Sustainable Competence
in Advancing Healthcare

SELF-REGULATORY INITIATIVE FOR MEDICAL IMAGING EQUIPMENT

ECODESIGN TARGET FOR MAGNETIC RESONANCE EQUIPMENT

2012/2017

**DRAFT REPORT FOR DISCUSSION
WITH THE
ECODESIGN CONSULTATION FORUM**

MARCH 2012

"Self-regulatory Initiative for medical imaging equipment"
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1. INTRODUCTION

The Ecodesign Steering Committee started in 2010 to work on MRI systems to develop ecodesign targets on energy consumption that has been identified by the methodology (Step 3) as the most significant environmental aspect.

This report is completed by the following documentation:

1. Magnetic resonance Equipment (MRI) - Study on the potential for environmental improvement by the aspect of energy efficiency

The Ecodesign Steering Committee hired in July 2011 an external consultant with long experience in the field of ecodesign to study the potential for improvement of MRI equipment with regard to energy efficiency. The study analyses MRI energy consumption, the allocation of power usage in the different modules during off, ready-to-scan and scan mode and technological solutions to improve the efficiency.
Results of the study are used as input for Step 4 of the SRI methodology for setting the ecodesign target for MRI.

2. Magnetic resonance Equipment (MRI) - Measurement of energy consumption

The Ecodesign Steering Committee mandated in October 2010 an Expert Working Group on MRI with the objective to develop a methodology to measure the energy consumption as there are no recognized standards at the moment. The measurement methodology allows company to measure the energy consumption of MRI on a common basis providing comparable data that are used in Step 4 of the SRI methodology.

2. EXECUTIVE SUMMARY

This report presents the application of the SRIv2 methodology to MRI equipment to define ecodesign targets on energy consumption. It is divided in 4 main chapters:

Chapters 3 introduces the MRI technology, the main technologic aspects, the different solutions present on the market and the trend in the development of future designs.

Chapters 4 presents the market data for MRI, such as the total turnover in EU and the unit sold in Europe per each of the three categories.

Chapters 5 describes the methodology developed to measure the energy consumption, the main basic assumptions, the factors influencing the energy performance of MRI and how such factors have been taken into account to ensure data comparability.

Chapters 6 describes how the SRI methodology has been applied to MRI and defines the ecodesign target reduction that participating Companies commit to achieve by 2017.

Participating Companies measured many MRI systems according to the measurement procedure developed by the Ecodesign Steering Committee.

The data has been analysed by PE INTERNATIONAL in the study on improvement potentials for MRI which defined possible development of the technology in the coming 5 years. An increase in the energy consumption due to increased functionalities, stronger magnetic field and more powerful gradient and RF amplifiers is expected.

The identified technological solutions to reduce energy consumption could limit this increase in the off and ready-to-scan mode only, while the energy usage in scan mode could hardly be reduced due to the physics of the process.

3. MRI TECHNOLOGY

3.1. Technology description

Magnetic resonance imaging (MRI)[1] is a medical imaging technique used in radiology to visualize detailed internal structures of the human body. MRI makes use of the property of magnetic resonance of nuclei to create medical diagnostic images.

An MRI machine creates a powerful magnetic field to align the magnetization of atoms within the body. Radio frequency waves are used to systematically alter the alignment of this magnetization. This causes the nuclei to produce a rotating magnetic field detectable by the scanner. Very powerful magnetic field gradients are needed to cause nuclei at different locations to rotate at different speeds providing the necessary 3-D spatial information.
The information collected is manipulated with high speed mathematical formulas to generate extremely detailed medical diagnostic images.
MRI provides excellent contrast between the different soft tissues of the body, which makes it especially useful in imaging the brain, muscles, internal organs, and cancers. Compared with other medical imaging techniques such as computed tomography (CT) or X-rays, MRI uses no ionizing radiation.

3.2. Superconductive magnet and permanent magnet

MRI equipment uses two different technologies to generate the required magnetic field strength that could vary from 0,35 Tesla up to 7 Tesla or even more.

Permanent magnet: permanent magnets are used to generate magnetic field up to 1,2 Tesla. Commonly such models are equipped with non-cylindrical magnets allowing more patient comfort. Non cylindrical magnet MRIs are called "Open MRI".

Superconductive magnet: superconductive electromagnets, cryo-cooled to 4 Kelvin using liquid helium, are used to generate magnetic fields up to 7 Tesla or more. The boiled helium is re-condensed by a cryo-cooler (Gifford-McMahon or pulse tube). The cryo-cooling system cannot be switched off except in case of emergency. This causes the helium to boil off and get lost. Normally superconductive MRIs are equipped with cylindrical magnets but sometimes with open magnets.

Figure 1: *Open MRI and cylindrical MRI*

[1] http://www.mr-tip.com

3.3. Magnetic field strength

The strength of the magnetic field and the power of the gradient coil and the RF senders determine the quality and resolution of the image. High end machines for hospital use are equipped with 3 Tesla magnets. Higher fields equipment, up to 7 Tesla, are actually under development and test and used only for research purposes.

3.4. Bore size

The bore diameter is important for patient comfort. Patient suffering from claustrophobia could experience better comfort in larger bores. Moreover, large bores allow the examination of "big" patients suffering from obesity. Nonetheless larger bore size requires the use of more powerful and energy consuming magnet systems, as the field strength decrease exponentially with the distance.

3.5. Modes

Three modes have been defined for MRI equipment.

Off mode:
The MRI is in a low power state. In superconductive cylindrical MRIs the magnet and the cry-cooler can never be switched off[2] so the energy consumption is determined by those two modules.

Ready-to-scan mode:
The MRI is on and ready to acquire the image. All modules except the ones needed for the scan are on (gradient amplifiers and RF senders and receivers).

Scan mode:
The MRI is actively scanning the patient to generate the image by sending high frequency waves and reading the resulting variations in the magnetic field. The computing system interprets the data and generates the image.
The power consumption of MRI in the three modes is represent in figure 2.

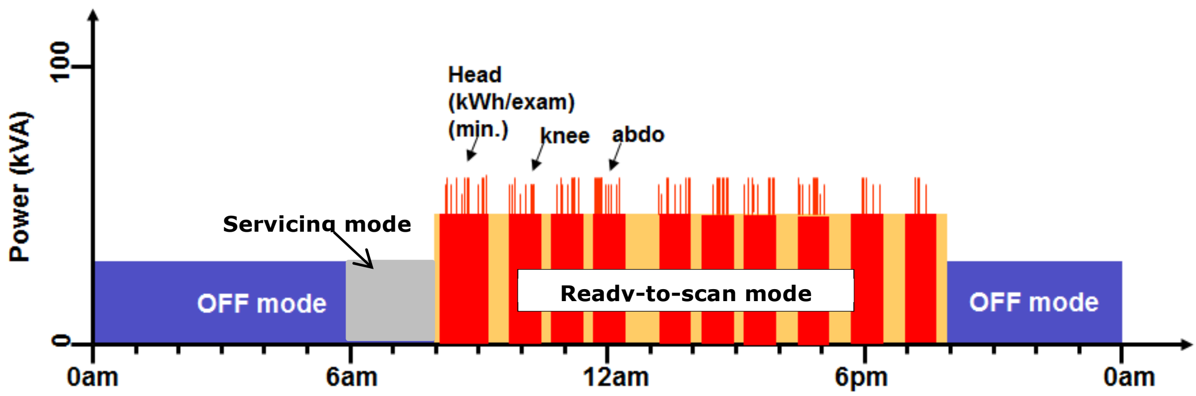


Figure 2: *Exemplary power consumption of MRI*

[2] In case the magnet or the cooling system is shut down, the helium boils and it is released. Restoring the MRI functionality is a very expensive process as the helium needs to be refilled and the system cooled down again to 4 kelvin.

