Report

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

PE INTERNATIONAL
EXPERTS IN SUSTAINABILITY

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

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Nomenclature

BAU	Business as Usual
BAT	Best Available Technology
BNAT	Best not yet Available Technology
MFD	multi function devices
MRI	Magnetic Resonance Imaging
RF	radio frequency
SRI	Self-Regulatory Initiative
VA	Voluntary Agreement

1 Introduction

The motivation of this report is to define a methodology and to estimate the potential for environmental improvements for Magnetic Resonance Imaging equipment (MRI). The identified improvement potentials in total and per Company are used by COCIR in the Self-regulatory Initiative (SRI) for medical imaging equipment to define ecodesign targets for MRI. As investigations in earlier phases of the SRI of COCIR showed, the use phase dominates and provides the highest potential for environmental improvements by energy efficiency.

It is in the nature of the product group to be extremely complex and provide manifold functions. This leads to the fact, that improvement aspects are not easy to be identified while at the same time ensuring availability of established and new functions, providing physically and technically required performances and new developments.

The document is the result of a continuous accompaniment of COCIR and its members from August 2011 until March 2012. In this time data had been collected and calculations had been taken place to proof the applicability of the method. The given calculations are therefore a theoretical potential and serve as support to COCIR to calculate their requested target.

The method shows how the improvement potential goes beyond Business as Usual (BAU) and that it is proofed to be ambitious independently from the resulting percentages of efficiency increase or absolute reduction of power. It also serves hints and potentials how individual companies can improve and what it means for the market, if improved devices will be delivered, motivated and initiated from the SRI and its underlying method.

2 Executive Summary

The document is structured into three sections;

The first one introduces to the product group of magnetic resonance, the scope of the COCIR SRI and its intention of implementing ecodesign, in order to provide a solid information base and to allow understanding the complexity.

The second section provides a description of the method that has been applied in order to quantify the improvement potentials in a meaningful, realistic and comparable way to the constant increase of functions. Only this ensures freedom and leveraging in all developments (innovation through ecodesign), whilst ensuring that the environmental impacts are reduced through best applied energy efficiency.

Finally the third section provides data and information how the method was applied in order to provide the data required by the SRI target setting methodology. The identified improvement potential has to be considered as the maximum improvement that could be achieved under the unrealistic assumption that all the different technological solutions are applied at the same time. As shown in the report, the technical possibilities to reduce the energy use depend on the specific technology of the MRI and are limited by the required performances of the equipment that cannot be compromised under any circumstance.

The study also concluded that due to the technological complexity of MRI and the constant trend towards higher performances and functionalities a single efficiency factor is not applicable. For this reason the analysis focused on single modules and single operating modes.

The results from the applications of the identified improvements show that the technical developments towards MRI with more and improved functions have an impact on the possible environmental improvements. It changes the reference, i.e. functional unit, for comparisons of power consumption. However, many modules in each mode have options for technical improvement which lead to lower power consumption. But some modules clearly have to follow physical constraints in order to provide the intended functions appropriately.

The highest improvement potentials are buried in modules and modes, in which in principle no function is provided, i.e. off mode and partly ready-to-scan mode. A combination of increased efficiencies and smart switching off functions are therefore considered. Also, the more the modules are investigated separately and understood as individual sub-products or parts with individual improvement options the higher is the probability to reap the potential.

Overall there are two scenarios presented for category B products, in which an increase of power consumption is expected in case of BAU. The improvement potentials initiated from the SRI can lower these increases, but due to more functions and better examinations a low increase of the level of power consumption in absolute terms might occur. However the measures and improvement potentials are all proven to be ambitious and that the scenarios reflect the best possible situation. This is supported from action items, which would not work without the SRI for example the influence on the supplier of the cryo-cooler because of combined market power.

3 Overview COCIR and PE INTERNATIONAL

COCIR is the voice of the European Radiological, Electromedical and Healthcare IT Industry. COCIR is a non-profit trade association, founded in 1959, representing the medical technology industry in Europe. COCIR's members play a driving role in developing the future of healthcare in Europe and worldwide.

COCIR's aim is to represent the interests and activities of its members at European level, and to communicate with policymakers on economic, regulatory and technical issues related to healthcare. COCIR also cooperates with international organizations on issues of common interest.

