Evaluation and Monitoring for the EU Directive on Energy End-Use Efficiency and Energy Services

EMEEES bottom-up case application 13: Variable Speed Drives

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evaluate energy savings EU

coordinated by
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The Project in brief

The objective of this project is to assist the European Commission in developing harmonised evaluation methods. It aims to design methods to evaluate the measures implemented to achieve the 9% energy savings target set out in the EU Directive (2006/32/EC) (ESD) on energy end-use efficiency and energy services. The assistance by the project and its partners is delivered through practical advice, technical support and results. It includes the development of concrete methods for the evaluation of single programmes, services and measures (mostly bottom-up), as well as schemes for monitoring the overall impact of all measures implemented in a Member State (combination of bottom-up and top-down).

Consortium

The project is co-ordinated by the Wuppertal Institute. The 21 project partners are:

Project Partner	Country
Wuppertal Institute for Climate, Environment and Energy (WI)	DE
Agence de l'Environnement et de la Maitrise de l'Energie (ADEME)	FR
SenterNovem	NL
Energy research Centre of the Netherlands (ECN)	NL
Enerdata sas	FR
Fraunhofer-Institut für System- und Innovationsforschung (FhG-ISI)	DE
SRC International A/S (SRCI)	DK
Politecnico di Milano, Dipartimento di Energetica, eERG	IT
AGH University of Science and Technology (AGH-UST)	PL
Österreichische Energieagentur – Austrian Energy Agency (A.E.A.)	AT
Ekodoma	LV
Istituto di Studi per l'Integrazione dei Sistemi (ISIS)	IT
Swedish Energy Agency (STEM)	SE
Association pour la Recherche et le Développement des Méthodes et Processus Industriels (ARMINES)	FR
Electricité de France (EdF)	FR
Enova SF	NO
Motiva Oy	FI
Department for Environment, Food and Rural Affairs (DEFRA)	UK
ISR – University of Coimbra (ISR-UC)	PT
DONG Energy (DONG)	DK
Centre for Renewable Energy Sources (CRES)	EL

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Contents

1 Summary

1.1 Title of the method

Variable Speed Drives

1.2 Type of EEI activities covered

End-use EEI action	
Sector	Industry and tertiary
Energy end-use	Motors and drives
Efficient solution	Variable speed drives smaller than 22kW and variable speed drives bigger than or equal to 22kW
EEI Facilitating measure	
Types of EEI facilitating measures	- Performance Contracting - Financial Tools (rebates, low interest rates, taxation) - White Certificates Schemes - Regulations (minimum efficiency standards) - Information Tools (Advice, Training and Audits)

1.3 Detailed definition of EEI activities covered

The facilitating measures covered can take the following forms.

- Performance Contracting:

  - A certain amount of energy savings is contracted typically to the lowest bidder (e.g. an ESCO) who has a timeframe to achieve an energy savings target. VSDs are among the most common measures for industrial programmes

- Financial Tools:

  - Rebates covering part of VSD cost
  - Zero or low interest rates
  - Taxation (e.g. faster depreciation rates)

- Special EEI mechanism: White Certificates Schemes:

  - Electricity distribution network or supply companies/ESCOs should promote the adoption of VSDs
  - Financial Support for users of VSDs

- Percentage of energy sales revert to suppliers of WhCs

- Regulations forcing energy consumers and distributors to increase global efficiency (minimum efficiency standards).

- Information Tools:

  - Advice and training
  - Energy Audits
  - Lifecycle costing

1.4 General specifications

- conditions for energy savings to be eligible (e.g. compliance with a quality charter or minimum level of energy performance):
  - Variable load requirements (set a minimum/reference: e.g. part-load operation ≥ 20% of operating time)
  - Number of operating hours (set a minimum/reference: e.g. ≥2000 hours)
  - Process improvements (as an additional positive condition).

- Regulations and Standards:

Norm CEI EN 61800-2: Electrical drives with variable speed. Part 2: general prescription and nominal specifications for drives in low tension with ac motors.

  - Motor Labeling (Eff1, Eff2, Eff3) and new motor classification standards (IEC-60034-30)

- conditions requiring level 2 and 3 efforts for a particular point or for the whole evaluation (e.g., special conditions on a parameter responsible of major uncertainties)

Conditions requiring level 2 of efforts:

  - European Average Data is thought to have some uncertainty, particularly for buildings on space conditioning loads, probably leading to an underestimation of savings.

Conditions requiring level 3 of efforts:

- Situations in which the variable load requirement diagrams are largely unknown.
- Large units (above 22 kW, inclusive), which deserve a more detailed evaluation.

1.5 Formula for unitary gross annual energy savings

For this method on variable speed drives, the unit is an electric motor of a certain mechanical power, on which a VSD is installed.

For motors with a mechanical power < 22 kW:

$$\text{unitary gross annual energy savings} = \left(\frac{P_{mec}}{\eta} * Av.LoadFactor * Av.OperatngHours\right) * Av.DefaultSavings$$

(Equation S1a)

Where:
P_{mec} - Mechanical power taken from nameplate;
η - Motor Efficiency from reference Table 1.

For motors with a mechanical power of 22 kW and higher:

$$\text{unitary gross annual energy savings} = \sum_i \left(\left(P_T^i - P_{VSD}^i\right) * h^i\right)$$

(Equation S1b)

Where:
P_T^i – Electrical Power, with throttle control
P_{VSD}^i – Electrical Power, with VSD
h^i – Number of working hours for each power level
i – Load profile index (Number of hours for each load range).

1.6 Indicative default value for unitary gross annual energy savings

Two different approaches are recommended for VSDs. For power levels below 22 kW, the level of effort that the present evaluation method suggests is level 1, 2 or 3 (specific for the facilitating measure), always using equation S1a. On the other hand, for VSDs above 22 kW, inclusive, the level of effort for the evaluation should be level 3 and unit case-specific, using equation S1b.

EU default/harmonised values	
Unitary annual energy savings Default/harmonised	Default values for (a) Motor efficiency (Table 1), as well as, for different end uses, (b) Annual operating hours (Table 2), (c) Load factors (Table 2), and (d) percentage of energy savings through VSDs (Table 3) are included in this document (chapter 3).

1.7 Formula for total ESD annual energy savings

If all correction factors are included, the formula for the total ESD (net) annual energy savings will read:

total net annual energy savings
= total gross annual energy savings of all VSDs (from equation 3)
** (1 - free-rider coefficient*+ multiplier coefficient)*
** double-counting factor*

(Equation S2)

**not mentioned in the ESD, only to be applied if the aim is to calculate additional energy savings*

1.8 Indicative default value for energy savings lifetime

The following value is suggested as a default value.

EU default/harmonised values	
Savings Lifetime Default	8 years (value of CWA 27)

1.9 Main data to collect

Data needed in calculation for EU values (level 1)	Examples of corresponding data sources
Mechanical power	Nameplate data and information from participants
Type of application (pump, fan, compressor, conveyor, other)	
Number of VSD sold	information from participants

Before the 1998 (date of the CEMEP-EC efficiency labelling voluntary agreement), most motors had neither the nominal efficiency, not the efficiency class in the nameplate. However before this agreement the motor market was largely dominated by Class 3 motors. After 1998 the efficiency class appears in the nameplate, and the motor market progressively became a Class 2 market. Because motor efficiency can not be collected from nameplates, Table 1 indicates the motor efficiencies to be used.