Table 1: *MRI Use Mode Definition.*

Mode	Description	Typical time in mode per day (hours)	Estimate of % energy in use phase**
Off mode	Lowest power state; requires interaction to make system ready; system circuit breakers on.	12	45
Ready to scan mode	System on, ready to scan, gradient system quiescent.	(varies)*	30
Scan mode	System is activating gradient system and capturing image data.	(varies)*	25

** The duration of ready-to-scan and scan mode is variable and depends on the scan speed of the equipment and the logistic operations and administrative time such as data input, patient preparation, patient positioning, data archiving, etc.*

*** The distribution of energy usage in modes greatly varies from model to model*

3.6. Modularization

The most important power consuming modules of the entire MRI system have been identified[3].

- Gradient amplifier
- RF unit
- Reconstruction unit
- Console, Computer
- All required electronics
- Patient table
- Cryogen compressor
- Water heat exchanger (assumes facility cooled water is provided)
- Magnet
- Helium-conservation equipment (ZBO)

Due to the high technical complexity of the system and the difficulty to allocate the power consumption to the right module the following modules had been analyzed by companies with respect to the individual power consumption and their improvement potential:

- Gradient Amplifier (including RF Sender, RF Receiver and cooling device)
- Magnet (including cryo-cooling)
- Computation
- Others, mainly patient table

Figure 3 and 4 summarize the average estimated energy allocation of the power consumption and energy consumption for category B models.

[3] PE Internationl: Magnetic Resonance Equipment (MRI) - Study on the potential for environmental improvement by the aspect of energy efficiency

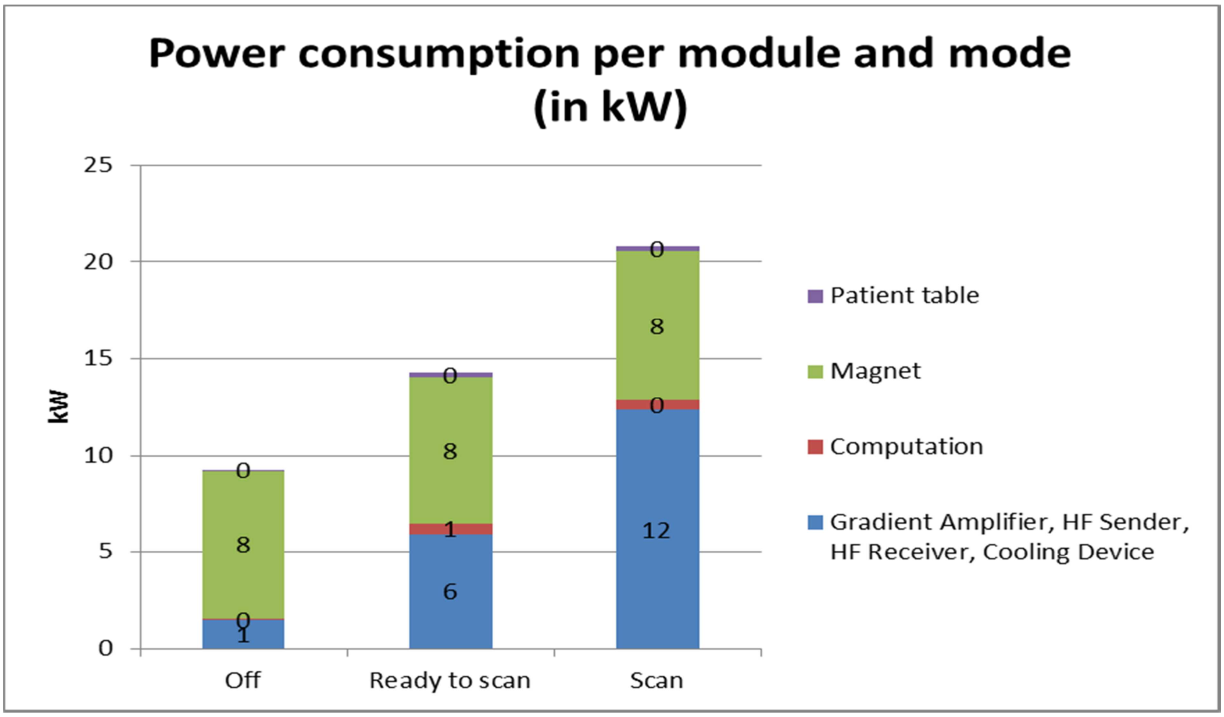


Figure 3: *Average power consumption[4] (kW) per module and mode*

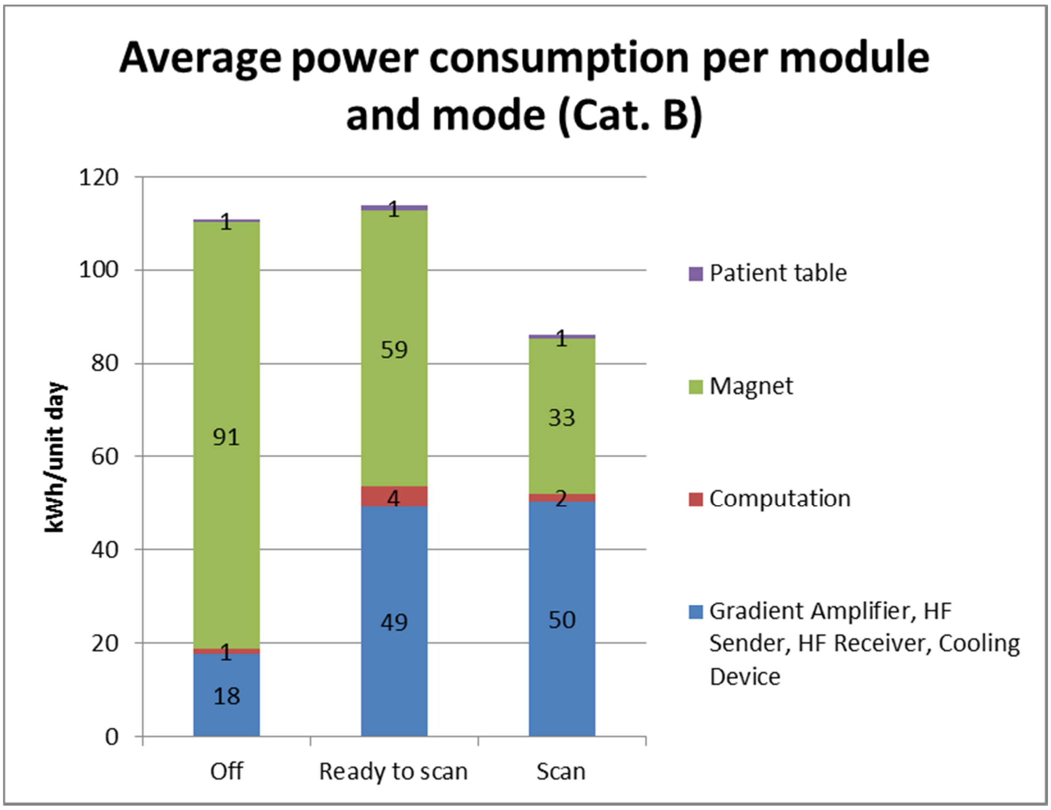


Figure 4: *Average power consumption (kWh/ unit day) per module and mode*

[4] Values of zero appear due to rounding

4. MARKET DATA

4.1. Total turnover and units sold

The 5 Companies participating in the SRI for the MRI sector represent a total turnover in Europe of 776 million euros in 2010 thus covering about 98% of the European market.