COCIR seeks to promote the development of harmonized international standards and regulatory control respecting the quality and effectiveness of medical devices and healthcare IT systems, without compromising the safety of patients and users. COCIR's key objectives include promoting free worldwide trade of medical devices and maintaining the competitiveness of the European imaging, electromedical and healthcare IT industry.

COCIR encourages the use of advanced medical technology to support healthcare delivery worldwide, through cost-efficient and state-of-the art healthcare systems.

PE INTERNATIONAL provides companies with cutting-edge tools, in-depth knowledge and an unparalleled spectrum of experience in making both corporate operations and products more sustainable. Applied methods include implementing management systems, developing sustainability indicators, life cycle assessment (LCA), carbon footprint, design for environment (DfE) and environmental product declarations (EPD), technology benchmarking, or eco-efficiency analysis, emissions management, clean development mechanism projects and strategic CSR consulting. PE INTERNATIONAL uses its broad range of expertise to jointly find solutions with our clients to meet their varied needs in the above areas of Sustainability. We run workshops, provide training, manage full projects and offer standard and customized software solutions complete with data bases. By ensuring a thorough understanding of the client's needs, we can focus our services on what matters. We take pride in our efficiency and effectiveness and we ensure that our clients will reap the benefit of a cost effective investment in their sustainability needs.

4 COCIR SRI

The Self-Regulatory Initiative (SRI) for medical imaging device is a voluntary agreement between Companies under the framework of the ecodesign Directive (2009/125/EC).

Participating Companies commit to improve the environmental performances of medical imaging equipment through a transparent and open process with the involvement of the European Commission and stakeholders.

The most significant environmental aspects are identified and quantified. A specific methodology is developed to measure them and to evaluate the improvement potentials. Reduction targets are set and improvements are tracked and yearly communicated to the European Commission and to stakeholders.

The initiative and a first pilot project on Ultrasound equipment was firstly presented to the Consultation Forum in 2009. The comments received during and after the meeting were used to refine the proposal that has been submitted for official endorsement to the European Commission end of January 2012.

4.1 The SRI Methodology for Target Setting for MRI

The SRI adopts the “fleet approach” regarding to ecodesign targets. Targets are defined as the average performance of all model placed on the market in the year under consideration, not as specific threshold levels on product performances.

The SRI defines a methodology for setting targets on the identified environmental aspects which requires the knowledge of the performances of all the models on the market and an estimation of the potential for improvement for the selected aspect.

The methodology defines 3 scenarios (baseline today, business-as-usual BAU, best not yet available technologies BNAT). Under certain assumption a fourth one is calculated (beyond BAU) and the market average for this scenario is used as industry target to be achieved in a period of time equal to the innovation cycle of the equipment under consideration. The methodology also defines company targets that are used as tools to monitor the achievement of the industry target and to plan corrective actions.

4.2 Goal and Scope of the Project

Main goal of this project is the evaluation of the expected product improvements in order to provide the data required by the SRI methodology for the definition of a reduction target for identified environmental aspects for the product group of MRIs.

In particular PE INTERNATIONAL has been required to provide the following information as a result of the study:

1. Definition of a realistic Business as usual scenario for year 2017 based on the current and expected trend in the MRI technology and market
2. Estimation of the maximum potential for improvement for MRI based on best available technologies and technologies now under development (best not yet available technologies)
3. Realistic estimation of the potential for improvement per company required by COCIR SRI for the target setting process

To achieve this goal, companies participating to the SRI provide information about the improvement potentials of their products. PE INTERNATIONAL evaluates data and information and delivers the main results to COCIR.

Data and information referred to in points 1 and 2 above are provided in this report. Individual company improvement potentials are extremely confidential and cannot be disclosed. Data have been submitted to COCIR only according to the SRI methodology requirements.

Challenges of the project are the continuous development of new functions and examination options, the difficulties to measure power consumption per module and the definition of the functional unit.

5 Methodology for Defining the Potential for Improvement

This chapter introduces MRI equipment to provide a better understanding of the products and their related functions. This is a key element to realise the provided method as a logical solution to motivate for environmental improvements whilst allowing all freedom in design and in developing new options and functions with the goal. It is important to bear in mind that the medical Industry is committed to develop lifesaving equipment to provide better diagnostic tools and better healthcare to patients. Any solution that would reduce environmental impacts while reducing performances at the same time cannot be adopted. Moreover any restriction to innovation capability could have negative consequence on healthcare that must be avoided.