Data to be collected National or measure-specific method for motors of less than 22 kW (level 2 and 3)	Examples of corresponding data sources
Average percentage of energy savings from VSDs (per end-use and possibly power range)	Previous European (e.g. SAVE) and MS Studies (see Bibliography); studies specific for the facilitating measure
(Average) Number of working hours (per end-use and power range)	
(Average) Load Factor (per end-use and power range)	
Mechanical power	Nameplate data and information from participants
Type of application (pump, fan, compressor, conveyor, other)	
Number of VSD sold	information from participants

Data to be collected Specific method for motors of 22kW and higher (level 3, case-specific)	Examples of corresponding data sources
Motor electricity consumption	End-use Metering diagrams
Flow Data Requirements	Analysis of Process Time Diagrams Flow Measurement
Number of VSD sold	information from participants

2 Introduction

2.1 Twenty bottom-up case applications of methods

Within EMEEES, task 4.1 provided methodological materials in the internal working paper “Definition of the process to develop harmonised bottom-up evaluation methods”, version 20 April 2007; an update has been published as an Appendix to the report on Bottom-up methods at www.evaluate-energy-savings.eu. Based on this draft report, concrete bottom-up case applications were developed by EMEEES partners within task 4.2, and reference values were to be specified within task 4.3.

This report deals with case application 13 “Variable Speed Drives” developed by University of Coimbra (ISR-UC).

Eleven project partners have developed concrete bottom-up case applications for a specific type of technology or energy efficiency improvement measure or end-use action. All gave comments and input to the methods developed by the other organisations.

The 20 case applications developed are presented in the table below:

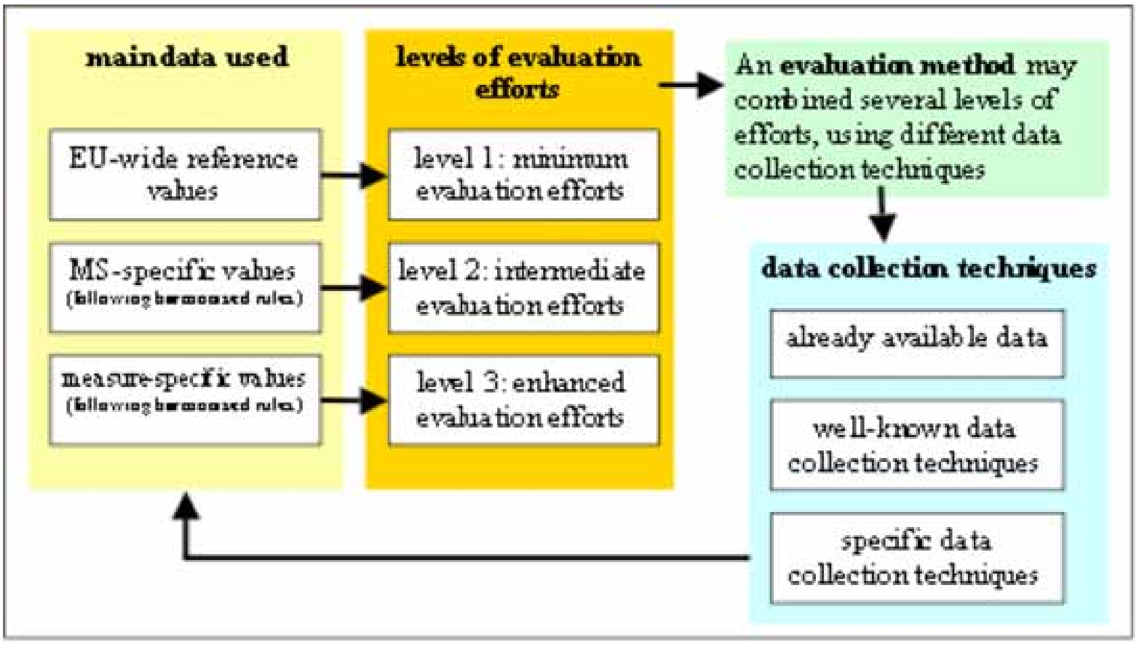
Nº	End-use or end-use action, technology, or facilitating measure	Sector	Responsible organisation
1	Building regulations for new residential buildings	Residential	SenterNovem
2	Improvement of the building envelope of residential buildings	Residential	AEA
3	Biomass boilers	Residential	AGH-UST
4	Residential condensing boilers in space heating	Residential	Armines
5	Energy efficient cold appliances and washing machines	Residential	ADEME
6	Domestic Hot Water – Solar water heaters	Residential	AGH-UST
7	Domestic Hot Water - Heat Pumps	Residential	AGH-UST
8	Non residential space heating improvement in case of heating distribution by a water loop	Tertiary	eERG
9	Improvement of lighting systems	Tertiary (industry)	eERG
10	Improvement of central air conditioning	Tertiary	Armines
11	Office equipment	Tertiary	Fraunhofer

Nº	End-use or end-use action, technology, or facilitating measure	Sector	Responsible organisation
12	Energy-efficient motors	Industry	ISR-UC
13	Variable speed drives	Industry	ISR-UC
14	Vehicle energy efficiency	Transport	Wuppertal Institute
15	Modal shifts in passenger transport	Transport	Wuppertal Institute
16	Ecodriving	Transport	SenterNovem
17	Energy performance contracting	Tertiary and industry end-uses	STEM
18	Energy audits	Tertiary and industry end-uses	Motiva
19	Voluntary agreements – billing analysis method	Tertiary and industry end-uses	SenterNovem
20	Voluntary agreements with individual companies – engineering method	Tertiary and industry end-uses	STEM

2.2 Three levels of harmonisation

In order to be as practicable as possible and to stimulate continued improvement, the harmonised reporting on bottom-up evaluation is structured on three levels (cf. figure 1).