Table 2: *MRI - EU market[5] data*

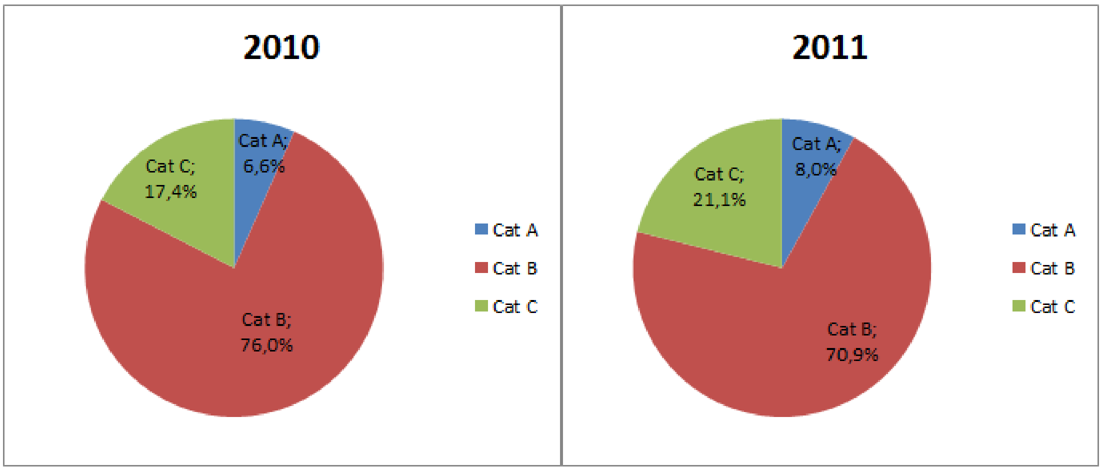
Modality	2009 Market Value	2010 Market Value	2011 Market Value	Estimated EU Market Coverage[6]
Magnetic Resonance Imaging (MRI)	708 M€	777 M€	643 M€	96%

The MRI units sold in 2010 and 2011 are reported in table 3 in total and according to the 3 categories identified in chapter 6.2.

Table 3: *MRI – Units sold in 2010 and 2011 in EU[7]*

	Units sold* 2010	Units sold* 2011
Category A	41	59
Category B	471	521
Category C	108	155
Total Units	620	735

*Open magnet units are not included in the figures as they are not in the scope of the SRI



[5] COCIR Imaging Market Statistics source (SHARE). Countries included: Estonia, Latvia, Lithuania, Bosnia, Bulgaria, Croatia, Czech Republic, Hungary, Poland, Romania, Serbia, Slovakia, Slovenia, Ukraine, Portugal, Spain, Denmark, Finland, Norway, Sweden, Ireland, UK, Austria, Belgium, France, Germany, Greece, Italy, Netherlands, Switzerland
[6] COCIR estimation based on 2010 SHARE data
[7] EU 27 Market

5. MEASUREMENT OF ENERGY CONSUMPTION

5.1. Brief history

The Ecodesign Steering Committee started in October 2010 to develop a methodology to measure the energy consumption of MRI equipment, as there are no available standards that could be used.

The methodology ensures that:

- Results of the measurements are comparable and repeatable
- The measured energy consumption has a strict relation with the real energy consumption in everyday hospital use. Such information is important for hospitals and clinics to understand the real running cost of MRI to plan and allocate correctly their budget
- The procedure does not involve disproportionate costs or resources
- The measurement results allow the determination of all the information that could be considered relevant for the SRI target setting process but could also be useful for MRI users.

A first methodology, extremely complex, was defined in May 2011 and Participating Companies started a measurement campaign providing a first set of 5 measured machines. After a deep analysis of the data the methodology was simplified by introducing average values for the ready-to-scan mode durations (see the "Magnetic Resonance – Measurement of energy consumption" document for additional information). Participating companies measured according to the new methodology 14 models.

The study on the MRI potential for improvement showed that the energy use in scan mode could not be reduced due to physical limits (see **"Magnetic resonance Equipment (MRI) - Study on the potential for environmental improvement by the aspect of energy efficiency")**.

For the above mentioned reasons, the SRI adopted a simplified version of the methodology as it is further described in chapter 6.5.

The methodology has been finalized in February 2012 and is available for download at COCIR website.

5.2. Measuring the energy consumption

The energy consumption could normally be calculated by summing the energy consumption in each mode, calculated multiplying the power consumption for each mode for the relative duration:

Energy use= $\mathbf{T}_{off}*\mathbf{P}_{off} + \mathbf{T}_{ready\text{-}to\text{-}scan}*\mathbf{P}_{ready\text{-}to\text{-}scan}+\mathbf{T}_{scan}*\mathbf{P}_{scan} + \mathbf{P}_{servicing}*\mathbf{T}_{servicing}$

The power consumption in off mode, servicing mode and ready-to-scan mode can be easily measured. For MRI the following elements are unknown:

$T_{ready\text{-}to\text{-}scan}$	: Duration of ready to scan mode
T_{scan}	: Duration of scan mode
P_{scan}	: Power consumption in scan mode

Those durations depend very much on which examination is performed, the scan speed of the machine and the logistic operations to be performed by doctors during the examination (patient preparation, data input, data archiving, patient positioning, etc.).

While for off mode it is easy to set an average value according to hospital practices, setting average values for the remaining two modes would not allow to take into consideration a very important factor, the "productivity" of the MRI, the number of patients that can be examined per day (see chapter 5.6).

5.3. System Boundaries

The Ecodesign SC defined the scope for the measurement of MRI equipment.

In Scope: All system-critical items needed to perform a basic scan, e.g. gradient amplifiers, RF unit, MR coils needed for the specific measurements, reconstruction engine(s), required electronics such power supplies, controllers, console/computer, cryogen compressor, water heat exchanger (facility cooled water is provided), patient table, magnet, helium-conservation equipment.

Out of scope: Any equipment and accessories beyond basic product offering and not required for a basic scan, or customer-provided equipment, e.g. optional MR coils, patient vital signs accessories, facility-provided cooling water equipment and hardware for advanced medical applications.