5.1 Description of Product Group MRI

5.1.1 The Functional Unit

The functional unit is the reference ensuring the comparability of power consumption of different products and their developments over time.

In general, the underlying functional unit is the number of patients that can be examined per day. Such number is not fixed a priori but depends on the needs of patients, the nature of examinations, the required quality and functionality and furthermore the power and performance of the machine. Last but not least the way a user, typically a medical expert, conducts the examination has influence on the time it need, taking into consideration for example the conditions and provided options given by the device how to run examinations or drive variations of examinations for better information gain.

For a specific MRI the number of patients examined per day is derived by dividing the working time in a hospital[1] per the number of examination that could be performed by the equipment. As people are investigated because of different diseases, the most common examinations (head, spine, abdomen, knee, angio) and sequences for each examination have been defined as basis for the functional unit. Basis of this approach is the “2007 MRI Market Summary Report”, page II-2, May 2008, IMV Medical Information Division, Des Plaines, IL USA: www.imvinfo.com.

The duration of each examination (measured) and the distribution in a given time frame (10h) allow for the calculation of the number of examinations per day.

Measurements of MRI model showed that there is a direct relationship between the number of patients that can be examined by an MRI and the energy consumption. MRIs with higher patient per day ratio use more energy. As the patient per day ratio can be considered as the “productivity“of the equipment, it seems appropriate to refer the energy consumption (per day) to the number of patient (per day): kWh/patient

Thus in principle, to reduce the energy consumption per patient (kWh/p), there is the option to reduce the time per examination which increases the number of examined patients per day. This is not a linear calculation, e.g. in the sense of higher performance level leads to shorter investigation cycles. This reduction could be achieved only by changing the defined sequences with new ones that could produce the same images in shorter

[1] 12h off-mode, 2h servicing, 10h for examination. For additional information see “Magnetic resonance equipment (MRI) – Measuring the energy consumption” report available at www.cocir.org

time. This would result in the loss of comparability of power consumptions due to a different functional unit.

5.1.2 Modules

Magnetic Resonance Imaging (MRI) is based on the magnetic resonance phenomenon. The basic hardware components of all MRI systems are the magnet, producing a stable and very intense magnetic field, the gradient coils, creating a variable field and radio frequency (RF) coils which are used to transmit energy and to encode spatial positioning. A computer controls the MRI scanning operation and processes the information.

Due to the high complexity of the system, the definition of the most important modules is needed to simplify by separation into single functions (out of the entire product functionality) and to figure out the modules with the highest power consumption.

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

- Gradient amplifier
- RF unit
- Reconstruction unit
- Console, Computer
- All required electronics
- Patient table
- Cryogen compressor
- Water heat exchanger (facility cooled water is supposed)
- 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, PE INTERNATIONAL suggested to minimize the number of investigated modules and to summarize certain modules.

Therefore, the following modules had been analysed by companies with respect to the individual power consumption and their improvement potential:

- Gradient Amplifier
- RF Sender
- RF Receiver
- Water heat exchanger
- Computation
- Magnet
- Patient table

In addition to those modules, several companies suggested to take another module into account: the cryo-cooling device. Different experts stated out the significant reduction potential of this module. According to these insights of experts, PE INTERNATIONAL advises to consider this as option for target setting.

As conclusion from the conducted interviews the following aggregation of modules had been chosen, because the improvement mechanisms follow similar principles:

- Gradient Amplifier (RF Sender, RF Receiver and water heat exchanger)

- Magnet (including cryo-cooling)
- Computation
- Others, mainly patient table

5.1.3 Application

The MRI works mainly in three different modes. Either it's off, in ready-to-scan mode or in scan mode. The ready–to-scan mode can take place within an examination in between the scans as well as between examinations, e.g. when examinations or patients change, as shown in Figure 1. The different modes result in a diverse activity of the modules. Therefore the impact on power consumption differs between the modules and modes. Some of the modules are almost inactive during off, if the system runs down. Due to this fact, power consumption should be measured by mode and module in order to derive an accurate estimation that would lead to an ambitious target.