Figure 1: Three levels of harmonisation



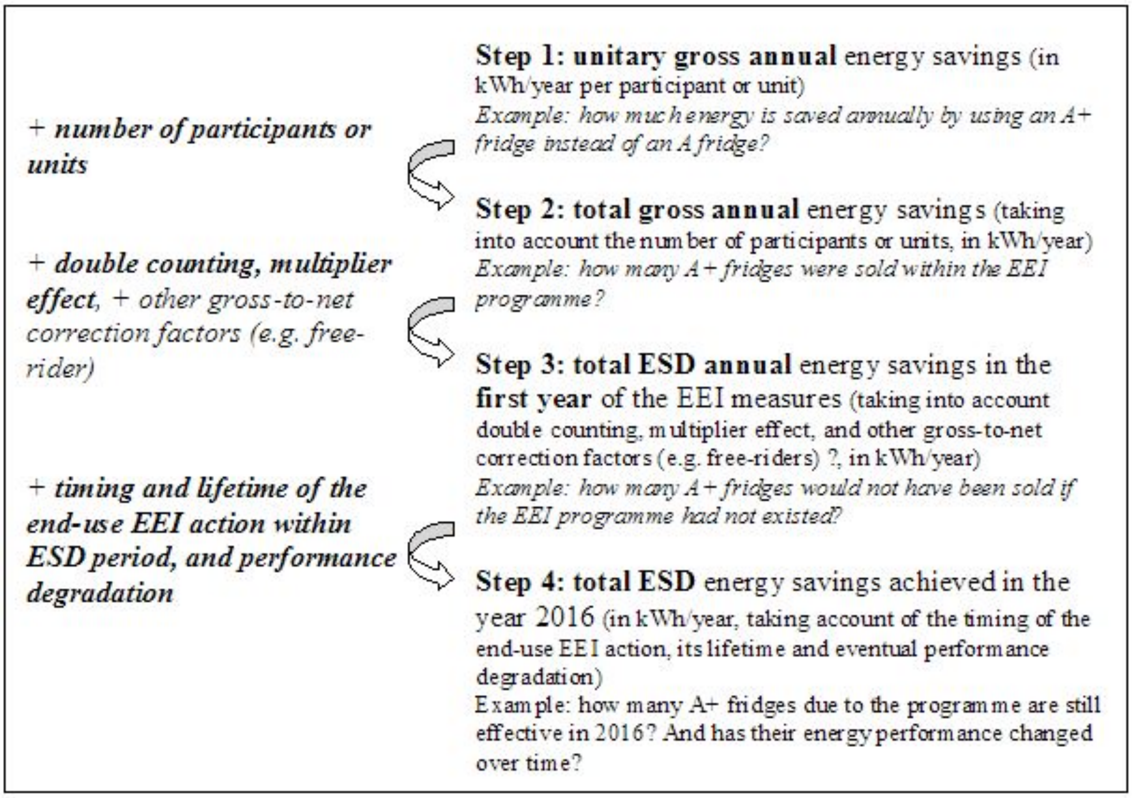
As a consequence, the EMEEES case applications for bottom-up evaluation methods present:

- EU wide reference values, if applicable;
- Guidelines how Member States can use country-specific values following harmonised rules;
- Guidelines how measure- or action-specific (national) values can be developed, following harmonised rules.

2.3 Four steps in the calculation process

The harmonised rules for bottom-up evaluation methods are organised around four steps in the calculation process (cf. figure 2). These steps are presented in detail in the report for WP 4.1.

Figure 2: Four steps in the calculation process



The reports on the concrete bottom-up case applications follow the format of these four steps and they each hold six chapters plus some annexes:

1. summary
2. introduction
3. step 1: unitary gross annual energy saving
4. step 2: total gross annual energy savings
5. step 3: total ESD annual energy savings
6. step 4: total ESD energy savings for year "i"

2.4 Pilot tests

Additional to the development of the 20 bottom-up case applications, some of these cases were tested in practice in Work Package 8.
Pilot tests of the following case applications were performed by EMEEES partners in Italy, France, Denmark, and Sweden:

EMEEES case application	Sector	Italy	France	Denmark	Sweden
Building envelope improvement	Residential		X		
Energy-efficient white goods	Residential	X			
Biomass boilers in the residential sector	Residential		X		
Condensing Boilers	Residential	X	X		
Improvement of lighting system	Tertiary (industry)				X
High efficiency electric motors	Industry	X			
Variable speed drives	Industry	X			
Energy audits	Tertiary and industry end uses			X	
Energy performance contracting	Tertiary and industry				X

The following EEI measures were evaluated ex-post using the above-mentioned EMEEES bottom-up case applications:

Country	Subject	Sector(s) addressed
France	Condensing boilers, building envelope improvements and compact fluorescent lamps under the French White Certificates.	Residential
Italy	Schemes under the Italian White Certificates system	Residential, tertiary, industry
Sweden	Energy Efficiency Investment Programme for Public Buildings (2005-2008)	Public non-residential buildings
Denmark	Energy audits performed in Denmark between 2006 and 2008	Industry, tertiary

As a result of the pilot tests, some of the case applications tested were updated to reflect the findings of the tests.

3 Step 1: Unitary gross annual energy savings

3.1 Step 1.1: General formula and calculation model

LEVEL 1, 2 and 3 for VSDs < 22 kW

The unit is one VSD installed. The unitary gross annual energy savings are given by the following formula.

$$\text{unitary gross annual energy savings per unit} = \left(\frac{P_{mec}}{\eta} * Av.LoadFactor * Av.OperatingHours\right) * Av.DefaultSaving$$

(Equation 1)

For LEVEL 1, the proposed average Load factor and average number of Operating hours by power range and end-use are provided in Table 2. The average default savings for LEVEL 1 are provided in Table 3. For LEVELS 2 and 3, country-wide or measure-specific values for these parameters have to be evaluated (ex-ante or ex-post). The electric input power of the motor, on which the VSD is installed, is always to be collected for each individual unit with the following equation for LEVELS 1, 2 and 3.

$$P_{elec} = \frac{P_{mec}}{\eta}$$

Where:

P_{mec} - Mechanical power taken from nameplate;

P_{elec} - Electric power;

η - Motor Efficiency from reference Table 1

(n.b only P_N between 0,75 and 18,5 kW in Table 1 is relevant for this method).

Table 1 – Efficiency values from motors per power range[1]*.*

P_N(kW)	Efficiency	P_N(kW)	Efficiency
	Standard		**Standard**
0,75	72,1	22	89,9
1,1	75,1	30	90,8
1,5	77,2	37	91,3
2,2	79,7	45	91,7
3	81,5	55	92,2
4	83,1	75	92,7
5,5	84,7	90	93
7,5	86,1	110	93,3
11	87,6	132	93,6
15	88,7	160	93,8
18,5	89,4	200 and above	94

LEVEL 3 for VSDs on motors ≥ 22 kW

Case Specific (data to be directly measured or collected for each case):

Unitary gross annual energy savings can directly be calculated for each VSD, using the following formula.

$$\text{unitary gross annual energy savings per unit} = \sum_i \left(\left(P_T^i - P_{VSD}^i\right) * h^i\right)$$

(Equation 2)

Where:
P_T^i – Electrical Power, with throttle control
P_{VSD}^i – Electrical Power, with VSD
h^i – Number of working hours for each power level
i – Load profile index (Number of hours for each load range)

This method is used, e.g., in Italy for the White Certificates schemes for motors ≥ 22 kW.

[1] See Appendix I – Justification and Sources, nº1.