5.4. Equipment configuration

To allow comparability of the measurements the Ecodesign SC identified the most relevant parameters having an impact on the energy consumption:

- Number of slices
- Field of view
- Slice thickness
- Resolution
- Bandwidth
- Sequence duration

As shown in table 4, a set of parameter has been defined for each sequence. The values have been determined on the basis of the experience of Companies' experts as the most commonly used in hospital practice.

Moreover, the values have been validated according to the following documentation:

- the German "Guidelines of the Federal Medical Council for Quality Assurance of magnetic resonance imaging" (BAK)
- and the "guidelines on criteria for quality assessment in nuclear magnetic resonance imaging pursuant to § 136 SGB V i.V.m. § 92 SGB V, Section 1 of the Federal Committee of Physicians and Sickness Funds (Quality assessment guidelines for magnetic resonance imaging)

Both documents are available for download at the Greening at COCIR/SRI section of the COCIR website (www.cocir.org).

For each parameter and for each sequence the minimum and maximum value is indicated in the table. A third column indicates the reference value from the two above mentioned documents.

***Table 4:** abstract of the configuration parameters table. The complete table is available in the "MRI – Measurement of energy consumption" report.*

HEAD	Slices	FoV / mm x mm			Slice thickness / mm			Resolution / mm			Bandwidth / Hz/Px		Sequence duration
	S/P	BÄK	Max	Min	BÄK	Max	Min	BÄK	Max	Min	Max	Min	BÄK
localizer	1		280x280	240		8	6		1,1	0,6	83,3	290	
t2_tirm_tra_dark-fluid_320	28	≤ 250	230 x 200	220x220	≤ 6	5	5	≤ 1	0,8	0,7	31,3	191	< 00:05:00
t2_tse_sag_512	27	200..250	250 x 225	220x220	5..6	5	5	≤ 1	0,5	0,5	195	31,3	< 00:05:00
ep2d_diff_3scan_trace_p2	23	≤ 250	240	210		5	5	≤ 1	1,9	1,2	1305	250,0	< 00:05:00
t1_se_tra_320	28	200..250	230 x 230	220x220	5..6	5	5	≤ 1	0,9	0,4	163	25	< 00:05:00
t1_se_tra_320	28	200..250	230 x 230	220x220	5..6	5	5	≤ 1	0,9	0,4	163	25	< 00:05:00
t1_se_cor_320	32	200..250	230 x 230	220x220	5..6	5	5	≤ 1	0,9	0,4	163	25	< 00:05:00
SPINE	Slices	FoV / mm x mm			Slice thickness / mm			Resolution / mm			Bandwidth / Hz/Px		Sequence duration
	S/P	BÄK	Max	Min	BÄK	Max	Min	BÄK	Max	Min	Max	Min	BÄK
localizer	5		450x450	240		8	8		1,8	0,6	290	83,3	
t2_tse_sag_512	16	≤ 350	300x300	260	≤ 4	4	3	≤ 1	0,8	0,5	244	41,67	< 00:05:00
t1_tse_sag_512	15	≤ 350	300x300	260	≤ 4	4	3	≤ 1	0,8	0,5	250	62,5	< 00:05:00
t2_tse_tra_512	20	≤ 350	230 x 230	150x150	≤ 4	4	4	≤ 1	0,7	0,4	195	250	< 00:05:00
t1_tse_tra_448	20	≤ 350	230 x 230	150x150	≤ 4	4	4	≤ 1	0,7	0,4	228	25	< 00:05:00
ABDOMEN	Slices	FoV / mm x mm			Slice thickness / mm			Resolution / mm			Bandwidth / Hz/Px		Sequence duration
	S/P	BÄK	Max	Min	BÄK	Max	Min	BÄK	Max	Min	Max	Min	BÄK
localizer	5		500x500	380		8	6,0	1,7	2,0	0,989583	450	83,3	
t1_fl2d_opp-in_tra_p2_mbh	30	300..400	380	330x350	≤ 6	6	6	≤ 2	1,5	1,1875	977	83,3	< 00:00:45
t2_trufi_cor_p2_bh	25	300..400	400	350x300	≤ 6	6	5	≤ 2	1,4	1,0	651	125	< 00:05:00
t2_tse_tra_p2_mbh_320	30	300..400	380	330x350	≤ 6	6	5	≤ 2	1,2	1,1	651	62,5	< 00:05:00
t1_vibe_fs_tra_p2_320_bh_pre	64	300..400	400	330x350	≤ 6	4	3	≤ 2	1,25	1,1	488	166,7	< 00:00:45
t1_vibe_fs_tra_p2_320_bh_arterial	64	300..400	400	330x350	≤ 6	4	3	≤ 2	1,25	1,1	488	166,7	< 00:00:45
t1_vibe_fs_tra_p2_320_bh_venous	64	300..400	400	330x350	≤ 6	4	3	≤ 2	1,25	1,1	488	166,7	< 00:00:45
t1_vibe_fs_tra_p2_320_bh_delayed	64	300..400	400	330x350	≤ 6	4	3	≤ 2	1,25	1,1	488	166,7	< 00:00:45
t1_vibe_fs_cor_p2_bh_288_post	128	300..400	400 x 345	350x315	≤ 6	4	1,6	≤ 2	1,4	1,1	600	166,7	< 00:00:45
KNEE	Slices	FoV / mm x mm			Slice thickness / mm			Resolution / mm			Bandwidth / Hz/Px		Sequence duration
	S/P	BÄK	Max	Min	BÄK	Max	Min	BÄK	Max	Min	Max	Min	BÄK
localizer_tra	3		500x500	280		8	5		2,0	0,7	250	83,3	
localizer_sag+cor+tra	3		350	215x231		8	5		1,4	0,7	250	83,3	
t1_se_sag_512	32	≤ 250	160 x 160	160x160	3,0	4	3	≤ 0,5	0,5	0,3	244	31,25	< 00:07:00
t2_tse_fs_sag_320	30	≤ 250	160 x 160	160x160	3,0	4	3	≤ 0,5	0,5	0,5	244	41,67	< 00:07:00
pd_tse_fs_cor_p2_512	30	≤ 250	160 x 160	140	3,0	4	3	≤ 0,5	0,5	0,3	195	41,67	< 00:07:00
ANGIO	Slices	FoV / mm x mm			Slice thickness / mm			Resolution / mm			Bandwidth / Hz/Px		Sequence duration
	S/P	BÄK	Max	Min	BÄK	Max	Min	BÄK	Max	Min	Max	Min	BÄK
I_Localizer_feet	7		500x500	400 x 400		8,0	7		2,0	1,6	558	244	
II_Localizer_legs	7		500x500	400 x 400		8,0	7		2,0	1,6	558	244	
III_Localizer_upper_legs	7		500x500	400 x 400		8,0	7		2,0	1,6	558	244	
IV_Localizer_abdomen	7		500x500	400 x 400		8,0	7		2,0	1,6	558	244	
IV_Angio3D_abdomen_pre	96	≤ 400	400 x 350	330x350		2,6	1,3	≤ 2	1,4	1,1	680	488	< 00:05:00

5.5. MRI Use Scenario

To define a functional unit, the use scenario must first be defined. The use scenario includes applicable use modes, typical customer applications, and equipment capability. Use modes have been defined as:

> **Off mode**: The system functions into the minimum energy consumption state that the typical user can access, through selection of off or shutdown, at the operator console.
>
> **Ready-to-scan mode**: This mode represents the state of the system during patient handling and/or archiving, between individual scans.
>
> **Scan mode:** The MRI is actively scanning the patient to generate the image by sending high frequency waves and reading the resulting variations in the magnetic field. The computing system interprets the data and generates the image.