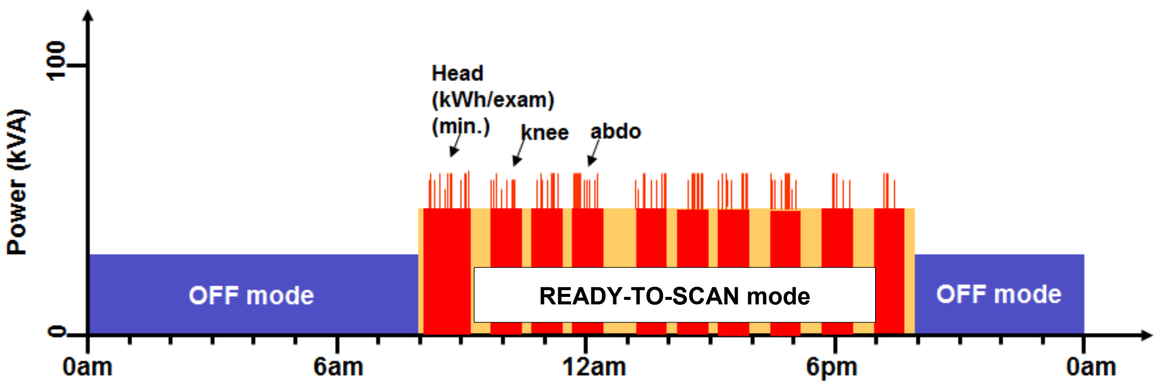

Figure 1: Representation of MRI power absorption during the day

Economic and technical constraints appear in the complicated and cost intensive power consumption measuring process, as defined in the COCIR "Magnetic Resonance - Measurement of energy consumption"[2] standard. Thus, the power consumption was measured in each mode, but the allocation to various modules followed an engineering approach, by determining percentages per module from the total.

5.1.4 Examination of Patients

The examination of patients differs because of different targets to be examined. The time needed to perform an examination depends on the scan speed of the equipment, the functionality, the chosen sequences and the time required for patient preparation, data input and archiving etc.

With respect to those aspects, 5 general examinations with 27 different sequences[3] were defined like stated above. As the systems have different levels of efficiency and power

[2] Available for download at www.cocir.org

[3] A sequence is a preselected set of defined RF and gradient pulses, usually repeated many times during a scan, wherein the time interval between pulses and the amplitude and shape of the gradient waveforms will control NMR signal reception and affect the characteristics of the MR images. Pulse sequences are computer programs that control all hardware aspects of the MRI measurement process.

use, improvements can be either achieved by reducing the time needed for examination or minimizing the power consumption.

Though assuming a continuous improvement of efficiency, the increasing level of functionality and performance could lead to a higher energy demand. This again leads to a change of the reference for the energy consumption, i.e. the functional unit.

5.1.5 Modes

The three modes are off, ready-to-scan and scan. The devices are used for different kind of examinations, which cause different intensities of power usage. Depending on the type of examination, the time for different modes and thus, the power consumption intensity varies. Therefore the different modes were measured individually.

5.1.6 Reason for Need of Increasing Energy Usage

The quality of the images generated by a MR is directly related with the strength of the magnetic field aligning the spins of the atom nuclei and the power of the gradient and RF amplifiers. More powerful magnetic fields and amplifiers allow to obtain images with less noise and higher resolutions. Therefore an increase in the energy usage is expected in the next years.

5.1.7 Bore Size

Another aspect that has to be considered is the increase of the bore size. Larger bores allow higher patient comfort during examination (claustrophobia) and also the possibility to examine “larger” patients (e.g. patients suffering from obesity). As the magnetic field decrease exponentially with the distance, additional energy is required.

5.2 Description of the Approach

5.2.1 General Considerations for Energy Improvements of MRIs

Influence on the potential for improvement can either be exerted on decrease of power consumption, on the increase of speed of examination per patient or on the combination of existing functions and adding new functions into one product in order to avoid several independent devices. Examples for these mechanisms showing the complexity and challenge of single targets are:

- A decrease of power consumption typically derives from increase of efficiency. However, the product MRI consists of numerous individual modules, functional devices and separate individual, highly complex sub-products, that a common efficiency factor is not applicable. Also the sum of all individual efficiency factors to an average efficiency factor is not feasible, since devices such as computing, power transforming, converting, inverting, cooling, moving, magnetising etc. do not follow a general efficiency pattern, which would make sense to aggregate.