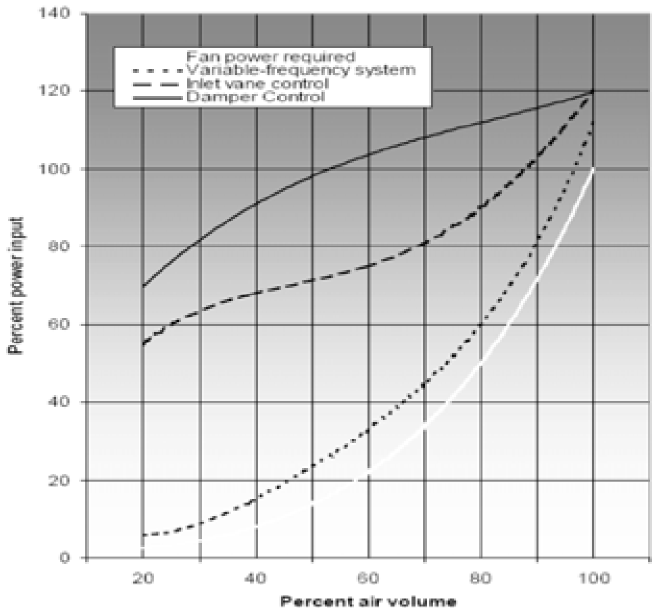


Figure 1 – Input Power versus Flow for a Ventilation System[2]. Example of the type of system curves that is necessary for calculations.

3.2 Step 1.2: Baseline

The baseline to be considered is EFF2 motors with throttle control. EFF 2 motors represent about 85% of motor sales in 2005 in the EU [17, page 52]. However, the motor stock is still dominated by low efficiency motors EFF3. Therefore, if we consider as the baseline EFF2 motors, the evaluated savings will be conservative.

This baseline should, however, be assessed from time to time, e.g., after introduction of the EuP standard for electric motors. If the market and stock of motors have become more energy-efficient, the baseline will have to be adapted.

The energy consumption before installation of a VSD is valid as the baseline, no matter whether the aim is to calculate all or additional energy savings.

[2] See Appendix I – Justification and Sources, nº3, pag 31.

level 1	**Default:** European Average Load Factor values and annual Operating Hours by type of end-use, for motors with throttle control **Power Ranges:** (kW) [0.75;4[, [4;10[, [10;22[.
level 2	**Guidelines:** Baseline should be based on MS National data **Data needed:** National Average Motor load factor, per power range and end-use, for motors without speed control. National Average Operating hours of motors. **Power Ranges:** (kW) [0.75;4[, [4;10[, [10;22[**Source:** national statistics, surveys, samples
level 3 (for motors < 22kW)	**Guidelines:** Baseline should be based on data specific for the EEI measure **Data needed:** Target-group specific Average Motor load factor, per power range and end-use, for motors without speed control. Target-group specific Average Operating hours of motors. **Power Ranges:** (kW) [0.75;4[, [4;10[, [10;22[**Source:** national statistics, surveys, samples
level 3 (case specific, motors of 22 kW and bigger))	**Guidelines:** Baseline should be **based on participants' data** **Data needed:** System curve: e.g. Power Consumption Vs. Flow, Number of Operating hours, Motor efficiency (previous to the installation of the VSD equipment). **Power Ranges:** (kW) [22,70[, [70,130[, [130,500[, [500;---[**Source:** new measurements or previous data collections

3.3 Step 1.3: Requirements for normalization factors

Annual Operating hours and Load factors are both an input parameter for the calculation of energy savings, and a potential normalization factor for VSDs.

In evaluations using Equation 1 for motors < 22 kW, average values are taken to calculate energy savings. Whenever these averages are changed based on new data that become available, the energy savings of the VSDs that are still in place must be recalculated accordingly.

In evaluations using Equation 2 for motors of 22 kW and larger, the Operating hours are estimated for the individual motor, and the load profile, too. In principle, for each motor, the validity of these data would need to be constantly monitored and adapted each year. This will, however, be too costly. A solution could be to estimate the magnitude of any changes based on a random sample of electric motors, and apply this to the overall calculated energy savings.

3.4 Step 1.4 Specifying the calculation method and its three related levels

level 1, 2 and 3 for motors < 22 kW	Deemed Estimates based on previous EU studies, combined with monitoring of electric input power of individual motors, on which VSDs are installed Statistically adjusted engineering analyses as an instrument to improve default values and normalize energy savings to changing average Load factors and Operating hours
level 3 for motors of 22 kW or bigger	Direct Measurements: End-use Load Data Metering (for load profile and power input by load profile range) Possibly: Billing Analysis in installations with load monitoring and/or submetering Engineering Estimates: Simple engineering estimates Mixed deemed and Ex-post estimates

3.4.1 **Conversion factors** (when relevant)

Not applicable (SI units should be used wherever possible).

3.4.2 Considering the direct rebound effect

It seems reasonable to assume that there is no direct rebound effect for VSDs. No reference to a direct rebound effect from the use of VSDs was found in the literature.

3.4.3 From EMEEES tasks 4.2 to 4.3: defining values and requirements

3.4.3.1 Default values for energy consumption and/or related parameters

Benchmarks and default values may be either directly values for the corresponding parameters/coefficients, or values of energy consumption related to parameters.

Data that can affect the evaluated energy consumption of VSD (cf. equations 1 and 2):

- Number of working hours per power range
- Load Diagram per power range
- Load Factor (by power range)
- Flow Diagram per power range
- Motor Efficiency by power range.

Average Operating Hours	
level 1	**Default values** from previous studies (Table 2).
level 2	**Guidelines to derive national default values**: data from national statistics Data required: Average number of operating hours **Source:** national statistics, surveys, samples.
level 3 for motors < 22kW	**Guidelines to derive measure-specific average values**: data from national and target-group specific statistics Data required: Average number of operating hours **Source:** national and target-group specific statistics, surveys, samples.
level 3 (case-specific)	**No default values. Guidelines to collect individual data**: data from registries and measurements Data required: number of operating hours for each load range **Source:** end-use metering, registries.

Default Load Factor Values	
level 1	**Default values** from previous studies (Table 2).
level 2	**Guidelines to derive national default values:** data from national statistics for each MS Data required: Average Load Factor Values **Source:** national statistics, surveys, samples.
level 3 for motors < 22kW	**Guidelines to derive measure-specific average values**: data from national and target-group specific statistics Data required: Average Load Factor Values **Source:** national and target-group specific statistics, surveys, samples.
level 3 (case-specific)	**No default values. Guidelines to collect individual data**: function of the system curve, to be used in eq. 2 - calculation of savings: measure-specific **Data required**: Power vs. Flow Data time diagrams.

LEVEL 1: if data not directly available (eq.1)[3]:

For LEVEL 1 effort, the following values (Table 2) can be used. These values have been estimated based on previous Motors SAVE studies.

[3] Additional data, including average operating hours, average load factor, average efficiency, number of motors and average power by power range in several industrial sectors: See Appendix I – Justification and Sources, nº2

Table 2 – Estimated values for operating hours and load factor from previous studies[4].