To determine the time an MRI system remains in each mode, participants referenced confidential field usage records and an industry market report (“2007 MRI Market Summary Report”, May 2008, © 2008 IMV Medical Information Division, Inc, www.imvinfo.com). Given the use mode definitions and typical use scenarios, and then inspecting various member company systems, the typical power usage allocation was determined.

To evaluate the energy consumed during scanning mode, the most commonly used examinations were determined based on the “2007 MRI Market Summary Report”, page II-2, May 2008, IMV Medical Information Division, Des Plaines, IL USA: www.imvinfo.com.
This mix served as the "standard application mix" on which basis specific MRI protocols were defined and performed to measure for Scanning Mode. Members agreed to use the top 5, normalized to 100% as shown in Table 5.

Table 5: *Scan Mode application mix**

Diagnostic Application	IMV © Market Distribution	Normalized Distribution
Head	25%	24%
Spine	26%	25%
Abdomen	25%	24%
Knee	20%	19%
Angio	9%	9%

According to companies’ experts the following daily usage has been defined:

Off:	12h (Off mode)
Examination:	10h (Ready-to-scan + scan mode)
Diagnostic/Servicing:	2h (Ready-to-scan/reduced power consumption)

5.6. Patient per day

A very important feature of MRI is the patent/day ratio. The patient/day ratio measures the maximum number of patients (or examinations) that a MRI machine could scan in one day according to the examination distribution (use scenario) set as typical by the measurement methodology.

This value is determined by performing each examination (head, spine, abdomen, knee, angio) using phantoms[8] but simulating the procedure in between scans and measuring the time. Using the distribution provided by the use scenario, it is possible to determine how many examinations could be performed in one day (how many patients could be examined per day).

The patient/day ratio is very important for at least 2 main reasons:

- The productivity of the machine represents a high value information for the user (hospital/clinic) and for EU patients.
- There is a linear correlation between the productivity and the energy consumption. MRI with higher patient/day ratio consumes more energy as shown by figure 5.

That means that MRI with lower performances in terms of patients per day are consuming less energy. Reducing the number of patients per day could help reducing the energy consumption of MRI equipment. On the other end this is not acceptable as Medical

[8] Phantoms are models made of resin and other materials that simulate body parts and are used to test and calibrate MRI equipment.

Companies are committed to deliver equipment with improved performances and benefits for patients.

As the technological evolution is moving towards machines with faster scan time and higher patient throughput (higher productivity) the energy consumption in absolute value could be expected to grow accordingly. Therefore the patient per day ratio can be used to "normalize" the data on energy consumption.

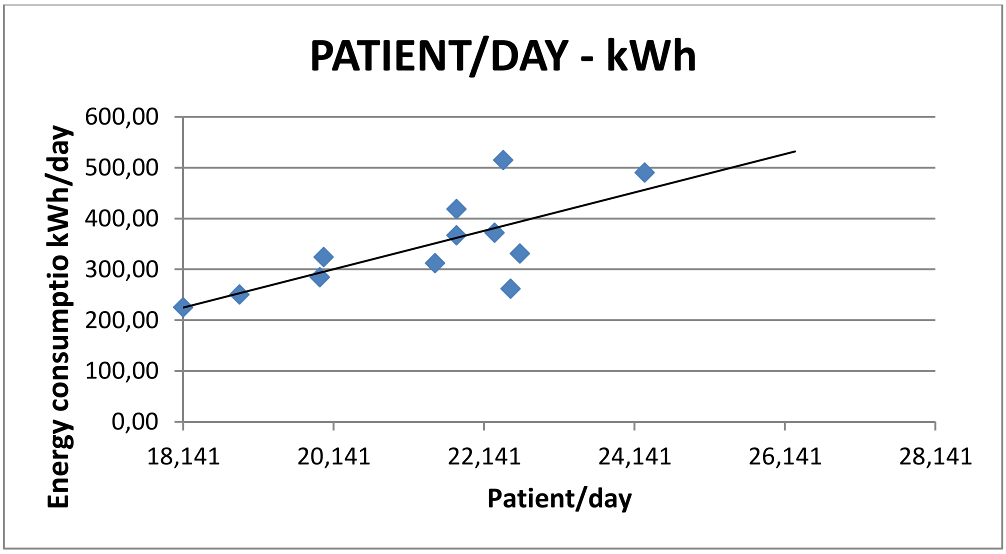


Figure 5: *correlation between patient/day and total energy daily consumption, measured on 10 Category B and 2 Category C MRI.*

5.7. Energy measurement in scan mode

The power consumption in scan mode cannot be easily measured as it is different for each sequence and moreover it varies extremely during the same sequence as shown by figure 6.

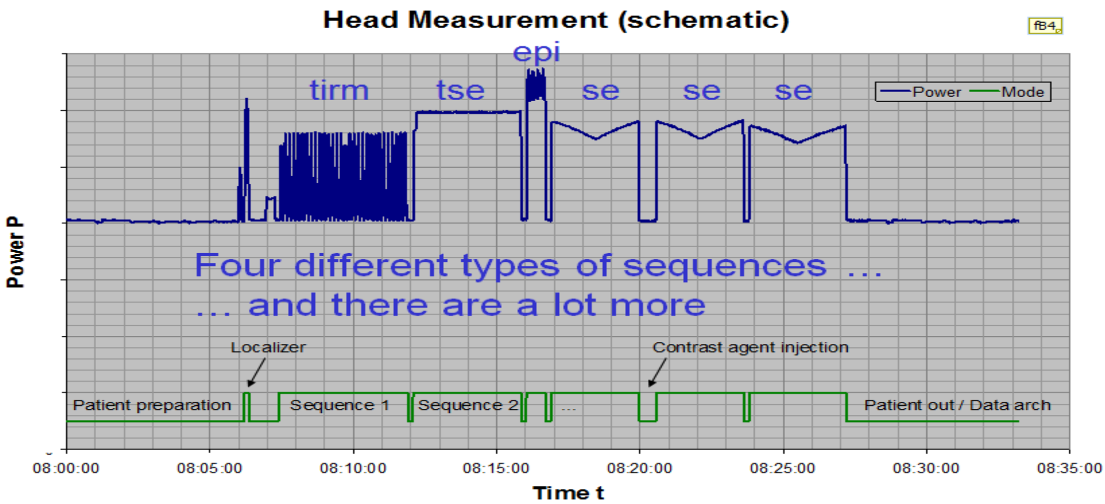


Figure 6*: Power consumption for different sequences in abdomen examination*

5.8. The methodology in brief

The methodology requires and explains how to measure the following data:

1. Power consumption in off mode
2. Power consumption in ready–to-scan mode
3. Average power consumption in scan mode for each one of the 27 sequences
4. Duration of each one of the 27 sequences

The duration of each examination is calculated as the sum of the time in scan mode (measured) and the time in ready-to-scan-mode (average value derived by companies' experience and first simulations).