Examples from other products show that typically one main function allows the target setting for higher efficiency, e.g. external power supply units, electric motors, transformers or TV sets. Though TV sets already showed the challenge that watching TV is not necessarily a feasible functional unit the efficiency can refer to. Performance aspects such as screen size, quality of picture, number of pixels, contrast range are influencing the efficiency but are difficult to get reflected quantitatively by a changing functional unit. Thus, it can be seen that the complexity of functions to be delivered and the constant change and increase of functions through innovation and development on MRI devices make the application of one single factor impossible.

- A faster examination of patients while increasing the energy consumption per day, would lead to less power per examination. However, time on its own is not the full story that makes MRIs so precious for medical investigations. The true value is in the amount of information that can be given to medical experts. The information is based on imaging of things which cannot be seen from outside but depends on the type, quality, perspective, resolution, static or dynamic visuals, material and concentration and many aspects more. Different investigations need different time and the shorter the good, but the investigation options rule typically the timing. Thus, it is impossible to compare and track timing of the numerous options theoretically possible and the numerous combinations of all possible scenarios. Consequentially at this stage of the SRI it is yet impossible to realize and measure shorter investigation times within the constraints of the defined and fixed investigation sequences, which is necessary to fix in order to have a solid and fixed reference point for comparison.

Examples from other products show that increased performance resulting into fulfilling function in shorter time works, if the reference or functional unit is clearly quantified. Those products are dishwashers, washing machines or dryers, which have a clear, singular, quantifiable function and the environmental impacts can be decreased in case the run time is shorter.

- The combination of existing functions and adding new functions into one product avoids several independent devices to fulfil respective functions. Typically such combinations can use many synergies and therefore result into less environmental impacts. However, the MRIs increase the functions of providing images constantly by innovations and new developments as well as by combination with other medical examination disciplines. This leads into an even more complex set of performance requirements, an extension by additional devices, modules and sub-modules as well as to entirely new functions and is still identified as a MRI product. In order to identify the synergies quantitatively an allocation could take place that identifies the power consumption per each function, which is not possible with MRI, because of missing clear boundary conditions or system boundaries for applying allocation.

Examples from other products can be given on the so called multi-function devices (MFD) from printing and imaging market. They combine clearly identifiable functions such as printing, faxing and scanning, for which discrete products also exist. Thus a comparison between discrete products and MFDs can take place and the allocated shares of the MFD typically are lower than the discrete products. This approach is not applicable to MRIs, because of either missing discrete products for comparison or unclear allocation options.

As consequence from the above identified challenges and in order to provide a quantifiable functional unit, sequences had been defined being representative for typical examinations of representative MRIs. This serves as reference for measurements as well as for quantifying the power consumption. An examination is composed of sequences (scan time) and time in between sequences (ready-to-scan time). Scan time is mostly fixed due to physical constraints. The increase of speed is only possible in-between the sequences. A possible option relating to future developments could be to change sequences with other that could provide the same quality information but in shorter time, which would be a proof of “innovation through ecodesign”. However, in this phase of the SRI for MRIs a change of the functional unit is not appropriate.

5.2.2 MRI Categories

Due to big differences in design and therefore power consumption, the MRI need to be grouped into categories in order to have a slightly similar basis of equipment from different companies. A categorization method based on scoring has been developed in the COCIR SRI.

Three categories have been defined according to many features of MRIs[4]. The 3 categories could be summarized in a simplified way as following:

- Category A: Clinical models. Normally open or cylindrical superconductive magnets with field strength up to 1.5 Tesla.
- Category B: Hospital models. Cylindrical superconductive magnets with field strength from 1.5 to 3 Tesla. Most of MRI models fall into this category.
- Category C: Research models. Cylindrical superconductive magnets high end models with magnetic fields of 3 Tesla or more.

The power consumption of the MRI of each category has been assessed.

The SRI Steering Committee, on the basis of the measured data and the available market data decided to exclude category A and category C products from the scope of the SRI for the following reasons (from “Ecodesign target for Magnetic resonance Equipment: 2012/201” report).

