIS+OIV	4	8	8	Mton/yr	variable speed OIS+OIV	4	8	8	Mton/yr
pistons OL	1	1	1	Mton/yr	pistons OL	1	1	1	Mton/yr
TOTALS	24	22	20	Mton/yr	TOTALS	24	21	20	Mton/yr
Abs. difference (Ecodesign-BAU)									
fixed speed OIS+OIV	(ref.)	0,0	-0,1	Mton/yr	fixed speed OIS+OIV	(ref.)	-0,1	-0,3	Mton/yr
variable speed OIS+OIV	(ref.)	0,0	0,0	Mton/yr	variable speed OIS+OIV	(ref.)	0,0	-0,1	Mton/yr
pistons OL	(ref.)	0,0	0,0	Mton/yr	pistons OL	(ref.)	0,0	0,0	Mton/yr
TOTALS		0,0	0,0	Mton/yr	TOTALS		-0,2	-0,4	Mton/yr
Rel.difference TOTALS		-0,2%	-0,2%				-0,9%	-2,0%	

Overall savings are between 0.1 - 0.5 TWh in 2020 and 0.1 - 1.2 TWh in 2030, compared to BAU.

3.3.3 Scenario III

Scenario I applies a d=-5 for the first tier and d=0 for the second tier.

Table 3-12 Scenario III target table

TARGETS	Ecodesign option		
Year	2017	2021	2023
Ecodesign targets	Tier I	Tier II	Tier III
fixed speed OIS+OIV	-5	0	0
variable speed OIS+OIV	-5	0	0
pistons OL	-5	0	0

Scenario III targets result in a phase out of approximately 22-27% of 2011 models in the first tier and about 39-45% of 2011 models in the second tier.

Table 3-13 Scenario III overview table

Option with limit repl.	2010	2020	2030		Option with avg. repl.	2010	2020	2030	
ENERGY CONSUMPTION									
fixed speed OIS+OIV	48,4	35,2	35,1	TWh/yr	fixed speed OIS+OIV	48,4	34,9	34,5	TWh/yr
variable speed OIS+OIV	8,9	20,2	23,0	TWh/yr	variable speed OIS+OIV	8,9	20,0	22,6	TWh/yr
pistons OL	1,5	1,4	1,5	TWh/yr	pistons OL	1,5	1,4	1,5	TWh/yr
TOTALS	58,8	56,8	59,6	TWh/yr	TOTALS	58,8	56,3	58,6	TWh/yr
Abs. difference (Ecodesign-BAU)									
fixed speed OIS+OIV	(ref.)	-0,20	-0,46	TWh/yr	fixed speed OIS+OIV	(ref.)	-0,50	-1,07	TWh/yr
variable speed OIS+OIV	(ref.)	-0,02	-0,01	TWh/yr	variable speed OIS+OIV	(ref.)	-0,19	-0,42	TWh/yr
pistons OL	(ref.)	-0,00	0,01	TWh/yr	pistons OL	(ref.)	-0,02	-0,02	TWh/yr
TOTALS		-0,22	-0,46	TWh/yr	TOTALS		-0,72	-1,51	TWh/yr
Rel. difference (Ecodesign-BAU)									
fixed speed OIS+OIV	(ref.)	-1,0%	-2,0%	% diff to BAU	fixed speed OIS+OIV	(ref.)	-2,5%	-4,6%	% diff to BAU
variable speed OIS+OIV	(ref.)	-0,1%	0,0%	% diff to BAU	variable speed OIS+OIV	(ref.)	-0,9%	-1,8%	% diff to BAU
pistons OL	(ref.)	-0,1%	0,9%	% diff to BAU	pistons OL	(ref.)	-1,7%	-1,5%	% diff to BAU
TOTALS		-0,4%	-0,8%	% diff to BAU	TOTALS		-1,3%	-2,5%	% diff to BAU
SALES AFFECTED									
related to 2011 models	2017	2021	2023						
fixed speed OIS+OIV	27%	41%	41%	% of models in 2011					
variable speed OIS+OIV	22%	45%	45%	% of models in 2011					
pistons OL	26%	39%	39%	% of models in 2011					
Related to Tier I/II models									
'Limit' replacement					**'Average' replacement**				

assumed for BAU					assumed for BAU				
fixed speed OIS+OIV	11%	17%	14%		fixed speed OIS+OIV	24%	36%	34%	
variable speed OIS+OIV	8%	18%	6%		variable speed OIS+OIV	17%	34%	32%	
pistons OL	4%	13%	10%		pistons OL	21%	30%	10%	
EXPENDITURE									
fixed speed OIS+OIV	4483	3408	3445	mln. EUR	fixed speed OIS+OIV	4483	3412	3429	mln. EUR
variable speed OIS+OIV	889	1932	2201	mln. EUR	variable speed OIS+OIV	889	1939	2193	mln. EUR
pistons OL	391	395	423	mln. EUR	pistons OL	391	404	431	mln. EUR
TOTALS	5763	5734	6069		TOTALS	5763	5755	6053	
Difference (Ecodesign-BAU)									
fixed speed OIS+OIV	(ref.)	5	-20	mln. EUR	fixed speed OIS+OIV	(ref.)	9	-36	mln. EUR
variable speed OIS+OIV	(ref.)	2	-6	mln. EUR	variable speed OIS+OIV	(ref.)	9	-13	mln. EUR
pistons OL	(ref.)	-1	-4	mln. EUR	pistons OL	(ref.)	8	4	mln. EUR
TOTALS		6	-29		TOTALS		26	-45	
Rel. difference (Ecodesign-BAU)									
fixed speed OIS+OIV	(ref.)	0,1%	-,6%		fixed speed OIS+OIV	(ref.)	0,3%	-,0%	
variable speed OIS+OIV	(ref.)	0,1%	-,3%		variable speed OIS+OIV	(ref.)	0,5%	-,6%	
pistons OL	(ref.)	-,1%	-,9%		pistons OL	(ref.)	2,0%	0,9%	
		0,1%	-,5%				0,5%	-,7%	
GHG EMISSIONS									
fixed speed OIS+OIV	20	13	12	Mton/yr	fixed speed OIS+OIV	20	13	12	Mton/yr
variable speed OIS+OIV	4	8	8	Mton/yr	variable speed OIS+OIV	4	8	8	Mton/yr
pistons OL	1	1	1	Mton/yr	pistons OL	1	1	1	Mton/yr
TOTALS	24	22	20	Mton/yr	TOTALS	24	21	20	Mton/yr
Abs. difference (Ecodesign-BAU)									
fixed speed OIS+OIV	(ref.)	-0,1	-0,2	Mton/yr	fixed speed OIS+OIV	(ref.)	-0,2	-0,4	Mton/yr
variable speed OIS+OIV	(ref.)	0,0	0,0	Mton/yr	variable speed OIS+OIV	(ref.)	-0,1	-0,1	Mton/yr
pistons OL	(ref.)	0,0	0,0	Mton/yr	pistons OL	(ref.)	0,0	0,0	Mton/yr
TOTALS		-0,1	-0,2	Mton/yr	TOTALS		-0,3	-0,5	Mton/yr
Rel.difference TOTALS		- 0,4%	- 0,8%				- 1,3%	- 2,5%	

Overall savings are between 0.2 - 0.7 TWh in 2020 and 0.5 - 1.5 TWh in 2030, compared to BAU.

3.3.4 Scenario IV

Scenario I applies a d=0 for the first tier and d=+5 for the second tier.

Table 3-14 Scenario IV target table

Year	2017	2021	2023
Ecodesign targets	Tier I	Tier II	Tier III
fixed speed OIS+OIV	0	5	5
variable speed OIS+OIV	0	5	5
pistons OL	0	5	5

Scenario IV targets result in a phase out of approximately 39-45% of 2011 models in the first tier and about 51-76% of 2011 models in the second tier. The highest value relates to piston compressors.