Power ranges	Type of Applications	Industry			Tertiary		
		Hours (h)	Load factor	LFH(Load Factor*Hours)	Hours (h)	Load factor	LFH(Load Factor*Hours)
[0,75;4[	Pumps	3.861,03	0,55	2.123,57	3.800,00	0,55	2.090,00
[4;10[		4.501,94	0,58	2.611,13	3.050,00	0,60	1.830,00
[10;22[		5.040,47	0,59	2.973,88	3.000,00	0,60	1.800,00
[0,75;4[	Fans	4.910,47	0,53	2.602,55	2.250,00	0,60	1.350,00
[4;10[		4.137,76	0,56	2.317,15	2.500,00	0,65	1.625,00
[10;22[		5.210,64	0,59	3.074,28	2.500,00	0,65	1.625,00
[0,75;4[	Air Compressor	2.177,99	0,63	1.372,13	1.030,00	0,40	412,00
[4;10[		4.057,72	0,60	2.434,63	1.000,00	0,45	450,00
[10;22[		4.625,99	0,68	3.145,67	980,00	0,45	441,00
[0,75;4[	Conveyors	3.060,75	0,42	1.285,52	621,00	0,61	378,81
[4;10[		2.787,90	0,41	1.143,04	916,00	0,53	485,48
[10;22[		3.908,61	0,51	1.993,39	725,00	0,49	355,25
[0,75;4[	Cooling Compressors	5.051,90	0,60	3.031,14			-
[4;10[		1.890,63	0,65	1.228,91			-
[10;22[		5.066,59	0,70	3.546,61			-
[0,75;4[	Refrigeration				4.200,00	0,70	2.940,00
[4;10[					4.170,00	0,70	2.919,00
[10;22[					4.050,00	0,75	3.037,50
[0,75;4[	Others	3.086,64	0,34	1.049,46	500,00	0,30	150,00
[4;10[		2.859,49	0,39	1.115,20	530,00	0,30	159,00
[10;22[		2.299,44	0,45	1.034,75	570,00	0,30	171,00

To calculate the savings one can use the values in table 1 and table 2, and equation 1 is then simplified as follows:

$$\text{unitary gross annual energy savings} = \frac{P_{mec}}{\eta} * LFH * Av.Def\,aultSaings$$

[4] See Appendix I – Justification and Sources, nº2

Default Average Percentage Energy Savings Values	
level 1	**Default values** from previous studies (Table 3).
level 2	**Guidelines to derive national default values:** data from nation-wide studies for each MS Data required: Average Percentage Energy Savings from VSDs by type of end use **Source:** national statistics, surveys, samples.
level 3 for motors < 22kW	**Guidelines to derive measure-specific average values**: data from national and target-group specific statistics Data required: Average Load Factor Values **Source:** national and target-group specific statistics, surveys, samples.
level 3 (case-specific)	**Not relevant in eq. 2**

Table 3– Average percentage VSD Energy Savings, per end-use[5].

End-Use	Average VSD Savings (%)
Pumps	28*
Fans	28
Air Compressors	12
Cooling compressors	12
Conveyors	12
Other Motors	12

NOTE: the average savings presented in Table 3 are conservative values. Therefore the technical interaction effects are not taken into consideration.

* This methodology is generic, appropriate for any kind of load. Obviously there are some loads where the potentail is higher than in others, but the method can always be applied with a margin of error. When VSDs are applied to pumps with lifting systems (like the case of water pumping systems), it may happen that the application of VSDs does not bring any savings or the savings are lower than the potential mentioned here, because the VSD has to overcome the frictional resistence. Therefore, this method is valid for all kind of pumps excluding pumps with lifting systems. In this case, level 3 should be used.

3.4.3.2 Requirements to define level 2 and level 3 values

The proposed condition for using level 1 and 2 is that the motor, on which the VSD is installed, has a mechanical power smaller than 22 kW. The same method can also be used for motors smaller than 22 kW, but with special analysis or sample studies to

[5] See Appendix I – Justification and Sources, nº2

calculate averages for annual hours of use, power factor, and percentage of energy savings from using VSDs that are specific for the facilitating measure (level 3, measure-specific for motors smaller than 22 kW, using equation 1).

Correspondingly, if the motor has a mechanical power of 22 kW or bigger, the proposal is to require that the case-specific level 3 method (equation 2a or 2b) be used.

Specific Requirements:

Specific data:

Level 2 → National Data

Level 3 → Installation-Specific

Requirements (level 3, case-specific):

- Measurement issues:

Table 4– Measurement Equipment and associated tolerances.

Measurement Equipment	Measurement Tolerances
4-Channel power data loggers , True RMS power analyzer, Flow meter	Data loggers: +/- 1% Power analyzer: +/- 1% Flow meter: +/- 2%

Special meters may be used to measure physical quantities or to submitter an energy flow, equipment runtime or operating temperature. To determine energy savings with reasonable accuracy and repeatability, good measurement practices should be followed for these quantities.

Measurement of variable load, variable operating hour equipment generally requires time-series measurements of electric power. One-time tests of electric power and current, combined with time-series measurements of current, can serve as a reasonable proxy for true electric power measurements, as long as the relationship between true electric power and current is fairly constant over the operating range of the equipment.

Flow measurement:

In general, flow meters can be grouped into two different types of meters: Intrusive Flow Meters (Differential Pressure, Obstruction and Miniturbine) and Non-Intrusive Flow Meters (Ultrasonic and Magnetic)

- Sampling issues:
  Samples of the measures selected for monitoring at a particular site shall be representative of all measures at the site and shall be selected at random.
  The evaluator must have the flexibility to respond to data issues as they arise in order to maximize the reliability of the savings. Therefore, focusing on sample error, while giving relatively little attention to other sources of error (e.g. representativeness of the sample), would compromise the objective of obtaining *reliable* estimates of kWh and kW impacts.
- Modelling issues:
  Unit energy savings and engineering parameters collected during the M&V analysis should include a reference indicating their source, uncertainty estimates (when available), and limits of their applicability. These data should be delivered and stored in a standard format.
- Skills Required:
  Auditing experience with instrumentation such as power analyzers run-time data loggers with a general science or engineering background. For Sampling, it is advised at least basic graduate statistics or equivalent experience.
- List of Normalisation factors to take into account:
  - Motor population, within each type of end-use, with a potential for application of VSDs.
  - In principle: Variation of load diagrams (histograms) of the number of operating hours as a function of the load range); however, too costly to monitor for more than a small sample of representative motors (cf. chapter 3.3)

4 Step 2: Total gross annual energy savings

4.1 Step 2.1: Formula for summing up the number of unitary actions

- unit = each installed VSD, both for equation 1 and 2.

$$Total\_gross\_annual\_energy\_savings = \sum_{i}^{n} [energy\_savings\_of\_VSD\_i]$$

(Equation 3)

Where:
i – number of VSD application.

4.2 Step 2.2: Requirements and methods for accounting for the number of unitary actions

The number of actions always has to be defined for the evaluated (EEI) facilitating measure (i.e., level 3 effort). The method(s) proposed for monitoring the number of actions are strongly related to the facilitating measures chosen[6].

Methods proposed for monitoring the number of actions (always LEVEL 3):

Table 5 – Methods for monitoring the number of actions.