Exclusion of category A

Category A products represents a small percentage of the whole sales in EU. Most of category A MRIs are open models, equipped with permanent magnets that normally do not require power to generate the magnetic field (cryo-cooling system). Therefore contribution of category A to the total 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 ca. 30% 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 only 3 companies. If applied, the methodology would open critical issues related to the confidentiality of delivered results and could harm competitiveness and innovation.

Moreover the required high level performances reduce the potential for improvement. Possible technical solutions to reduce the energy consumption, such as the ones identi-

[4] For additional information refer to the “Ecodesign target for MRIs” report available for download at www.cocir.org

fied for category B equipment, should be investigated with extreme care to avoid that the performances could be compromised or reduced.

Given the above mentioned reasons, only Category B equipment is taken into account in this study.

5.2.3 Specification of Typical Patient Examination Routines

The specification of a typical patient examination routine is important to have a similar examination basis for every company's measurements. As the chosen patient examinations represent a combination of the most common examinations, the scope of the measurements represents a typical day in hospital. As products and functions -even though belonging to the same category- differ, this similar approach for measurements is the basis for comparable results for the data evaluation. Due to the fact that a target will be defined for the whole industry, comparable data is the basis for this industry-wide approach.

5.2.4 Data Collection

According to the functional unit and the scope and regulations for data collection that was agreed between the partners, measurements of models were provided by industry. The measurement provides scan time and ready-to-scan time (while off time has been set as fixed) as well as power consumption to the different modes. The power consumption of each mode is then allocated and divided to the module accountable for the power consumption. Because of the above mentioned economic and technical constraints for measuring the power consumption of different modalities, the percentage of the power consumption was provided through an engineering approach.

PE INTERNATIONAL collected the data from each company to calculate an average of the market and discussed and verified the provided data with the individual companies and COCIR in a confidential manner.

5.2.5 Innovation cycle

The innovation cycle is defined as the time needed to develop new or enhanced products and place them on the market. 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 on the average:

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

This study therefore estimates the improvements that could be achieved in the period 2012/2017 according to the technologies available today or still under development.

5.2.6 Identification of Improvement Potentials

According to the scope of this analysis and the common agreement to focus on category B modalities, companies were asked in individual interviews to provide not only information about the power consumption of the different modules but also about their assumptions of improvement potentials per module with a 5 years horizon. In addition to quantified improvement potentials, companies provided also an outlook of possible technical developments. To summarize the assumptions, the trend goes towards modalities with more functions and better quality. Therefore, the power consumption of the modality might increase.

Thus, to achieve a power reduction that is beyond BAU, three main options were identified:

1) Reduction of power consumption during 24 hours usage time due to an increase of efficiency
2) Switching off or allowing modules/parts to drop to a lower energy consumption mode in times these modules/parts are not needed
3) Increase of number of patients to decrease the kWh/patient.

For the first option, the assessment of reduction potentials resulted in an estimation that the potential is rather low because MRI are highly improved machines that already work on an extended efficiency level.

With respect to expected developments of IT systems towards smarter switches between off, ready-to-scan and scan mode, the second option offers possibilities to achieve lower power consumption.

To get a lower kWh rate per patient, a higher efficiency and/or speed rate of examinations have to be reached.

5.3 Reasons and Advantages of this Approach

- Complexity of products regarded, by categorisation and modularisation
- Functional unit quantified as much as possible
- Quantitative base for reference and comparison created
- Market importance identified and scope reduced to significant aspects
- Communication about ecodesign motivated and in between partners established
- Moderation as objective third party enabling open discussion about improvements
- Improvement potentials identified and quantified
- Incentives in each organisation to implement improvement potentials into the company design processes
- Provide profound base for calculating the SRI target

6 MRI Potential for Improvement

This chapter presents the results of the data collection and represents a summary of the information exchanged between companies and PE INTERNATIONAL regarding the actual situation of the technology and the expected developments and improvements of the MRI sector. As information about technical improvements is highly confidential, the summary tries to provide an overview of possible improvements by respecting the agreement not to provide any details of individual improvements of a company. PE INTERNATIONAL's role in this process was characterized by being an independent third party operator. Thus, PE INTERNATIONAL got information about individual developments and improvements and advised COCIR on the target setting.