Table 3-15 Scenario IV overview table

Option with limit repl.	2010	2020	2030		Option with avg. repl.	2010	2020	2030	
ENERGY CONSUMPTION									
fixed speed OIS+OIV	48,4	35,0	34,8	TWh/yr	fixed speed OIS+OIV	48,4	34,7	34,2	TWh/yr
variable speed OIS+OIV	8,9	20,1	22,8	TWh/yr	variable speed OIS+OIV	8,9	19,9	22,5	TWh/yr
pistons OL	1,5	1,4	1,5	TWh/yr	pistons OL	1,5	1,4	1,5	TWh/yr
TOTALS	58,8	56,5	59,2	TWh/yr	TOTALS	58,8	56,0	58,2	TWh/yr
Abs. difference (Ecodesign-BAU)									
fixed speed OIS+OIV	(ref.)	-0,35	-0,71	TWh/yr	fixed speed OIS+OIV	(ref.)	-0,65	-1,31	TWh/yr
variable speed OIS+OIV	(ref.)	-0,12	-0,19	TWh/yr	variable speed OIS+OIV	(ref.)	-0,32	-0,58	TWh/yr
pistons OL	(ref.)	-0,00	0,01	TWh/yr	pistons OL	(ref.)	-0,02	-0,02	TWh/yr
TOTALS		-0,47	-0,89	TWh/yr	TOTALS		-0,99	-1,91	TWh/yr
Rel. difference (Ecodesign-BAU)									
fixed speed OIS+OIV	(ref.)	-1,7%	-3,1%	% diff to BAU	fixed speed OIS+OIV	(ref.)	-3,2%	-5,7%	% diff to BAU
variable speed OIS+OIV	(ref.)	-0,6%	-0,8%	% diff to BAU	variable speed OIS+OIV	(ref.)	-1,6%	-2,5%	% diff to BAU
pistons OL	(ref.)	-0,1%	0,9%	% diff to BAU	pistons OL	(ref.)	-1,7%	-1,5%	% diff to BAU
TOTALS		-0,8%	-1,5%	% diff to BAU	TOTALS		-1,7%	-3,2%	% diff to BAU
SALES AFFECTED									
related to 2011 models	2017	2021	2023						
fixed speed OIS+OIV	41%	51%	51%	% of models in 2011					
variable speed OIS+OIV	45%	52%	52%	% of models in 2011					
pistons OL	39%	76%	76%	% of models in 2011					
Related to Tier I/II models									

'Limit' replacement assumed for BAU					**'Average' replacement assumed for BAU**				
fixed speed OIS+OIV	26%	27%	25%		fixed speed OIS+OIV	38%	46%	45%	
variable speed OIS+OIV	31%	25%	13%		variable speed OIS+OIV	40%	41%	39%	
pistons OL	17%	50%	48%		pistons OL	33%	67%	48%	
EXPENDITURE									
Option with limit repl.	2010	2020	2030		Option with avg. repl.	2010	2020	2030	
fixed speed OIS+OIV	4483	3407	3438	mln. EUR	fixed speed OIS+OIV	4483	3413	3422	mln. EUR
variable speed OIS+OIV	889	1934	2197	mln. EUR	variable speed OIS+OIV	889	1939	2190	mln. EUR
pistons OL	391	395	423	mln. EUR	pistons OL	391	404	431	mln. EUR
TOTALS	5763	5736	6057		TOTALS	5763	5755	6042	
Difference (Ecodesign-BAU)									
fixed speed OIS+OIV	(ref.)	4	-27	mln. EUR	fixed speed OIS+OIV	(ref.)	10	-43	mln. EUR
variable speed OIS+OIV	(ref.)	4	-10	mln. EUR	variable speed OIS+OIV	(ref.)	9	-17	mln. EUR
pistons OL	(ref.)	-1	-4	mln. EUR	pistons OL	(ref.)	8	4	mln. EUR
TOTALS		8	-41		TOTALS		26	-56	
Rel. difference (Ecodesign-BAU)									
fixed speed OIS+OIV	(ref.)	0,1%	-0,8%		fixed speed OIS+OIV	(ref.)	0,3%	-1,2%	
variable speed OIS+OIV	(ref.)	0,2%	-0,4%		variable speed OIS+OIV	(ref.)	0,4%	-0,8%	
pistons OL	(ref.)	-0,1%	-0,9%		pistons OL	(ref.)	2,0%	0,9%	
		0,1%	-0,7%				0,5%	-0,9%	
GHG EMISSIONS									
Ecodesign option A	2010	2020	2030		Ecodesign option A	2010	2020	2030	
fixed speed OIS+OIV	20	13	12	Mton/yr	fixed speed OIS+OIV	20	13	12	Mton/yr
variable speed OIS+OIV	4	8	8	Mton/yr	variable speed OIS+OIV	4	8	8	Mton/yr
pistons OL	1	1	1	Mton/yr	pistons OL	1	1	1	Mton/yr
TOTALS	24	21	20	Mton/yr	TOTALS	24	21	20	Mton/yr
Abs. difference (Ecodesign-BAU)									
fixed speed OIS+OIV	(ref.)	-0,1	-0,2	Mton/yr	fixed speed OIS+OIV	(ref.)	-0,2	-0,4	Mton/yr
variable speed OIS+OIV	(ref.)	0,0	-0,1	Mton/yr	variable speed OIS+OIV	(ref.)	-0,1	-0,2	Mton/yr
pistons OL	(ref.)	0,0	0,0	Mton/yr	pistons OL	(ref.)	0,0	0,0	Mton/yr
TOTALS		-0,2	-0,3	Mton/yr	TOTALS		-0,4	-0,7	Mton/yr
Rel.difference TOTALS		-0,8%	-1,5%				-1,7%	-3,2%	

Overall savings are between 0.5 - 1.0 TWh in 2020 and 0.9 - 1.9 TWh in 2030, compared to BAU.

3.3.5 Scenario V

Scenario I applies a d=5 for the first tier and d=15 for the second tier.

Table 3-16 Scenario V target table

TARGETS	Ecodesign option		
Year	2017	2021	2023
Ecodesign targets	Tier I	Tier II	Tier III
fixed speed OIS+OIV	5	15	15
variable speed OIS+OIV	5	15	15
pistons OL	5	15	15

Scenario IV targets result in a phase out of approximately 51-76% of 2011 models in the first tier and about 81-91% of 2011 models in the second tier. The highest values relate to piston compressors.

Table 3-17 Scenario V overview table

Option with limit repl.	2010	2020	2030		Option with avg. repl.	2010	2020	2030	
ENERGY CONSUMPTION									
fixed speed OIS+OIV	48,4	34,8	34,1	TWh/yr	fixed speed OIS+OIV	48,4	34,5	33,5	TWh/yr
variable speed OIS+OIV	8,9	19,9	22,2	TWh/yr	variable speed OIS+OIV	8,9	19,8	21,8	TWh/yr
pistons OL	1,5	1,4	1,5	TWh/yr	pistons OL	1,5	1,4	1,5	TWh/yr
TOTALS	58,8	56,2	57,8	TWh/yr	TOTALS	58,8	55,7	56,8	TWh/yr
Abs. difference (Ecodesign-BAU)									
fixed speed OIS+OIV	(ref.)	-0,54	-1,49	TWh/yr	fixed speed OIS+OIV	(ref.)	-0,83	-2,04	TWh/yr
variable speed OIS+OIV	(ref.)	-0,26	-0,82	TWh/yr	variable speed OIS+OIV	(ref.)	-0,45	-1,24	TWh/yr
pistons OL	(ref.)	-0,00	0,01	TWh/yr	pistons OL	(ref.)	-0,02	-0,02	TWh/yr
TOTALS		-0,80	-2,30	TWh/yr	TOTALS		-1,31	-3,30	TWh/yr
Rel. difference (Ecodesign-BAU)									
fixed speed OIS+OIV	(ref.)	- 2,7%	-6,5%	% diff to BAU	fixed speed OIS+OIV	(ref.)	- 4,1%	- 8,8%	% diff to BAU
variable speed OIS+OIV	(ref.)	- 1,3%	-3,6%	% diff to BAU	variable speed OIS+OIV	(ref.)	- 2,2%	- 5,4%	% diff to BAU
pistons OL	(ref.)	- 0,1%	0,9%	% diff to BAU	pistons OL	(ref.)	- 1,7%	- 1,5%	% diff to BAU
TOTALS		- 1,4%	-3,8%	% diff to BAU	TOTALS		- 2,3%	- 5,5%	% diff to BAU
SALES AFFECTED									
Sales affected by measure	Tier I	Tier II	Tier III						
Option with limit repl.	2017	2021	2023						
fixed speed OIS+OIV	51%	81%	81%	% of models in 2011					
variable speed OIS+OIV	52%	82%	82%	% of models in 2011					
pistons OL	76%	91%	91%	% of models in 2011					