Direct accounting methods are particularly appropriate with the use of: - Financial Tools (rebates, low interest rates, targeted taxation, e.g., tax rebates or faster depreciation rates) - Energy Audits - Energy Performance Contracting - White Certificates Schemes	**Examples of methods** - Collection of accounting documents (e.g. invoices, vouchers) - registry/database to collect details about participants and end-use actions proposed/taken
Indirect accounting methods are particularly appropriate with - Minimum Energy Performance Standards - Lifecycle costing campaigns	**Examples of methods** - surveys among the target groups to assess the portion/number of implemented end-use actions - surveys among the whole population targeted to assess compliance

Finally, ex-post verification for a sample of participants should be done: monitoring of implementation and of energy consumption to ensure that end-use (EEI) actions are actually in place and operational, as specified initially.

[6] See Appendix I – Justification and Sources, nº10.

5 Step 3: Total ESD annual energy savings

In this section, the correction factors required by the ESD and potential further correction factors are dealt with. Applying these factors will allow to calculate the total ESD annual energy savings from the gross annual energy savings calculated in step 2.

5.1 Step 3.1: Formula for ESD savings

total net annual energy savings
= total gross annual energy savings of all VSDs (from equation 3)
** (1 - free-rider coefficient+ multiplier coefficient)*
** double-counting factor*

(Equation 4a)

Possible range of coefficients:

Free-rider: share [0, 1] *(not mentioned in the ESD, only to be applied if the aim is to calculate additional energy savings)*

Multiplier coefficient: >=0

Double Counting: factor [0, 1]

Simplified formula, if total annual energy savings are below 40 million kWh/year, or if there is evidence that both the multiplier and the free-rider effects will be small:

total net annual energy savings
= total gross annual energy savings of all VSDs (from equation 3)
** double-counting factor*

(Equation 4b)

5.2 Step 3.2: Requirements for avoiding double counting

In case of overlap, the decision to allocate the corresponding energy savings to one or another EEI measure is up to the Member-States. Possible overlaps include:

- Overlap of national activities using different promotion measures
- Overlap of national, local or EU activities

Risk of overlap:

Table 6– Risk of overlap map for VSDs and energy-efficient motors

	Energy Audits	Energy Performance Contracting	White Certificates Schemes	Energy Taxation	Subsidy schemes	Risk of Overlap
Installation of Variable Speed Drives	X	X	X	X	X	**X**
Energy Efficient Motors	X	X	X	X	X	**X**
Improved Maintenance	X				X	
….						

Double counting can best be avoided by cross-cutting available information in a central database of registered participants and the equipment where VSDs are installed, and which VSDs are recommended in an energy audit or actually installed.

How to address double counting when reporting results:

- Group (EEI) facilitating measures targeting the same type of end-use action in a single package, reporting one global result by end-use action, or
- associate each targeted end-use with a particular facilitating measure or programme, allocating the corresponding energy savings only to this measure.

5.3 Step 3.3: Requirements for taking into account of technical interactions

Assessing evaluation risks:

Table 7 – Technical interaction map.

	VSDs	EEMs
VSDs		+
EEMs	+	

Table 8 shows that there is a small interaction between VSDs and energy-efficient motors (EEMs) in both directions.

Tracking risks:

- Central database/registry, listing participants and actions implemented (to take advantage of double counting database)
- Sampling will allow making an estimate and defining ratios of interaction: X% of participants that have adopted VSDs also installed EEMs and the energy savings from VSDs should be reduced by Y%. Typically in the range of 1 to 1.5%.

Level 2	National value
Level 3	Measure-Specific Value

5.4 Step 3.4: Requirements for multiplier energy savings

It is relevant to evaluate the multiplier potential of the facilitating measures, as a desirable outcome is to achieve higher market penetration of VSDs.

Assessment of the multiplier effect:

- Ex-ante calculations previewing the multiplier effect should be performed by the evaluator, as soon as the MS reveals its National Energy Efficiency Action Plan (NEEAP).

Calculation method:

- Ex-post evaluation of multiplier effect should be considered, through the following indicators:
  - Sales data analysis. This is a diffusion indicator method, which can be used as a bottom-up method, if a comparison area can be defined, or as a top-down method with a regression analysis (last method only appropriate for LEVEL 1 and 2)
  - Surveys among representative samples of (non-) participants
  - Surveys with trade allies and/or other relevant stakeholders

A comparison between ex-ante and ex-post calculations should be performed, in order to assess the degree of the multiplier effect.

Level 1	No EU default value for multiplier effect of VSDs possible
Level 2	Define MS market: MS national sales of VSDs – analysis according to figure 2 MS national retail prices
Level 3	Increased application of VSDs in the sector under consideration, outside the effect of the facilitating measure(s) being evaluated. Analysis according to Figure 2 or using surveys.

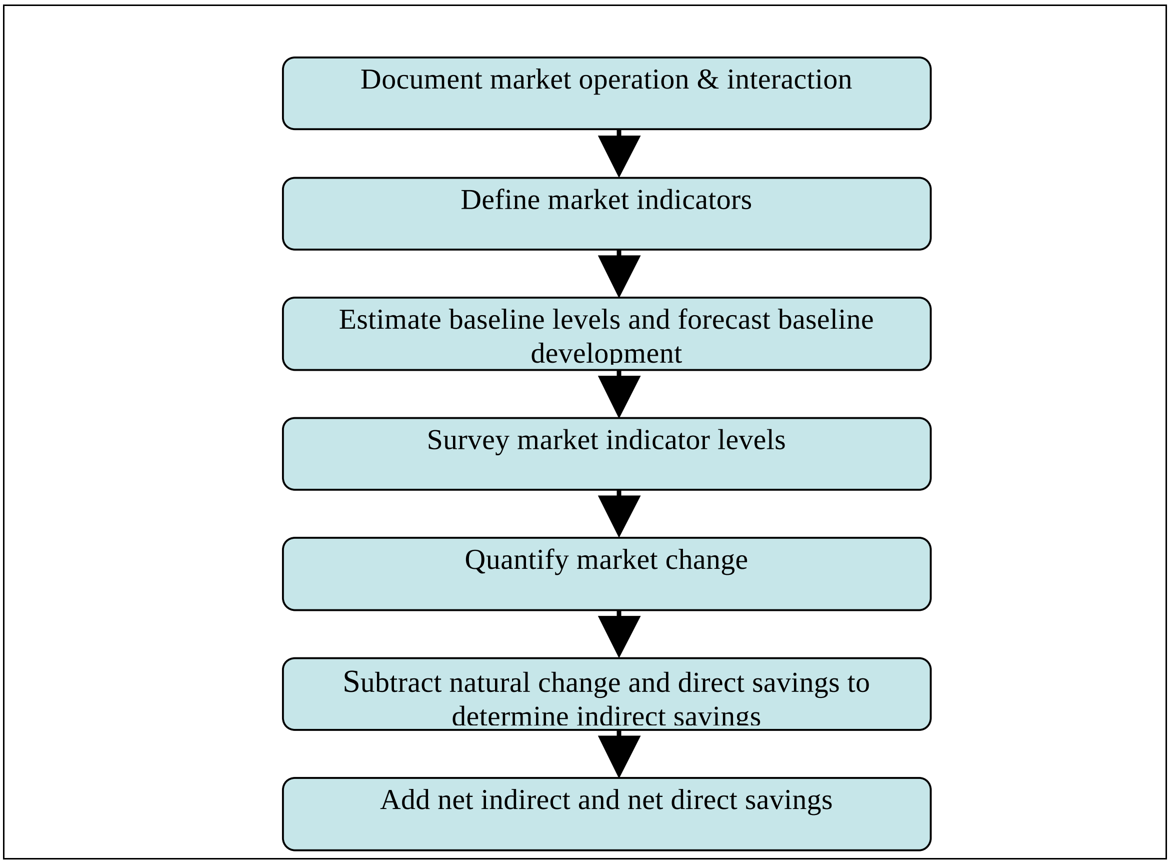


Figure 2 - Evaluation approach for indirect savings (mixed top-down diffusion indicator and bottom-up direct savings evaluation method)[7].