6.1 Assessment of Data

Basis of the results is the measured data that was provided by the following companies:

- GE Healthcare
- Hitachi Medical Systems Europe
- Philips Healthcare
- Siemens Healthcare
- Toshiba Medical Systems Europe.

Data have been collected taking into account:

- Differentiation between three modes:
    i. Off
    ii. Ready to scan
    iii. Scan mode
- Differentiation between 4 modules:
    i. Gradient amplifier, RF Sender, RF Receiver, Water heat exchanger as one module
    ii. Computation
    iii. Magnet (including cryo-cooler)
    iv. Patient table

6.2 Results from Data Collection

6.2.1 Summary of Results for Category B MRI

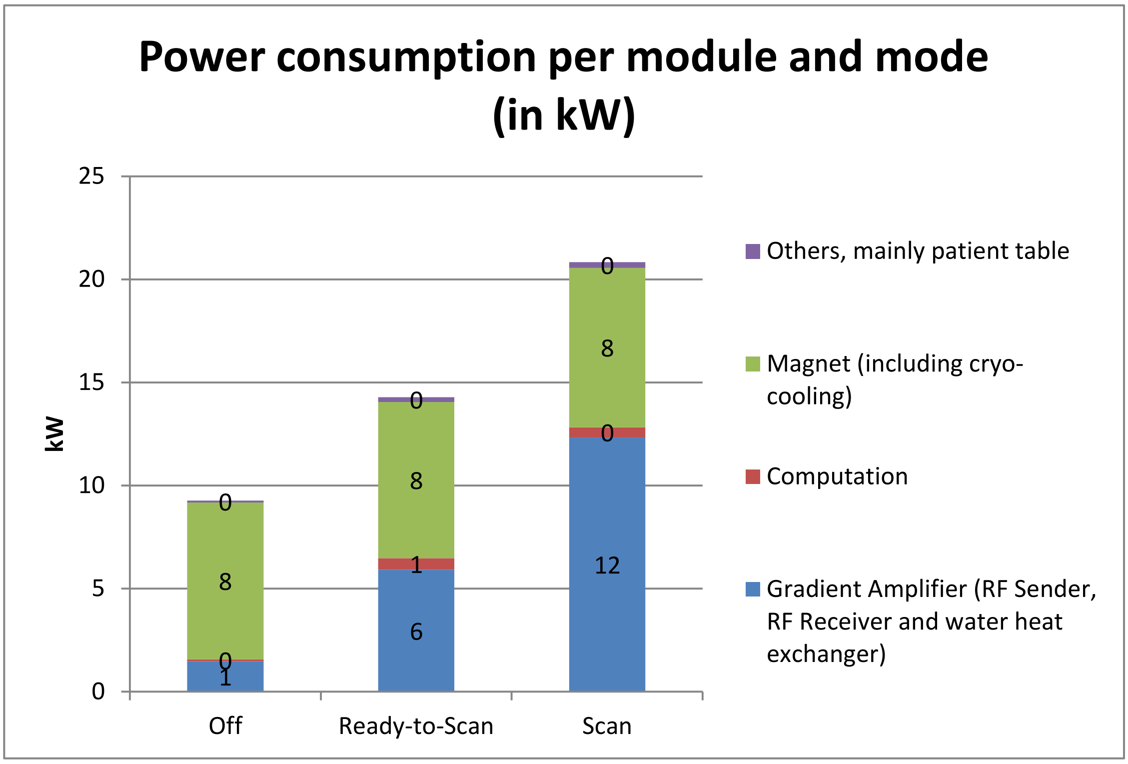

Figure 2: Average power consumption per module and mode (in kW) for category B equipment[5]

Figure 2 shows the average of the measured power consumptions allocated per module and mode. Calculation took place for each product and was summed up afterwards to create the average values. The magnet consumption of MRI is the same in every mode, because the magnet needs to be cooled down to 4 Kelvin constantly 24/7.