Related to Tier I/II models									
'Limit' replacement assumed for BAU					**'Average' replacement assumed for BAU**				
fixed speed OIS+OIV	36%	58%	55%		fixed speed OIS+OIV	48%	76%	75%	
variable speed OIS+OIV	38%	55%	44%		variable speed OIS+OIV	47%	72%	70%	
pistons OL	54%	65%	63%		pistons OL	71%	82%	63%	
EXPENDITURE									
Option with limit repl.	2010	2020	2030		Option with avg. repl.	2010	2020	2030	
fixed speed OIS+OIV	4483	3426	3421	mln. EUR	fixed speed OIS+OIV	4483	3431	3410	mln. EUR
variable speed OIS+OIV	889	1950	2187	mln. EUR	variable speed OIS+OIV	889	1957	2182	mln. EUR
pistons OL	391	395	423	mln. EUR	pistons OL	391	404	431	mln. EUR
TOTALS	5763	5770	6031		TOTALS	5763	5792	6023	
Difference (Ecodesign-BAU)									
fixed speed OIS+OIV	(ref.)	23	-43	mln. EUR	fixed speed OIS+OIV	(ref.)	28	-55	mln. EUR
variable speed OIS+OIV	(ref.)	20	-19	mln. EUR	variable speed OIS+OIV	(ref.)	27	-25	mln. EUR
pistons OL	(ref.)	-1	-4	mln. EUR	pistons OL	(ref.)	8	4	mln. EUR
TOTALS		42	-67		TOTALS		64	-75	
Rel. difference (Ecodesign-BAU)									
fixed speed OIS+OIV	(ref.)	0,7%	-1,2%		fixed speed OIS+OIV	(ref.)	0,8%	-1,6%	
variable speed OIS+OIV	(ref.)	1,0%	-0,9%		variable speed OIS+OIV	(ref.)	1,4%	-1,1%	
pistons OL	(ref.)	-0,1%	-0,9%		pistons OL	(ref.)	2,0%	0,9%	
		0,7%	-1,1%				1,1%	-1,2%	
GHG EMISSIONS									
Ecodesign option A	2010	2020	2030		Ecodesign option A	2010	2020	2030	
fixed speed OIS+OIV	20	13	12	Mton/yr	fixed speed OIS+OIV	20	13	11	Mton/yr
variable speed OIS+OIV	4	8	8	Mton/yr	variable speed OIS+OIV	4	8	7	Mton/yr
pistons OL	1	1	1	Mton/yr	pistons OL	1	1	1	Mton/yr
TOTALS	24	21	20	Mton/yr	TOTALS	24	21	19	Mton/yr
Abs. difference (Ecodesign-BAU)									
fixed speed OIS+OIV	(ref.)	-0,2	-0,5	Mton/yr	fixed speed OIS+OIV	(ref.)	-0,3	-0,7	Mton/yr
variable speed OIS+OIV	(ref.)	-0,1	-0,3	Mton/yr	variable speed OIS+OIV	(ref.)	-0,2	-0,4	Mton/yr
pistons OL	(ref.)	0,0	0,0	Mton/yr	pistons OL	(ref.)	0,0	0,0	Mton/yr
TOTALS		-0,3	-0,8	Mton/yr	TOTALS		-0,5	-1,1	Mton/yr
Rel.difference TOTALS		-1,4%	-3,8%				-2,3%	-5,7%	

3.3.6 Scenario VI

Scenario VI is a hypothetical scenario as the targets are at the level of the BAT technology. The target levels of d=20 and d=30 result in a phase out of approximately 89-95% of 2011 models in the first tier and about 97-99% of 2011 models in the second tier. The highest values relate to piston compressors. This scenario is introduced in for comparison only.

Table 3-18 Scenario VI target table

Year	2017	2021	2023
Ecodesign targets	Tier I	Tier II	Tier III
fixed speed OIS+OIV	20	30	30
variable speed OIS+OIV	20	30	30
pistons OL	20	30	30

Table 3-19 Scenario VI overview table

Option with limit repl.	2010	2020	2030		Option with avg. repl.	2010	2020	2030	
ENERGY CONSUMPTION									
fixed speed OIS+OIV	48,4	34,2	32,5	TWh/yr	fixed speed OIS+OIV	48,4	34,0	32,3	TWh/yr
variable speed OIS+OIV	8,9	19,4	21,0	TWh/yr	variable speed OIS+OIV	8,9	19,3	20,9	TWh/yr
pistons OL	1,5	1,4	1,5	TWh/yr	pistons OL	1,5	1,4	1,5	TWh/yr
TOTALS	58,8	55,0	55,0	TWh/yr	TOTALS	58,8	54,6	54,8	TWh/yr
Abs. difference (Ecodesign-BAU)									
fixed speed OIS+OIV	(ref.)	-1,21	-3,08	TWh/yr	fixed speed OIS+OIV	(ref.)	-1,42	-3,20	TWh/yr
variable speed OIS+OIV	(ref.)	-0,79	-2,05	TWh/yr	variable speed OIS+OIV	(ref.)	-0,94	-2,09	TWh/yr
pistons OL	(ref.)	-0,00	0,01	TWh/yr	pistons OL	(ref.)	-0,02	-0,02	TWh/yr
TOTALS		-2,01	-5,12	TWh/yr	TOTALS		-2,38	-5,32	TWh/yr
Rel. difference (Ecodesign-BAU)									
fixed speed OIS+OIV	(ref.)	-6,0%	-13,4%	% diff to BAU	fixed speed OIS+OIV	(ref.)	-7,0%	-13,9%	% diff to BAU
variable speed OIS+OIV	(ref.)	-3,9%	-8,9%	% diff to BAU	variable speed OIS+OIV	(ref.)	-4,6%	-9,1%	% diff to BAU
pistons OL	(ref.)	-0,1%	0,9%	% diff to BAU	pistons OL	(ref.)	-1,7%	-1,5%	% diff to BAU
TOTALS		-3,5%	-8,5%	% diff to BAU	TOTALS		-4,2%	-8,8%	% diff to BAU
SALES AFFECTED									
related to 2011 models	Tier I	Tier II	Tier III						
fixed speed OIS+OIV	90%	97%	97%	% of models in 2011					
variable speed OIS+OIV	89%	98%	98%	% of models in 2011					
pistons OL	95%	99%	99%	% of models					

				in 2011					
Related to Tier I/II models									
'Limit' replacement assumed for BAU					**'Average' replacement assumed for BAU**				
fixed speed OIS+OIV	74%	73%	70%		fixed speed OIS+OIV	87%	91%	90%	
variable speed OIS+OIV	75%	71%	60%		variable speed OIS+OIV	84%	87%	86%	
pistons OL	73%	74%	71%		pistons OL	90%	91%	71%	
EXPENDITURE									
fixed speed OIS+OIV	4483	3454	3394	mln. EUR	fixed speed OIS+OIV	4483	3447	3389	mln. EUR
variable speed OIS+OIV	889	1976	2175	mln. EUR	variable speed OIS+OIV	889	1971	2172	mln. EUR
pistons OL	391	395	423	mln. EUR	pistons OL	391	404	431	mln. EUR
TOTALS	5763	5825	5991		TOTALS	5763	5822	5991	
Difference (Ecodesign-BAU)									
fixed speed OIS+OIV	(ref.)	51	-71	mln. EUR	fixed speed OIS+OIV	(ref.)	44	-76	mln. EUR
variable speed OIS+OIV	(ref.)	46	-32	mln. EUR	variable speed OIS+OIV	(ref.)	41	-35	mln. EUR
pistons OL	(ref.)	-1	-4	mln. EUR	pistons OL	(ref.)	8	4	mln. EUR
TOTALS		96	-107		TOTALS		93	-107	
Rel. difference (Ecodesign-BAU)									
fixed speed OIS+OIV	(ref.)	1,5%	-2,0%		fixed speed OIS+OIV	(ref.)	1,3%	-2,2%	
variable speed OIS+OIV	(ref.)	2,4%	-1,4%		variable speed OIS+OIV	(ref.)	2,1%	-1,6%	
pistons OL	(ref.)	-0,1%	-0,9%		pistons OL	(ref.)	2,0%	0,9%	
		1,7%	-1,7%				1,6%	-1,8%	
GHG EMISSIONS									
fixed speed OIS+OIV	20	13	11	Mton/yr	fixed speed OIS+OIV	20	13	11	Mton/yr
variable speed OIS+OIV	4	7	7	Mton/yr	variable speed OIS+OIV	4	7	7	Mton/yr
pistons OL	1	1	1	Mton/yr	pistons OL	1	1	1	Mton/yr
TOTALS	24	21	19	Mton/yr	TOTALS	24	21	19	Mton/yr
Abs. difference (Ecodesign-BAU)									
fixed speed OIS+OIV	(ref.)	-0,5	-1,0	Mton/yr	fixed speed OIS+OIV	(ref.)	-0,5	-1,1	Mton/yr
variable speed OIS+OIV	(ref.)	-0,3	-0,7	Mton/yr	variable speed OIS+OIV	(ref.)	-0,4	-0,7	Mton/yr
pistons OL	(ref.)	0,0	0,0	Mton/yr	pistons OL	(ref.)	0,0	0,0	Mton/yr
TOTALS		-0,8	-1,7	Mton/yr	TOTALS		-0,9	-1,8	Mton/yr
Rel.difference TOTALS		-3,5%	-8,5%				-4,3%	-9,7%	

Overall savings are between 2.0 - 2.4 TWh in 2020 and 5.1 - 5.3 TWh in 2030, compared to BAU.