Market indicators[8]:

- Increased knowledge or awareness among planners, designers, and decision-makers about efficient technologies (e.g. recognition rate).
- Existence and deployment of decision-making tools and structures which are likely to lead to efficient design and equipment installation, and which are being used on more jobs (number of businesses with energy management strategies).
- More frequent recommendation or specification of efficient equipment and design (e.g. publicity rate of efficient equipment).
- Increased sales/purchases of efficient equipment or design (e.g. sales statistics of efficient equipment).
- Increased application of efficient equipment or design.
- Attendance at training and intent to implement training (e.g. number of training seminars and participants).

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[7] See Appendix I – Justification and Sources, nº12.
[8] See Appendix I – Justification and Sources, nº12.

- Changes in the costs of efficient technologies and practices (e.g. retail prices).
- Changes in the equipment stocked by retailers/end-users.

5.5 Step 3.5: Requirements for evaluation of the free-rider effect

The free-rider effect is not explicitly mentioned in the ESD. Free riders are final energy users who are counted when monitoring the effects of facilitating measures but would have taken the end-use actions promoted also without the facilitating measure. Consequently, including energy savings achieved by free riders in the total ESD annual energy savings would mean to include a part of the autonomous energy efficiency improvements. It has not yet been decided by the European Commission and the ESD committee, whether this effect shall be included in the total ESD annual energy savings or eliminated from them. In the latter case, the following requirements apply.

In the case of VSDs, there are two main types of free-rider effect: pure (or full) and deferred free-ridership. The first occurs when all of the gross impact related to an installation or some other unit of programme implementation would have occurred exactly as it did in the programme, even if the programme had not existed. The second exists when some portion of the gross impact would have occurred in the absence of the programme, but would have occurred at a later date.

Possible reasons for free-rider ship for VSDs include:

- Market surveys show that particularly for materials handling applications, VSDs are mostly used for process control to improve performance and to ensure the correct MTBF (Mean Time Between Failures), particularly in the lower power ranges [0,75;4[kW.
- VSDs may also be used to decrease noise levels

1st approach	Stock/Market modelling: Level 2 - Baseline based on National Statistics Level 3 – Measure specific Data
2nd approach	Definition of Net-to-Gross Ratios (NTGR) (implies surveys to participants or discrete choice modelling) Level 2 - National NTGR Level 3 – Measure Specific NTGR
3rd approach	Progressive Approach

Estimating Free-ridership:

A progressive approach is proposed here:

Table 8 – Progressive approach

Years after start of facilitating measure implementation	Accounting Method
[0,3[	General Default NTGR ratios <u>or</u> Stock/Market Modelling. MS can propose methods to define MS values of NTGR, taking into account that these methods should be applicable for all MS (it is up to the Commission – in a mid-term evaluation - to decide whether the methods are relevant or not).
>3	According to experience gained for all MS, new proposal not requiring the estimation of free-riders but the use of a default NTGR

Surveys to participants and non-participants:

To maximize the validity of the survey results, evaluators should conduct it as soon as possible after the participation decision.

6 Step 4: total ESD energy savings for year "i"

6.1 Requirements for the energy saving lifetime

The ESD text is interpreted so that only for those EEI measures that have not reached the end of their energy saving lifetime in the years of the intermediate (2010) and final (2016) targets, energy savings will be counted towards a Member State's intermediate or final energy savings target under the ESD.

Timing and Lifetime of End-Use EEI measure[9]:

Default lifetime for VSDs: (conservative estimate) 8 years. This reference value is established in the CWA-27. However, this is a very conservative value, but also assumes that within this period the savings magnitude of VSDs is not changing but remaining the same. Member States are, therefore, encouraged to do sample studies of lifetimes.

Persistence of savings[10] = f (measure retention, performance degradation);

Definitions[11]:

- Measure Retention is the degree to which measures are retained in use after they are installed.
- Performance Degradation is any degradation over time that includes both technical operational characteristics of the measures

Measure Retention:

Measure retention studies collect data to determine the proportion of measures that are in place and operational. The primary evaluation components of a measure retention study are research design, survey-site visit instrument design, establishing the definition of an operable status condition, identifying how this condition will be measured, and establishing the data collection and analysis approach.

The withdrawal of the installed VSDs, although not recommended, is easily done. Hence, ex-post verification to a sample of participants is necessary to evaluate what is the status of the factors that influence the lifetime of a VSD:

- Rate of effective installation
- Risk of failures

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[9] Enhanced calculations: See Appendix I – Justification and Sources, nº 4.
[10] See Appendix I – Justification and Sources, nº 5.
[11] See Appendix I – Justification and Sources, nº 6.

- Operation conditions and maintenance
- Removal: economical and technical reasons (in some rare occasions VSDs may lead to problems such as early failure of motors)

Level 1	EU Harmonised values (would need to be developed over the next three years – methods: cf. level 3)
Level 2	MS values – methods: cf. level 3
Level 3	Basic: Non-site methods (such as telephone surveys/interviews, analysis of consumption data, or use of other data). Enhanced: In-place and operational assessment based upon on-site inspections. Measure data (e.g. power, number of units installed and in operation) shall be collected and compared to participant program records as applicable. Proper measure operation shall be observed and compared to project design intent.

The reasons for lack of retention, and the rates of non-retention, should be gathered when feasible for use in developing Effective Useful Life (EUL) values and in future retention studies.

Performance Degradation:

Factors to consider:

- Performance or energy efficiency decay
- Conditions of operation (behaviour) and maintenance
- Degradation of electronic components, sensor drift or improper adjustment, and interactions between VSD operation and motors

Level 1	EU Harmonised values (would need to be developed over the next three years – methods: cf. level 3)
Level 2	MS values – methods: cf. level 3
Level 3	Basic: - Literature review required for technology-based degradation studies across a range of engineering-based literature, to include but not limited to manufacturer's studies, ASHRAE studies, and laboratory studies. Review of technology assessments. Assessments using simple engineering models for technology components and which examine key input variables and uncertainty factors affecting technology-based degradation - Telephone surveys/interviews on estimated performance degradation of the installed equipment. Enhanced: - Field measurement testing and observations.