The excel spreadsheet where the measured data has to be filled in calculates the following values:
1. Number of examinations per day: calculated by the spreadsheet from the duration of each examination and the examination distribution given in the use scenario in the given 10 hours daily working time.
2. Energy consumption in off mode: calculated multiplying the power consumption in off mode for 12 hours
3. Energy consumption in ready-to-scan mode: the energy consumption of each examination is calculated multiplying the measured power consumption for the set duration of ready-to-scan. The total energy consumption per day is obtained multiplying such values for the number of examinations per day.
4. Energy consumption in scan mode: Knowing the power consumption of each sequence and its duration, and the number of examinations in one day, the spreadsheet calculates the energy consumption in scan mode per day. However, scan mode is not in scope of the target setting at this time as explained in chapter 6.5, and this data will not be collected during this target cycle.

All the details and procedures on how to measure the energy consumption are presented in the "Magnet Resonance Equipment (MRI) – Measurement of energy consumption" document, available on the COCIR website in the "Greening at COCIR/SRI" section.

5.9. Required resources to perform the measurements

The measurement methodology requires the MRI to be available in a test lab. In alternative the test could be performed in a hospital or clinic.

The following tasks and technicians/specialists are required per system to measure one specific target MRI:

TASK	TIME	
Compilation of the sequences	4h	Application specialist
Installation of the measurement tool	1h	Electrician
Preparation of the templates	1h	Specialist
Running the sequences	3h	Specialist, Measurement specialist
Measurement and off mode De-installation of measurement tool	1h	Specialist, Measurement specialist, Electrician
Data archiving	1h	Application specialist
Data evaluation	4h	Specialist
Total	**20h**	

5.10. Aspects of the methodology to be improved

The measurement methodology is a powerful tool that allows the measurement of energy consumption based on a use scenario that is very close to everyday practice.

Nonetheless the methodology still has some weak points that the Ecodesign Steering Committee is committed to improve in the coming years.

Benefit for patients
In its current form the methodology takes marginally into account the benefits for patients. Companies are working to provide better technologies with improved functions, able to provide better comfort and benefits for patients such as:

- Image quality and resolution
- Integration with other technologies
- Shorter exam durations
- Larger bore sizes
- Noise insulation systems
- Active magnetic protection screens
- Larger field of view
- Alternatives to the use of contrast agents

Most of those options require higher energy use that is not reflected by the methodology. An increase in the average energy consumption for MRI due to the increased functionality is not recorded by the methodology but only reflected in the categorization (see chapter 6.2).

Duration of examinations
The duration of examinations determines the number of patients that can be examined per day. The patient/day ratio is important as it affects the energy consumption as shown in chapter 5.6.
The methodology, while able to capture the energy usage is not perfectly suited to capture the development and improvement of exam duration.

Scan time could not be reduced as it is determined by the physics of the specific technology as the time needed to reduce the noise and get a clear image. Improvements are limited by the physics of the process. The only way to reduce scan time is to define new sequences that could produce the same image in a shorter time. Unfortunately the methodology does not allow using different sequences than the defined ones. Using new sequences would mean losing data comparability.

The measurement of the time spent in ready-to-scan time is problematic as it depends on the ability of the doctor to perform all the operations. The human factor renders the measurement hardly repeatable and difficult to compare. Therefore the Ecodesign Steering Committee decided to use average values, identical for all the models, determined according to the performed real time measurement and the judgment of experts. This solution, while useful in practice, would not allow taking into account any technical solution that could improve the operation speed, such as new coil systems or larger FOVs which allow the examinations to be performed without the need to reposition the patient.

Therefore the methodology could hardly record improvement of examination speed as, for the above mentioned reasons the main aspects influencing the speed have been set as fixed.

6. ECODESIGN TARGET FOR MRI

6.1. SRI methodology for ecodesign target setting in brief

The fourth step of the SRI methodology sets the ecodesign target as the market average performance of the selected aspect, to be achieved in a time equal to the specific innovation cycle.

The SC Secretariat collects from Companies the measurements of all MRI models and, on the basis of the reduction potentials determined by the PE INTERNATIONAL study on MRI, calculates the target scenarios[9]:

- Baseline today
- Business as usual (BAU)
- Best not yet available technology (BnyAT)
- Beyond Business as usual.

Based on these scenarios, the Ecodesign SC decides on a feasible industry reduction target. Before it is integrated into the companies design targets, the industry target is proposed to the Consultation Forum for discussion.

The results of this step are two types of targets:

- Industry target: that's the target that all the participating companies have to achieve as the average of the market and is equal (unless a different decision is justified) to the value provided in the Beyond as usual scenario. This target is the target against which the success of the initiative has to be assessed.

- Individual company targets: Those are improvement targets that each company can derive from the reported scenarios. A company absolute target is equal to the average value provided by the BnYAT scenario. Such targets are used as an internal tool to keep track of improvements, to decide corrective actions and to ensure companies' commitment.

6.2. MRI Categories

The Ecodesign SC recognized that MRI equipment has different design intents, for specific clinical applications. The design intents result in energy consumption which is substantially different, due in large part to MR physics. For instance, a growing clinical need is for MRI systems with a large patient access (bore). Since MR physics is based on manipulation of a magnetic field, the power needed to manipulate the magnetic field increases exponentially as the diameter increases. Other features relevant to different image quality needs, such as number of data receiver channels, also affect energy consumption. It was recognized that a simple energy metric might cause confusion if systems with different clinical utilities are compared directly. As a result, member companies have developed a categorization table (Table 5) that will be refined according to practical measurement.

[9] For additional information on scenarios refer to SRIv2 documentation, Appendix V: www.cocir.org

Table 5: *MRI Equipment Categorization*

General information on categories included	– matrix columns represent key differentiation characteristics that differentiate different clinical utilities of a system – each characteristic results in a designated amount of points – total score of all characteristics will determine the overall category that a system belongs to			
Key characteristics	Field strength	1.5T	50	points
		3.0 T	100	points
	Bore size	< 60 cm	10	points
		≥ 60 & < 70 cm	20	points
		≥ 70 cm	30	points
	Maximum Gradient Amplitude per axis	< 35 mT/m	40	points
		≥ 35 mT/m	80	points
	Maximum Slewrate per axis	< 100 mT/m/s	20	points
		≥ 100 mT/m/s & < 150 mT/m/s	30	points
		≥ 150 mT/m/s	40	points
	Patient table	fixed table	10	points
		mobile table	20	points
	Maximum channels	< 16 channels	15	points
		≥ 16 channels & < 64 channels	35	points
		≥ 64 channels	45	points
	Useable FOV cm²	< 40 cm	25	points
		≥ 40 & < 50 cm	35	points
		≥ 50 cm	45	points
Final company model category	**Total points**			
	Clinical model - Category A		**< 220**	points
	Hospital model - Category B		**≥ 220 & < 315**	points
	Research model - Category C		**≥ 315**	points

6.3. Scope

The Ecodesign Steering Committee decided to apply the SRI methodology to set ecodesign targets only to category B equipment.