3.4 Analysis of compressors at system level (standard air only)

As stated in Task 3 the compressed air system introduces further losses. The Fraunhofer 2001 study[12] describes these losses and states that reducing air leakage is one of the most important actions for reducing energy consumption of compressed air systems.

The study stated that possibly some 20% can be saved in some approximately 80% of the installations. This results in overall savings of 16%. When this savings potential is applied to the overall energy consumption of compressors of 60 TWh then some 10 TWh could be saved.

Other options identified for reducing energy consumption of compressed air systems (non-exhaustive) are:

- improved drying, cooling, filtering
- improved system design (i.e. multi pressure systems)
- recovery of waste heat
- optimal end use devices, etc.

It is therefore reasonable to state that the energy savings potential at SYSTEM level vastly exceeds those at PRODUCT level. Achieving those savings however requires intervention at each compressed air system, through energy audits, awareness raising campaigns, education, etc.

3.5 Analysis of compressors in other application ranges

As stated in Task 6, section 1.2, it has not been possible to assess and analyse the sales, efficiencies, costs and other relevant information for compressors in other application ranges in the same level of detail as for the standard air application range.

Nonetheless many stakeholders have requested to insert -at minimum- an **estimate** of possible effects of improved efficiency of products within these application ranges.

This section meets that request by describing the development of energy consumption, based on the 'snapshot' of the annual energy consumption in 2010 (based on the Task 2 and 3 Pneurop 1st survey estimate). For the assessment of a saving potential an increase in sales was assumed:

- for low pressure and oil-free application ranges, the sales are assumed to follow the OECD trend;
- for process gas compressors (inert and hazardous) the sales follow a fixed trend, set at 1% per year.

These are assumptions and not backed by industry figures.

As regards the saving potential, the analysis of the standard air application ranges shows that a reduction of energy consumption of 2% to 4% is considered possible - this level of savings is based on the range of savings achieved by scenario II to IV.

For the application range low pressure and oil-free it is assumed that the savings could be in the same order of magnitude and therefore a savings percentage of 2% to 4% is applied in two tiers (expressed as % saved on energy consumption, not % improvement of isentropic efficiency).

For process gas applications, the savings potential is considered to be much more limited as most buyers already focus on energy efficiency. For these ranges a saving of 0.5% and 1% is assumed, also applied in two tiers.

[12] Source: Compressed air systems in the European Union, Fraunhofer 2009, based on data by Radgen et al, 2001

As this simplified model does not assume an incremental improvement of efficiency without policies, the baseline (BAU) is the same as the 'freeze' approach and the savings are calculated with this BAU/freeze as reference.

The calculated savings are shown in the table below.

Table 3-20 Estimate of savings in other application ranges

Application range	change in consumption of new models compared to 'BAU/freeze' (% of energy cons.)		BAU/Freeze electricity consumption (TWh/yr)		difference to 'BAU/freeze' (TWh/yr)	
	2017	2021	2020	2030	2020	2030
Low pressure	98%	96%	41 *	56 *	-0,32 *	-2,4 *
Oil-free	98%	96%	36	43 *	-0,20	-1,5 *
Process / inert	99,5%	99%	20	22	-0,02	-0,1
Process / other	99,5%	99%	30	32	-0,03	-0,2

*: note that values have changed with respect to presentation of 27 February 2014

The above assessment shows that in case these savings and other trends apply, which first needs to be assessed in a more in-depth follow-up study, the savings for the application range low pressure and oil-free are in the same range as for standard air (roughly between 0-2 TWh/yr).

The savings for the process gas application ranges however remain below 0.5 TWh (max 0.2 TWh for process gas / hazardous gases), which is partly because of the lower improvement potential, but primarily because of the -on average- longer product lives of this equipment.

3.6 Conclusions

Discussion of modelling of savings - limitations

Some forms of energy savings could not be included in the modelling. These are:

1) Savings by using variable speed drive compressors (in appropriate use cases)

The modelling assumes sales and use of fixed and variable speed compressors as a given. The savings relate to improved performance of either fixed or variable speed compressors. What is not quantified is the savings achieved by converting or replacing fixed speed compressors by variable speed compressors (although this is inherently included in the BAU through the historic and projected sales volume of these products).

Fixed speed oil-injected compressors are well suited to serve applications in which they do not idle or cycle frequently. When FS compressors idle or cycle often their overall efficiency deteriorates due to idling losses, especially if the idling frequency is increasing.

In applications and circumstances where there is a problem of high idling and cycling losses with FS OIS+OIV this problem can be overcome with variable speed drives (VSD), the introduction of which was a major breakthrough in the sector. Indeed OIS+OIV VS compressors show a lower isentropic efficiency at full load operation, which has to be regarded as a “price” which is paid for the capability to regulate speed and volume flow. The efficiency of VS at part load conditions is much higher than that of idling or on/off controlled fixed speed equipment and significantly over-compensates the losses introduced by the variable speed drive itself.

2) Savings achieved from changes beyond the product basic package: Manufacturers have invested heavily in the development of monitoring and control systems for complete installations with multiple compressors, which distribute the load over fixed speed and variable speed compressors to optimize the energy consumption for any demand of compressed air. Other savings

relate to improved system design and leakage reduction. These savings are achieved by changes outside the basic packages boundaries.

Discussion of modelling of savings – other application ranges

The conclusions to be drawn on the basis of the preceding analysis are limited to compressors in the standard air application range only, as these products could be analysed in sufficient detail.

As regards compressors in the other application ranges, the authors must conclude that no sufficient data for such an analysis was made available to the study authors, and therefore it is not possible to draw firm conclusion regarding products in these other application ranges.

3.6.1 Regarding eligibility for measures

The Task 1-8 reports show that for compressors in standard air applications the market (both in volume and value), as well as the environmental impacts and the potential for (environmental) improvement of compressors is significant. It should be noted however, that the actual sales of compressors in neither application range reaches the indicative threshold of 200 000 units per year. The sales in the standard air application range are highest at some 106 thousand units placed on the market in 2011.

3.6.2 Regarding the performance metric for energy efficiency

The Task 1-8 reports show that for compressors in standard air applications a performance metric can be constructed on the basis of the isentropic efficiency. This metric is preferred over the 'specific energy requirement' (popularly expressed as 'wire-to-air') using kW/(m^3/s) as units.

The isentropic efficiency allows to easily identify the losses of the compressor when compared to an ideal isentropic process. The higher the efficiency, the less losses occur. The isentropic efficiency is unaffected by differences in outlet pressure levels, and cannot be misunderstood as no conversion of units (from imperial to SI, etc.) is required. Furthermore, it allows a relatively simple integration into a parametric approach thereby avoiding long tables with specific values (such as the Chinese requirements) and potential threshold effects.

For positive displacement compressors the relevant performance standard ISO 1217 allows establishing all necessary parameters. ISO 5389 allows calculating efficiencies for turbo compressors, but the two values can however not be compared to each other as there are differences in the calculation methods.

3.6.3 Regarding possible target values

The analysis of the LCC in Task 7 shows that the economic optimum for the average fixed speed lies between d= 5-10 for the smallest compressors in this segment, to d=beyond 20 for the largest in this segment.

For variable speed OIS/OIV the optimum d-values are between d=10-20 for the smallest compressors to d= beyond 20 for the larger ones.

The above assessment however is based on a product life cycle based approach whereas manufacturers may decide on other aspects (shorter return on investment).

For pistons the situation is different as the LCC analysis shows that any increase in d-values could lead to higher LCC. This shows that the LCC of piston compressors, with limited annual operating hours, is less susceptive to a reduction in energy consumption. In countries with higher energy prices the situation might be different. Another reason for the increase of LCC may be an error in the assumptions underlying the LCC calculation, but so far no information has been received to correct that potential error.

A possible impact of very stringent requirements could be that manufacturers are forced to focus their development efforts towards improving basic package efficiency, and 'neglecting' other improvement options outside the basic package boundaries (whereas savings at system level may surpass those at package level).