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Effective Useful Life (EUL):

Main factors which may affect the lifetime of a VSD measure:

- Installation and Commissioning quality
- Performance or efficiency decay
- Operating conditions, namely power quality
- Maintenance
- Repair
- Failure
- Removal
- Changes in operation profile

Skills Required to Conduct Retention, EUL, and Technical Degradation Evaluations:

- EUL analysis evaluation efforts need to have the specific skills and experience in regression and statistics proving an ability to be able to conduct classic survival analysis and handle EUL functional form and issue analysis.
- Technical degradation studies require senior experienced engineers that are quite familiar with the equipment to be studied, with best practice procedures, and the components, mode of operation, and effects of changes in the operational conditions on the components and function of the equipment.
- Telephone surveys and interviews need to be conducted by experienced personnel. These studies and their instruments must be designed with personnel with experience in energy efficiency markets, and interview and survey instrument design, implementation and analysis.
- Behavioural degradation studies could be based upon survey and interview analysis methods and/or statistical/econometric methods. Although in building HVAC applications these aspects may be relevant, in industrial applications behavioural issues are not so relevant.

6.2 Special requirements for early actions

The definition of early actions may include two possibilities (to be clarified by the European Commission and the ESD Committee):

- *early (EEI) facilitating measures*, and only those energy savings that result from end-use actions that are implemented during 2008-2016, as a result of these facilitating measures that still have a lasting effect during 2008-2016, are eligible

OR

- *early energy savings* from end-use actions initiated between 1995 and 2008, with the end-use actions having a lasting effect in 2010 (for the intermediate target) or 2016 (for the overall target).

For VSDs, the following considerations apply:

If early energy savings are accepted, a contribution of VSDs to the target in 2016 can only be counted if the energy saving lifetime is greater than 8 years plus the time between installation and 2008. This needs to be proven. But with such proof, the energy savings from VSDs can be counted right away, since the EU or national default values for the baseline, the average savings %, the average load factor, and the annual operating hours are not depending on the vintage year of installation.

6.3 Uncertainties

For each parameter included in the calculation model, it should be considered if uncertainties **can** be addressed with a reasonable level of effort.

The efficiency values from motors per power range as presented in table 1 are estimated in the range of +/- 1 to 2 %.

The power ranges data (hours and load factor) as presented in table 2 for types of applications are average values from an EU study. The expert estimate for the uncertainty range is +/- 10 to 15 %.

The data on percentage of VSD energy savings as presented in table 3 for types of applications are average values from an EU study, too, after applying a safety reduction of 20 %. The expert estimate for the uncertainty range is +/- 10 %.

The Measurement Equipment for application of equation 2a should hold the following associated tolerances:

Measurement Equipment	Measurement Tolerances
4-Channel power data loggers , True RMS power analyzer, Flow meter	Data loggers: +/- 1% Power analyzer: +/- 1% Flow meter: +/- 2%

The quality grades for the data used in the methods is a medium to low uncertainty. This is assumed as the data are based on EU research studies and national statistic values.

Appendix I: Justifications and sources

Following the same frame as the description of the method, and providing justifications and sources for each choice and default value, using existing data and examples of evaluation methods targeting the same subject wherever possible.

1. IEC 60034-30 Ed.1: Rotating electrical machines – Part 30: Efficiency classes of single-speed three-phase cage induction motors.
2. De Almeida A, et al. "Improving the penetration of energy-efficient motors and drives". Report prepared for the European Commission, SAVE II. Coimbra, ISR-University of Coimbra, Portugal, 2000
3. De Almeida A, et al. "VSDs for Electric Motor Systems". Report prepared for the Directorate General of Energy, European Commission, May 2001 (Technical reports)
4. CEI EN 61800, first edition, March 1998 – "Adjustable speed electrical power drive systems - Part 2: General requirements - Rating specifications for low voltage adjustable frequency a.c. power drive systems"
5. European Committee for Standardization, CEN Workshop 27, 2007, "Saving lifetimes of Energy Efficiency Improvement Measures in bottom-up calculations"
6. TecMarketWorks, June 2004 - "The California Evaluation Framework**"**
7. TecMarketWorks , 2006 Energy Efficiency Evaluation Protocols – "Effective Useful Life Evaluation Protocol (Persistence and Technical Degradation)"
8. TecMarketWorks, April 2006 – "California Energy Efficiency Evaluation Protocols: Technical, Methodological, and Reporting Requirements for Evaluation Professionals"
9. Lisa A. Skumatz, John Gardner, Sera, July 2005 – "Revised/Updated EULs based on retention and persistence studies results"
10. Edward Vine, Jayant Sathaye, Ernest Orlando Lawrence Berkeley National Laboratory, May 1999 – "Guidelines for the monitoring, evaluation, reporting, verification and certification of energy-efficient projects for climate change mitigation"
11. Harry Vreuls, International Energy Agency Implementing Agreement on Demand-Side Management Technologies and Programmes, October 2005 - VOLUME II, "Country Reports and case examples used of the evaluation guidebook"
12. SRC International, April 2001, SAVE – "A European Ex-Post Evaluation Guidebook for DSM and EE Service Programmes"
13. U.S. Department of Energy – Energy Efficiency and Renewable Energy, Motor Challenge, May 2004, "Variable Speed Pumping – A guide to successful applications"
14. FEMP Monitoring and Verification (M&V) Instructional Tool
15. Robert Mowris, Kathleen Carlson, June 2005, "Measurement & Verification Load Impact Study for NCPA SB5X Commercial and Industrial Custom Incentive Programs",
16. EWC report - "Work Package 4.1 - Supply side: measurement and verification of energy efficiency"
17. California Public Utilities Commission, March 2007, "California Multi Measure Farm Program Evaluation, Measurement and Verification Report".
18. Paolo Bertoldi, Bodgan Atanasiu, "Electricity Consumption and Efficiency trends in the Enlarged European Union", Institute for Envronment and Sustainability, EU Joint Research Center, 2007.

19. EuP Pump study. Lot 11 Water Pumps (in commercial buildings, drinking water pumping, food industry, agriculture).

Case Studies:

1. Portugal:
   ERSE, January 2007, "Plano para a Promoção da Eficiência no Consumo"
2. Italy:
   Computation of energy savings according to the "default approach" and the "engineering approach" – Technical Form n.9 – " Installation of Electronic Variable Speed Drives (Frequency inverters) on electric motors, pump systems, in the power range inferior to 22 kW"

   EuroWhiteCert Project, Work Package 5, Annex 3 – "Evaluation of the Italian TWC scheme at one year after its implementation"
3. France:
   Certificats d'économie d'énergies, Opération nº IND-UT-02 – Fiche de calcul – "Système de variation électronique de vitesse sur un moteur"

Projects:

1. Energy Efficiency Policies and Measures Interactive Database, IEA, www.iea.org/textbase/effi/
2. INDEEP Database, IEA, http://dsm.iea.org/INDEEP/prog/home.new.asp
3. CALMAC database: http://www.calmac.org/