Exclusion of category A
Category A products represent a small percentage of the whole sales in EU as shown by table 3. Most of category A MRIs are open models equipped with permanent magnets that do not require power to generate the magnetic field (no cryo-cooling system). Therefore contribution of category A to the energy consumption of MRI is very limited and the absence of the cryo-cooled magnet reduces also the potential for improvement.

Exclusion of category C
Category C models accounts for 20% of all EU sales. Category C represents high-end models, with increased functionality, mostly used for research purposes. Only a few models are actually commercialized by few companies. If applied, the methodology would open critical issues related to confidentiality of delivered results and certainly would harm competitiveness and innovation.
The required high level performances involve higher energy consumption, due to the 3 Tesla magnetic field and its stability. For this reason the potential for improvement is extremely limited and should be investigated with extreme care to avoid that possible technical solutions to reduce the energy consumption (adopted for category B equipment) could compromise or reduce the performances.

For the above mentioned reasons the Steering Committee decided not to set targets for such equipment and to evaluate the feasibility of reducing the energy consumption without compromising performances and benefits for patients.

6.4. Functional Unit

The functional unit is the reference ensuring the comparability of power consumption of different products and their developments over time.
As identified by the study on improvement potential for MRI, the functional unit for MRI is the number of patients that can be examined per day. Such number, as already presented, is not fixed a priori but depends on the hospital workflow, the administrative time, the nature of examinations, the required quality and functionality and furthermore the power and performance of the machine. It is determined measuring the duration of each examination (scan time: measured + ready-to-scan time: set) and applying the examination distribution to the 10 hours working time of the machine.

6.5. Metric

The energy consumption of MRI is the sum of the energy consumption in the three different modes (off, ready-to-scan and scan).
The measurements run on 12 models and the results of the study on MRI potential for improvement have shown that:

1. Measuring the energy consumption in scan mode is complex, expensive and time consuming, as examined in chapter 5.7.

2. The potential for reducing the energy used to perform the scan is limited due to the physics of the process. A certain amount of energy is needed to stimulate the response from the body and to be read by receivers.

3. Improvements could be achieved by defining new technologies that use different sequences. Such improvements could not be recorded by the methodology at the

moment, as the sequences are set. Not setting the sequences would render difficult to compare the measurements.

Therefore the Ecodesign Steering Committee **decided to adopt as metric for setting the target for MRI the energy usage per model per day (kWh/unit day) in off and ready-to-scan mode to perform a certain number of examinations according to the use scenario.**

The target is to be expressed as the **average daily consumption per model in off and ready-to-scan mode:**

$$\boxed{\mathbf{kWh_{(off,\ ready\text{-}to\text{-}scan)}/unit\ day}}$$

This choice reflects the part of the energy consumption that could be reduced by ecodesign programs and takes into account the productivity of the MRI as the time in ready-to-scan mode is not defined but varies. In fact, even if the ready-to-scan time is defined per examination, the number of examinations per day depends on the total examination time, which account also for the scan time.

6.6. Innovation Cycle

The innovation cycle is defined as the time needed to develop new or enhanced products and place them on the market. For medical devices it could vary from 3 years to 7, depending on the complexity of the innovation being brought to market.

The below listed activities for MRI requires:

- Research and development - 1 year
- Realization, Verification and Validation - 3 years
- Regulatory Approvals - 1 year

The innovation cycle for MRI therefore corresponds to 5 years.

6.7. Setting the ecodesign target

The SRI methodology for target setting has been developed on the base of the experience gathered with the pilot ultrasound project. In particular the Business-as-usual scenario (BAU) is based on the assumption that that the energy consumption of the modality under consideration will get lower year after year due to existing ecodesign programs and due to the improvements of other technologies according to implementing regulations under the Ecodesign Directive or voluntary measures. This assumption has proven true for the Ultrasound pilot project.

The PE INTERNATIONAL study on MRI shows that this assumption is probably not true for MRI. New functionalities, larger bore diameters, increased magnetic field strength and more powerful gradient and RF amplifiers are going to increase the energy demand to meet clinical needs of medical care.

Therefore the BAU scenario, defined under the assumption that all companies will reach the front runner today at the end of the innovation cycle, has been redefined for MRI according to the findings of the PE INTERNATIONAL study on MRI improvement potentials and used as the baseline.

According to the findings of PE INTERNATIONAL, the BAU baseline shows an increase in the energy demand which can be mitigated by the reduction of energy usage in the most favorable case (BnyAT) where all possible improvements are implemented at the same time by all companies (extreme assumption not in line with technological limits).

Therefore the BnyAT scenario should be re-defined accordingly as the result of the application of the companies' potentials to the newly defined BAU baseline.

The four scenarios have been redefined as:

- Baseline today
- Business as usual scenario according to the SRIv2 methodology (front runner), used as reference value
- Business as usual (BAU): scenario for year 2017 where the average daily energy usage per model is expected to be increased around 14,3% compared to baseline according to the findings of the PE International Study.
- Best not yet available technology (BnyAT): scenario for year 2017 where the average daily energy usage per model is expected to decrease around 3,65% compared to the baseline 2011.
- Beyond Business as usual: scenario for year 2017 where the application of the SRI will reduce energy consumption from the BAU baseline by 15,5%.

As shown in table 6, taken from appendix V of the SRIv2, the maximum possible reduction potential identified for each Company determines the average value that is used to define the Best-not-yet-available scenario. The study collected the company data that cannot be disclosed due to confidentiality reasons.

***Table 6**: table 3, page 57 of SRIv2 – Step 4*

Gather Company Expert judgment on feasible improvement (expert judgment – best NOT yet available technology 2017 for later verification of final target (related to functional unit and use scenario)*					
Forecast individual feasible improvement per Company (expert judgment)	--	--	--	--	--
Average feasible improvement for SRI companies (expert judgment – BnyAT in 2017)	**-15,5%**				
Average improvement for the Beyond BAU scenario in 2017	**-12.4%**				
*Expert judgment of individual companies for aspect that has been selected in Step 3 of the methodology					

The four scenarios are determined as follows:

Scenario (kWh/unit day)	**Company**					**Average daily consumption in off and ready-to-scan per unit** (kWh/d)	**Range for setting targets compared to baseline**
	A	**B**	**C**	**D**	**E**		
BASELINE 2011 (kWh/d)	**XX**	**XX**	**XX**	**XX**	**XX**	**219**	baseline today
BAU 2017 according to SRI methodology	**XX**	**XX**	**XX**	**XX**	**XX**	**181**	
BAU 2017 (kWh/d)	**XX**	**XX**	**XX**	**XX**	**XX**	**250**	**+14,3%**
BnyAT 2017 (kWh/d)	**XX**	**XX**	**XX**	**XX**	**XX**	**211**	**-3,65%**
Beyond BAU 2017 (kWh/d)	**XX**	**XX**	**XX**	**XX**	**XX**	**219**	**0%**

Grey cells: confidential data

The baseline scenario is obtained as the weighted average of the energy performance of all models in $kWh_{(off+ready\text{-}to\text{-}scan)}$/unit day against the sales. This value differs from the baseline value of the PE INTERNATIONAL study as the study identified the improvement potential of a representative model therefore considering a simple average of the measured models. Therefore the data presented in this report are more accurate in absolute terms.