Too stringent regulation may create gaps in manufacturer's product portfolios which in consequence may lead to inadequate (i.e. less efficient) product selection for a given application: A certain spread in compressor package efficiency, is unavoidable, because manufacturers have to utilize a limited number of compressor element sizes and compressor package platforms.

Figure 3-8 'Gaps' may occur in the portfolio of manufacturers

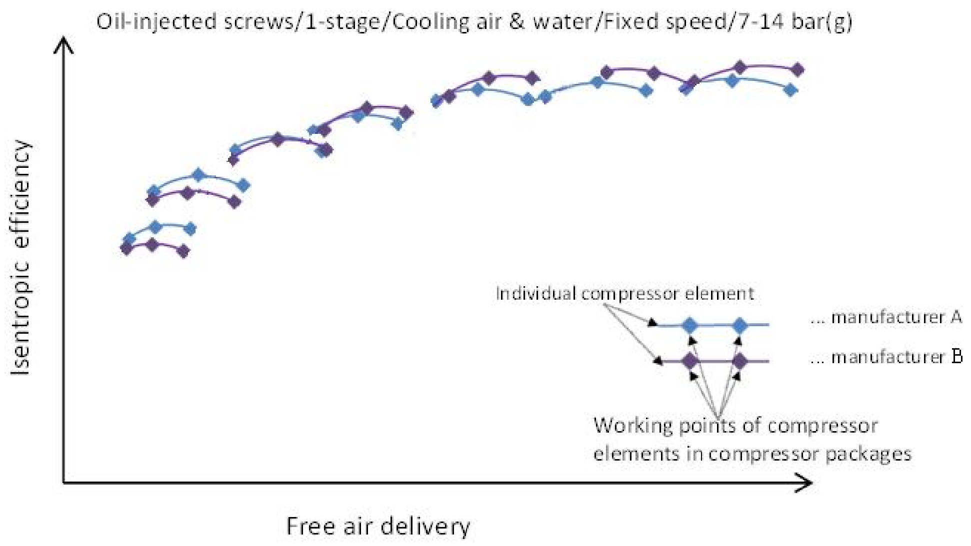


Table 3-21 Overview of 'sales affected' per scenario (FIXED SPEED only)

Fixed speed	d-values		Affected sales (% of models)			
	2017	2021	in 2011		in 2017/2021	
	Tier I	Tier II	Tier I	Tier II	Tier I	Tier II
Scenario I	-10	-5	19%	27%	16%	22%
Scenario II	-7.5	-2.5	22%	35%	19%	29%
Scenario III	-5	0	27%	41%	24%	36%
Scenario IV	0	5	41%	51%	38%	46%
Scenario V	5	15	51%	81%	48%	76%
Scenario VI	20	30	90%	97%	87%	91%

Table 3-22 Overview of 'sales affected' per scenario (VARIABLE SPEED and PISTON)

Variable speed & pistons	d-values	Affected sales (% of models)

Scenario I	variable	-10	-5	14%	22%	9%	11%
	piston	-10	-5	9%	26%	4%	17%
Scenario III	variable	-5	0	22%	35%	17%	24%
	piston	-5	0	26%	29%	21%	20%
Scenario IV	variable	0	5	45%	52%	40%	41%
	piston	0	5	29%	76%	22%	57%
Scenario VI	variable	20	30	89%	98%	84%	87%
	piston	20	30	95%	99%	90%	91%

3.6.4 Regarding saving potential

Limit or average replacement savings?

From the statistical approach one can see that there is a concentration of sales quantities for models in the middle between WAT and BAT. There are no reasons why this should be different in the future after regulations are in force, i.e. a similar concentration of sales quantities in the middle of the new range of available products can be expected. The costumer sees only the variety of products which are currently available on the market and it is to be expected that most costumers will take the average product (based on availability on market). This argumentation would identify the savings calculated on the basis of the 'average replacement' model. It is however possible that in the first years following the introduction of a measure some non-conforming sales are removed from the market. it is therefore possible that in the very first years immediately after the introduction of the measure the savings follow the limit replacement model. However this is not expected for year 2020 and 2030.

Table 3-23 Overview of energy savings per scenario

All (fixed, variable, piston)	d-values		Difference to BAU (TWh_e/yr)				% of scen.VI savings ("BAT")
			Limit repl.		Avg. repl.		
	2017	2021	2020	2030	2020	2030	
Scenario I	-10	-5	-0.0	+0.0	-0.4	-0.9	16%
Scenario II	-7.5	-2.5	-0.1	-0.1	-0.5	-1.2	20%
Scenario III	-5	0	-0.2	-0.5	-0.7	-1.5	30%
Scenario IV	0	5	-0.5	-0.9	-1.0	-1.9	40%
Scenario V	5	15	-0.8	-2.3	-1.3	-3.3	60%
Scenario VI	20	30	-2.0	-5.1	-2.4	-5.3	= BAT

Figure 3-9 Energy consumption 1990 – 2030 for all scenario's (TWh/year)

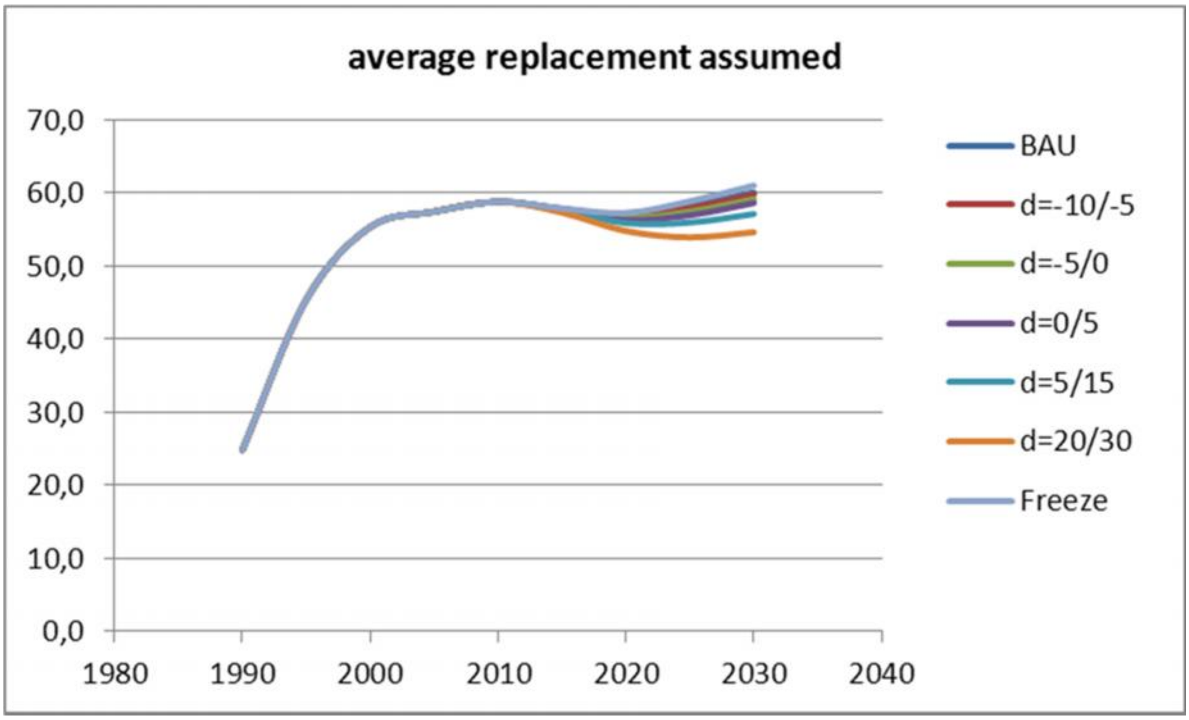
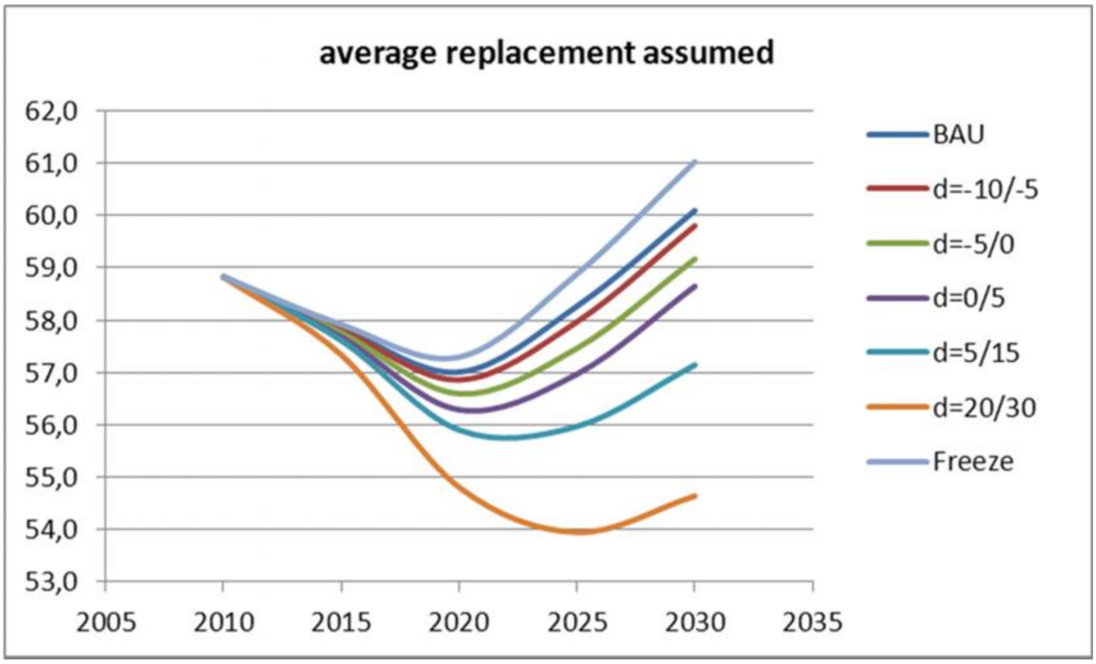


Figure 3-10 Energy consumption 2010 – 2030 for all scenario's (TWh/year)



The BAU saves approximately 1 TWh compared to 'Freeze' (2030). This means that the commitments of manufacturers to improve energy efficiency without regulatory pressure is already resulting in some 1 TWh savings.

The analysis presented in the Task 8 report and sections has led the study team to arrive at the following conclusions:

- for compressors in the 'standard air application range' a realistic saving potential would be approximately between 1-2 TWh/yr by 2030, through introduction of minimum energy efficiency requirements. The actual energy saving calculated depends on the stringency of measures, i.e. which impacts on percentage of sales volume affected is accepted.

- For compressors in the application ranges 'low pressure' and 'oil-free' it was not possible within the study constraints to retrieve sufficient data that allowed an assessment of realistic savings and their impacts. A very indicative analysis (see section 3.5) suggests that if a similar improvement as in standard air could be proven, the savings, through introduction of minimum energy efficiency requirements, would be of similar magnitude (0-2 TWh/yr).
- For compressors in the application ranges 'process gas' (both inert gases and hazardous gases) it was not possible within the study constraints to retrieve sufficient data that allowed an assessment of realistic savings and their impacts. A very indicative analysis (see section 3.5) suggests that, assuming a modest improvement potential could be proven, the savings, through introduction of minimum energy efficiency requirements, would be of much smaller magnitude (maximum 0.2 TWh/yr for process gas / hazardous gases). This is also due to the much longer product lives associated with this type of equipment (larger capital investments).

It should also be mentioned here that the savings potential **at system level** vastly exceeds that at (packaged) product level. An indicative analysis puts these savings, for the standard air application range, at some 10 TWh. However, the Ecodesign and Energy Labelling Directive are not suitable to unlock these system level savings. Energy audits (EMAS), awareness raising campaigns, and educational initiatives are more likely to be effective in realising these potential savings.

3.7 Recommendations

The study team recommends the following actions to be pursued by the Commission.

1. To prepare a Working Document, to be discussed in the Ecodesign Consultation Forum, that outlines a proposal for the introduction of generic and specific **ecodesign requirements**:
    a. minimum energy efficiency requirements: for compressors in the standard air application range:.
    b. information requirements: for compressors in the standard air application range, possibly to include also compressors in the low pressure and oil-free application range;
2. Discuss effectiveness and options for a potential **Energy labelling requirement** for compressors in the standard air application range;
3. To ask the relevant industries to start a **data collection effort**, similar to that of the 'statistical approach' applied to standard air compressors, regarding compressors in the low pressure and oil-free application range.
4. To be informed as regards the problems and solutions with regard to developing a **measurement and calculation method** that would allow a reasonable comparative assessment of the energy efficiency of positive displacement and turbo compressors.

Following the recommendations outlined above, certain elements of this Working Document have been elaborated.

3.7.1 Ecodesign requirements

3.7.1.1 Scope and definitions

Pending on the inclusion of compressors from the low pressure and oil-free application range, the scope will encompass either positive displacement compressors only (for standard air products) and/or turbo compressors as well (in case low pressure and oil-free are within scope).

The scope and definitions needed to regulate standard air products.

Scope

The measure applies to **variable speed compressors**, **fixed speed compressors** and **piston compressors** designed for use in **standard air applications** and for fixed and variable compressors has a minimum volume flow rate of 5 l/s and a maximum volume flow rate of 1280 l/s and for piston compressors a minimum volume flow rate of 2 l/s and a maximum volume flow rate of 32 l/s, with outlet pressures between 7 to 14 bar(g).

Definitions needed for compressors in standard air applications

1) **Compressor** means a product that comprises the prime mover or compression element, electric motor(s) and transmission or coupling, which is fully piped and wired internally, including ancillary and auxiliary items of equipment that is considered essential for safe operation and required for functioning as intended. A compressor may comprise additional components, such as components for air treatment (drying or filtering), etc.
2) **Positive displacement compressor** means a machine that creates a static pressure rise by allowing successive volumes of gas to be aspirated into and exhausted out of a closed space by means of the displacement of a moving member (source: ISO 1217)
3) **Rotary compressor** means a **positive displacement compressor** in which gas admission and diminution of its successive volumes or its forced discharge are performed cyclically by rotation of one or several rotors in a compressor casing.
4) **Reciprocating compressor** means a **positive displacement compressor** in which gas admission and diminution of its successive volumes are performed cyclically by straight-line alternating movement of a moving member(s) in a compression chamber(s)
5) **Fixed speed compressor** means a **rotary compressor** which is oil-injected, driven by a *three-phase electric motor*, which is not equipped with a *variable speed drive* when placed on the market.
6) **Variable speed compressor** means a **rotary compressor** which is oil-injected, driven by a three-phase electric motor, which is equipped with a variable speed drive when placed on the market.
7) **Piston compressor** means a **reciprocating compressor** in which the moving member constitutes a piston reciprocating in a cylinder, which is oil-injected and driven by a three-phase electric motor
8) **Three phase electric motor** (no need to define)
9) **Variable speed drive** means an electronic device controlling the motor speed pending on inputs
10) **Standard air application** means the intended use of the compressor is to supply air, aspirated from the ambient, at outlet pressure levels of between 7 to 14 bar(g) and which may have been in contact with media inserted in the compression chamber for cooling, lubrication and sealing of that chamber and the moving components contained therein.
11) **Volume flow rate** means the volume flow of compressed air, expressed for free air delivery at standard rating conditions

12) **Standard rating conditions** means air is aspirated at an inlet pressure of 1.013 * 10^5 Pa, a temperature of 20°C and a water content of .. gr/m^3

13) etc.

Note to reader: the elaboration of definitions for a possible Working Document is not part of the study and the above list is not complete. The above list should be regarded as a first, incomplete, attempt.

The scope and definitions needed to regulate low pressure and oil free products.

Scope

The measure applies to **low pressure compressors** and **oil free compressors** designed for use in **low pressure applications** and **oil free applications** that have a volume flow rate of at least xxx l/s and no more than yyy l/s.

Definitions needed for compressors in low pressure and oil free applications

1) **Low pressure compressors** means positive displacement compressors and turbo compressors intended for supplying a pressure ratio of xxx, and/or a maximum outlet pressure of ..., whichever forms the largest scope.
2) **Pressure ratio** means the outlet pressure divided by the inlet pressure, calculated for free air delivery at standard rating conditions
3) **Turbo compressor** means a compressor machine in which inlet, compression and discharge are continuous flow processes. The gas is conveyed and compressed in impellers and decelerated with further increase in pressure in fixed vane or vaneless stators (Source: ISO 5389)
4) **Positive displacement compressor** (see above, etc.)
5) etc.

Note to reader: the elaboration of the definitions for a possible Working Document is not part of the study and the above list is not complete. The above list should be regarded as a first, incomplete, attempt.