The Beyond BAU scenario is derived applying to all companies a reduction equal to the maximum improvement potential except the front runner today for which its declared relative improvement potential is applied.

This means that Companies producing MRI equipment participating in the SRI commit not to increase the energy consumption in off and ready-to-scan mode of the average model in 2017 compared to the 2011 baseline.

Table 7: *calculated values for year 2010-2011 and forecast until 2017 under the assumption of a linear trend*

	Sold units	**Total daily energy consumption (kWh)**	**Average daily energy consumption per unit**	**Beyond BAU**	**BAU**
2011	735	160.965	219		
2012				219	224,2
2013				219	229,3
2014				219	234,5
2015				219	239,7
2016				219	244,8
2017				219	250,0

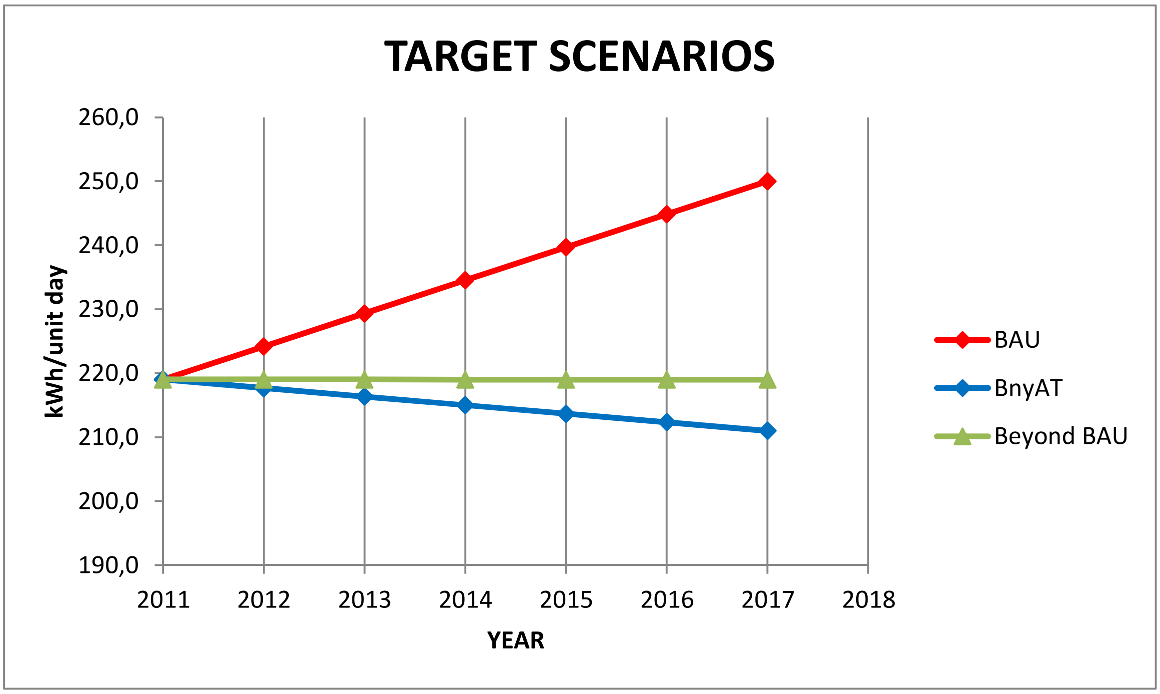


***Figure 8**: estimation of target scenarios*

The reduction compared with the BAU baseline implies that the SRI will save in 2017 around 8060[10] kWh per unit sold according to the Beyond as usual scenario, equivalent to 2,7 tons of CO_2[11] per year per unit.

6.8. Company targets

According to the SRIv2 methodology, each member company adopts an internal company target which together enables achievement of the industry target.
Every year the Ecodesign SC Secretariat can evaluate the achievement of each company by comparing the baseline with the measured average performance of all models from each company placed on the market each year.

Company targets are extremely important for participating companies as such targets are necessary to achieve the required improvements. At this time, individual member company targets have not been derived and a process to define individual targets is ongoing. When complete, member company targets are confidential unless a company wishes to disclose them.

The ErP Steering Committee is committed to derive Company Targets, and appreciates feedback from the Consultation Forum and interested stakeholders on compliance per section 5.3 of the SRI v2 methodology.

[10] *Assuming 5 days per week, 52 weeks per year*

[11] *Conversion factor gCO2/kWh = 335. Average value for EOCD Europe in 2008. Source: CO2 Emissions from Fuel Combustion (2010 Edition), IEA, Paris.*

APPENDIX I

Relationship between scan and ready-to-scan kWh

Figure 7 represents the relationship between the energy use in scan mode and the energy use in ready-to-scan mode measured on 12 models.
The linear regression shows a good correlation (R^2=0,77) which allows to determine the total daily consumption of a MRI given the consumption in off and ready to scan mode.

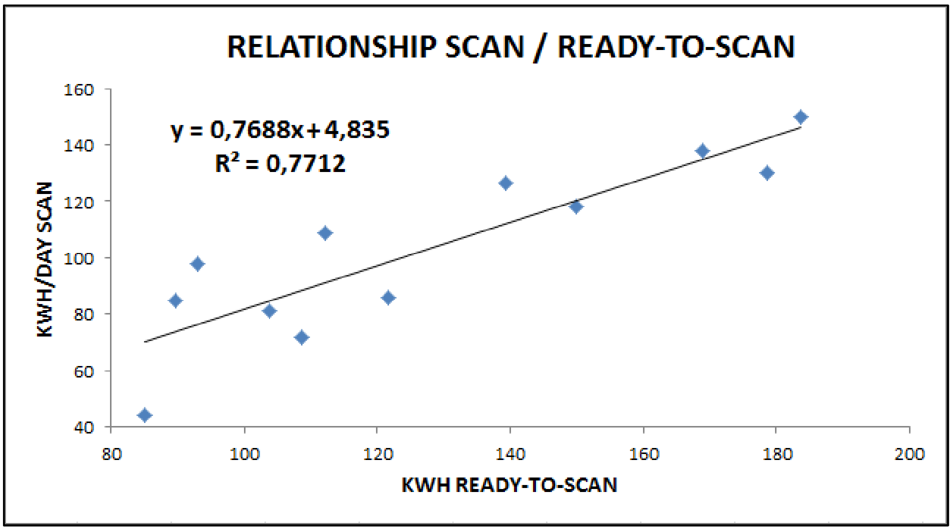


Figure 7: *linear correlation between energy consumption per day in scan mode and ready-to-scan mode*

$Scan_{kWh/d}$ = 0,7688 * Ready-to-scan$_{(kWh/d)}$ + 4.835

Therefore the total consumption of an MRI model per day can be derived, with good approximation, using the following formula:

$Total_{\ kWh/d}$ = Off $_{(kWh/d)}$ + 1.7688 Ready-to-scan $_{(kWh/d)}$ + 4,835