3.7.1.2 Exclusions

The scope may be limited by excluding compressors that

- operate under ATEX conditions (potentially explosive gas conditions, as defined in Directive 94/9/EC) as safety requirements are considered of higher importance than efficiency;
- are designed to handle hazardous gases, whereby hazardous refers to "gas or vapour with chemical, radioactive or biological properties (such as flammable, explosive, unstable, pyrogenic, corrosive, caustic, toxic, carcinogenic), which generate hazards by reactions inside the compressor or through dispersal or through reactions with the environment. A hazardous gas may be a mixture of gases with these properties" (text taken from EN 1012-1);
- are designed to function in ambient temperatures exceeding .. °C and/or designed to handle gases in below .. °C or beyond ..°C (exact values to determine later on).
- operate using single phase power, as these compressors are essentially more household products and have no significant energy consumption to reduce through ecodesign requirements.

Alignment with similar exclusion criteria for other, related, product groups should be sought.

The introduction of exclusions should not open up regulatory 'loopholes'. These exclusion criteria should be further refined during the preparation of Working Documents and the discussion in the Consultation Forum.

3.7.1.3 Ecodesign specific requirements

Minimum energy efficiency (during on-mode)

It is recommend to discuss in the Consultation Forum the possible introduction of minimum energy efficiency requirements. These can be expressed as a target value (in this study referred to as "d-value"), that -together with the formula for the regression curve - allow to calculate the specific minimum energy efficiency (isentropic efficiency) for a compressor.

Task 8 of this study shows the possible impacts of several 'd-values' as regards energy, costs and affected sales quantity.

Idle mode

Some stakeholders have suggested introducing a requirement regarding idle mode as well: Fixed speed OIS/OIV may operate in 'idle mode' on occasions. As the on-mode efficiency is regulated by minimum requirements on isentropic efficiency of the compressor (package) the idle mode power may be limited as well by introducing a requirement on maximum power consumption during idle mode. This requirement is not necessary for variable speed driven OIS/OIV as these operate continuously and also not necessary for piston compressors as these operate typically in on/off mode.

The operation of a compressor in no-load (idle) mode is the result of a typical control scheme applied by all almost all larger fixed speed (oil-injected screw) compressors. Such operation is required:

a) to enable easy start-up with reduced torque requirement (reduced back-pressure during starting) from standstill to full rotational speed;

b) to allow – when demand of compressed air is decreasing below full-load – short and/or frequent interruption of compressed air production without shutting down the compressor to standstill, if the past number or start-up sequences per operation time has reached a – size dependent – critical value. The background for this is that during each start-up the relatively large start-up currents heat the motor windings. To limit the motor winding temperature, the start-up frequency has to be limited and this sometimes requires an optional “parking” the compressor at idle mode, where the compressor is still rotating however at reduced power consumption (15…20% of full load power) and zero volume flow.

If the unload conditions remains for a certain time and there is no further risk of exceeding a critical start-up frequency, the compressor will shut-down.

Each full cycle from standstill over start-up to full load and back via venting and idling to standstill results in an additional energy requirement equivalent to about 15…20 seconds full load operation (for modern designed compressors). This is the “cycle energy requirement”.

Fixed speed oil-injected compressors therefore are well suited to serve applications in which they do not idle or cycle much. When fixed speed compressors idle or cycle much their efficiency deteriorates due to idling losses, especially if the cycling frequency is increasing.

The cycle frequency is defined by the compressor use and as such is **not part of the design** itself. Compressor manufacturers have tried to cope with this issue by introducing Master Controllers including advanced control algorithms (for multi-compressor installations) and Variable Speed Driven compressors (as stand-alone products and components of multi-compressor installations). It is obvious that the design of the compressed air network is of uttermost importance to minimize the losses; This is beyond the limits of the study and as was stated during the first stakeholder meeting this could only result in a recommendation, not in a requirement.

Small compressors, typically piston compressors, do not require steady state no-load operation because the problem of heating up the motor winding during start-up is less severe and the allowable start-up frequency is higher than for larger drives, but nevertheless mostly the pressure line between the compressor element and the storage vessel is vented before starting to reduce starting torque requirement and enable easy start-up.

The idle mode requirement could therefore be limited to an information requirement: Idle mode power as percentage of full load, or expressed as 'cycle energy requirement'. The current version of ISO 1217 however does not require any measurement of the transient behaviour, which would be a precondition to measure e.g. the "cycle energy requirement", which is not yet 100% precisely defined nor standardized anywhere.

3.7.1.4 Ecodesign generic requirements

In most cases the introduction of specific energy requirements are accompanied by mandatory information requirements. This is especially the case for rather complex products, and therefore this requirement is recommended to be introduced as well.

The information requirement to be developed under Ecodesign, could have an effect quite similar to that of the CAGI datasheets, as it presents the main information the buyers needs to know in a single overview.

But there is also a difference in the sense that the CAGI program is based on verification of performance (through random spot checks, factory visits, etc.) by an independent third party. Most Ecodesign requirements are based on self-declaration of performance, combined by market surveillance by national authorities. However, ongoing pressure on budgets of market surveillance authorities and their enlarged scope of responsibilities makes it more difficult to spot offenders.

The main model information could contain the following items (example for standard air application).

Table 3-24 Possible template for information requirements

Manufacturer			
Model identifier			
Cooling method	Air-cooled / water-cooled		
Oil-free	Yes / no	(if yes, then not 'standard air' application)	
Compression stages	.. (number of stages)		
	(value)	(unit)	(remark)
Rated capacity at full load operating pressure	..	Actual m^3/s	ISO 1217, Annex C
Full load operating pressure		Pa	
Maximum full load operating pressure		Pa	
Drive motor nominal rating		kW	
Drive motor nominal efficiency		%	
Fan motor nominal rating (if applicable)		kW	

Fan motor nominal efficiency	%	See also Regulation 327/2011
Basic package input power at zero flow	kW	Only core features enabled
Total package input power at zero flow	kW	All package features enabled
Basic package input power at rated capacity and full load operating pressure	kW	Only core features enabled
(for variable speed products the input power and capacity should be stated for volume flow of 100%, 70% and 40% of nominal volume flow)	kW	
Isentropic efficiency	%	

Notes:

a) Measured at the discharge terminal point of the compressor package in accordance with ISO 1217, Annex C; actual m^3 per second at inlet conditions.

b) The operating pressure at which the Capacity (Item 3) and basic package input power (Item 11) were measured Member for this data sheet.

c) Maximum pressure attainable at full flow, usually the unload pressure setting for load/no load control or the maximum pressure attainable before capacity control begins. May require additional power.

d) Total package input power at other than reported operating points will vary with control strategy.

e) Tolerance is specified in ISO 1217, Annex C.

It is important to state the intended or appropriate use in connection to the information requirements, so that comparing energy efficiency values is done for comparable products only.

3.7.2 Energy labelling

As discussed in section 3.2.1 of Task 8, the option for introduction of mandatory energy labelling should be discussed with stakeholders.

With most compressors being sold to professional clients, most often well aware of benefits from buying energy efficient products, the added benefit of a mandatory energy labelling scheme appears limited. In particular considering that the buyers who are believed to be most susceptible to energy labelling information (choosing smaller equipment), represent only a very small segment of overall compressor energy usage.

However, it is also known that a simple, useful and attractive energy efficiency metric could act as a powerful marketing tool, thereby spurring innovation and increasing awareness of buyers.

Whether the (possibly modest) energy savings weigh up against the additional burden for introducing and maintaining a credible energy labelling scheme could not be assessed by this study. Moreover so, since Ecodesign requirements may also lead to better informed prospective buyers. The main difference would be that the Energy Labelling Directive addresses retailers, and the Ecodesign Directive does not.

3.7.3 Data collection effort

Several stakeholders have asked the relevant industries to validate the indicative savings identified for the low pressure and oil free application ranges, or at minimum supply data that would allow a proper analysis. Having gone through a similar exercise for standard air application range, the additional effort was deemed to be limited.

This may be true for setting up the data collection, aggregation and consolidation process, but the time gained will be overcompensated by additional effort due to the higher complexity of the product ranges.

The low pressure application range consists of 6 basic families :

1. Roots blowers
2. Piston compressors
3. Screw blowers
4. Liquid ring compressors
5. Side-channel blowers
6. Turbo-compressors

Note: for low pressure applications often the word 'blower' is used. This term should not be confused with fan applications that may also be referred to as blowers.

The oil free application range also consists of 6 basic families :

1. Piston compressors
2. Scroll compressors
3. Rotary lobe compressors
4. Water-injected compressors
5. Screw compressors
6. Turbo-compressors

Within these application ranges it may be necessary to identify subcategories to differentiate the typical use of the compressors, similar to standard air (intermittent, fluctuating, steady-state).

As compressors of both the positive displacement and turbo compressor technology are present in both application ranges it should be made possible to compare the energy efficiency of overlapping product families within an application range. This however requires caution, as sometimes a single specific feature can justify the existence of the family. A detailed analysis has to be performed in order to avoid both loopholes and unjustified elimination of product families.

Performance data of positive displacement compressors are stated according to ISO1217, and of turbo compressors according to ISO5389. Both allow establishing the performance of the compressor, but the actual values cannot be compared directly, which means that there is no way to make a straightforward accurate comparison of the performance data of volumetric and dynamic compressors. This constitutes a complication for introducing implementing measures. This difficulty didn’t occur for standard air, where only “volumetric” compressors are included.

As the approach taken for standard air was based on “isentropic efficiency” as efficiency measure, the effect of the discharge pressure was cancelled out. This is simplification may not be possible for oil free applications and is certainly not possible for low pressure applications.

Other aspects to consider is the definition of the product boundaries as also in the low pressure and oil free application ranges (very) basic and 'featured' products are placed on the market.

Therefore, it is recommended that a “statistical approach” similar to that of standard air, but tuned towards tackling of issues identified above, needs to be developed, which requires quite possibly a comparable effort.

In anticipation of this effort manufacturer's association Pneurop will start to re-organize the representation of the manufacturers in the Ecodesign working group in view of an extension towards the application ranges low pressure and oil free.

3.7.4 Measurement and calculation methods

Basic package versus featured packages

In case the compressor package is equipped with additional features such as refrigerated dryers, the current ISO 1217 performance assessment does not give an agreed method to correct or compensate for these extra features in order to arrive at the basic package boundaries.

Therefore a method for either disconnecting the extra equipment, or for correcting for extra losses (i.e. pressure losses) needs to be described, possibly as transitory method or in the measurement and calculation Annex of the regulation.

Displacement and turbo compressor standards

For positive displacement compressors the ISO 1217 standards gives the performance measurement method. For turbo compressors the ISO 5389 standards gives the performance measurement method. These standards are globally accepted for this purpose.

As introducing ecodesign requirements in the low pressure and oil free application ranges is a possibility, provided a thorough analysis shows the criteria for setting requirements can be met, a comparative assessment of the different compressor technologies in the same application range needs to be developed. This method development will most likely take place both at manufacturer level (through Pneurop Working Groups) but will inevitably also be tabled in European Standardisation Organisations (likely a CEN subject).

This means that the Commission will amend the horizontal Ecodesign mandate M495, and is prone to observe the work items processed by the relevant technical committees and working groups.

In parallel the Commission services could continue to prepare the regulatory approach for the low pressure and oil free application ranges, in order to allow standardization efforts and regulatory efforts to go 'hand-in-hand'.

3.7.5 Programs and tools for system level savings

As energy savings at system level is believed to exceed the savings at product level, a recommendation is made to assess current EU programs and policy tools for their potential to address compressed air system level savings.

ANNEX I - Modelling of savings in other application ranges

Table 0-1 Other application ranges - sales ('000 units) + product life (yrs)

Sales ('000 units)	1990	1995	2000	2005	2010	2015	2020	2025	2030	product life (yr)
Low Pressure	9	15	17	15	12	12	13	17	27	15
Oil Free	1	2	3	2	2	2	2	3	4	20
Process / inert	0,02	0,02	0,02	0,03	0,03	0,03	0,03	0,03	0,03	
Turbo	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	30
Rotary lobe	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	20
process / hazardous	0,16	0,17	0,17	0,18	0,19	0,20	0,20	0,20	0,20	
Piston	0,12	0,13	0,13	0,14	0,15	0,15	0,15	0,15	0,15	35
Turbo	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	30
Screw/ oil free	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	20
Screw/ oil injected	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	20
Rotary lobe	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	20

Table 0-2 Other application ranges - stock ('000 units)

Stock ('000 units)	1990	1995	2000	2005	2010	2015	2020	2025	2030
Low Pressure	48	107	179	221	223	202	188	201	252
Oil Free	8	17	30	40	44	45	41	41	49
Process / inert	0,20	0,52	0,54	0,57	0,60	0,63	0,65	0,67	0,68
Turbo	0,00	0,31	0,33	0,34	0,36	0,38	0,39	0,41	0,42
Rotary lobe	0,20	0,21	0,22	0,23	0,24	0,25	0,26	0,27	0,27
process / hazardous	0,48	0,77	4,79	5,04	5,30	5,56	5,79	5,97	6,12
Piston	0,00	0,00	3,98	4,19	4,40	4,62	4,81	4,98	5,11
Turbo	0,00	0,27	0,28	0,29	0,31	0,32	0,34	0,35	0,36
Screw/ oil free	0,10	0,10	0,11	0,11	0,12	0,12	0,13	0,13	0,13
Screw/ oil injected	0,18	0,19	0,20	0,21	0,23	0,24	0,24	0,25	0,25
Rotary lobe	0,20	0,21	0,22	0,23	0,24	0,26	0,26	0,27	0,27

Table 0-3 Other application ranges - energy BAU-freeze

Energy / BAU-freeze	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**	
Low Pressure	11	24	40	49	49	45	41	44	56	TWh/yr
Oil Free	7	15	26	35	39	39	36	36	43	TWh/yr
Process / inert	0,18	16,16	16,99	17,87	18,79	19,71	20,50	21,13	21,61	TWh/yr
Turbo	0,00	15,96	16,79	17,65	18,56	19,47	20,25	20,88	21,36	TWh/yr
Rotary lobe	0,18	0,19	0,20	0,21	0,23	0,24	0,24	0,25	0,25	TWh/yr
process / hazardous	1,13	19,20	25,49	26,80	28,18	29,57	30,75	31,72	32,44	TWh/yr
Piston	0,00	0,00	5,30	5,58	5,86	6,15	6,41	6,62	6,80	TWh/yr
Turbo	0,00	18,01	18,94	19,92	20,94	21,97	22,85	23,56	24,10	TWh/yr
Screw/ oil free	0,38	0,40	0,43	0,45	0,47	0,49	0,51	0,52	0,53	TWh/yr
Screw/ oil injected	0,64	0,67	0,71	0,74	0,78	0,82	0,85	0,87	0,88	TWh/yr
Rotary lobe	0,10	0,11	0,11	0,12	0,13	0,13	0,14	0,14	0,14	TWh/yr

Table 0-4 Other application ranges - energy Eco-option

Energy / eco-option	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**	
Low Pressure	11	24	40	49	49	45	41	43	53	TWh/yr
Oil Free	7	15	26	35	39	39	36	36	41	TWh/yr
Process / inert	0,18	16,16	16,99	17,87	18,79	19,71	20,48	21,07	21,50	TWh/yr
Turbo	0,00	15,96	16,79	17,65	18,56	19,47	20,23	20,83	21,25	TWh/yr
Rotary lobe	0,18	0,19	0,20	0,21	0,23	0,24	0,24	0,25	0,25	TWh/yr
process / hazardous	1,13	19,20	25,49	26,80	28,18	29,57	30,72	31,63	32,28	TWh/yr
Piston	0,00	0,00	5,30	5,58	5,86	6,15	6,40	6,61	6,77	TWh/yr
Turbo	0,00	18,01	18,94	19,92	20,94	21,97	22,83	23,50	23,98	TWh/yr
Screw/ oil free	0,38	0,40	0,43	0,45	0,47	0,49	0,51	0,52	0,52	TWh/yr
Screw/ oil injected	0,64	0,67	0,71	0,74	0,78	0,82	0,85	0,86	0,87	TWh/yr
Rotary lobe	0,10	0,11	0,11	0,12	0,13	0,13	0,14	0,14	0,14	TWh/yr

Table 0-5 Other application ranges - savings

Energy / saved	2020	2030	
Low Pressure	0,3	2,4	TWh/yr
Oil Free	0,2	1,5	TWh/yr
Process / inert	0,0	0,1	TWh/yr
Turbo	0,02	0,11	TWh/yr
Rotary lobe	0,00	0,00	TWh/yr
process / hazardous	0,03	0,17	TWh/yr
Piston	0,01	0,03	TWh/yr
Turbo	0,02	0,12	TWh/yr
Screw/ oil free	0,00	0,00	TWh/yr
Screw/ oil injected	0,00	0,01	TWh/yr
Rotary lobe	0,00	0,00	TWh/yr

[end]