[5] Values of zero appear due to rounding

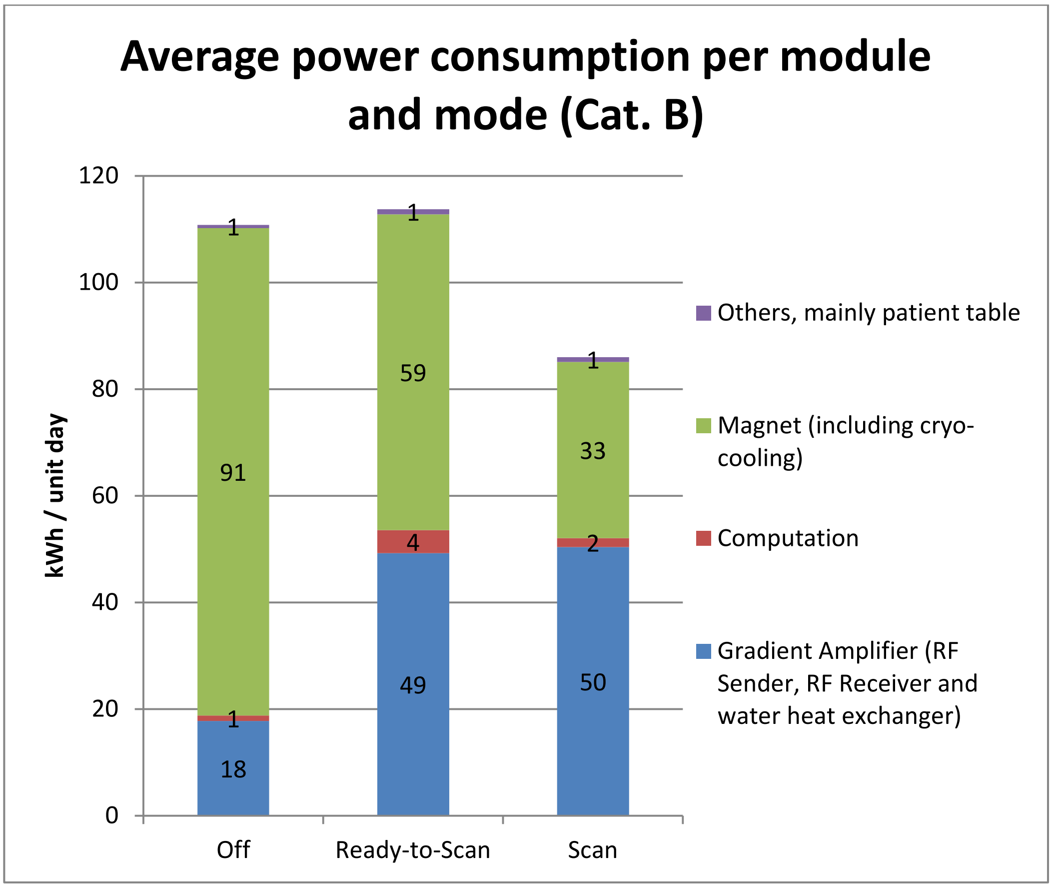

Figure 3: Average power consumption per day (in kWh) of category B equipment

Figure 3 shows the results of Figure 2 multiplied by the respective mode duration leading from kW to kWh.

Table 1 shows the average measured duration of scan and ready-to-scan mode for each examination. Using the examination distribution adopted for the use scenario the duration of each mode per day can be derived. The duration of ready-to-scan mode has been set as a fixed[6] value for all models as its measurement cannot be standardized.

Table 1: Average measured duration of scan and ready-to-scan mode for each examination

EXAMINATION		HEAD	SPINE	ABDOMEN	KNEE	ANGIO
Total Time	Calculated	00:32:52	00:27:05	00:25:08	00:25:38	00:21:31
Scan time	Measured	00:18:30	00:14:49	00:05:51	00:12:51	00:05:57
Ready-to-Scan	Fixed	00:14:21	00:13:41	00:22:43	00:14:10	00:16:07

From Figure 3 it can be concluded:

- Most of the power consumption in all modes is due to the magnet, the Amplifier/RF Sender/RF Receiver/Water heat exchanger
- Low energy influence of patient table and computation

[6] For additional information refer to the "Ecodesign target for MRI" report available at www.cocir.org

6.2.2 Improvement Potentials per Module and per Mode

Figure 4 shows the possible improvements for the power consumption of category B products in different modes. They result from the individual interviews with each company.

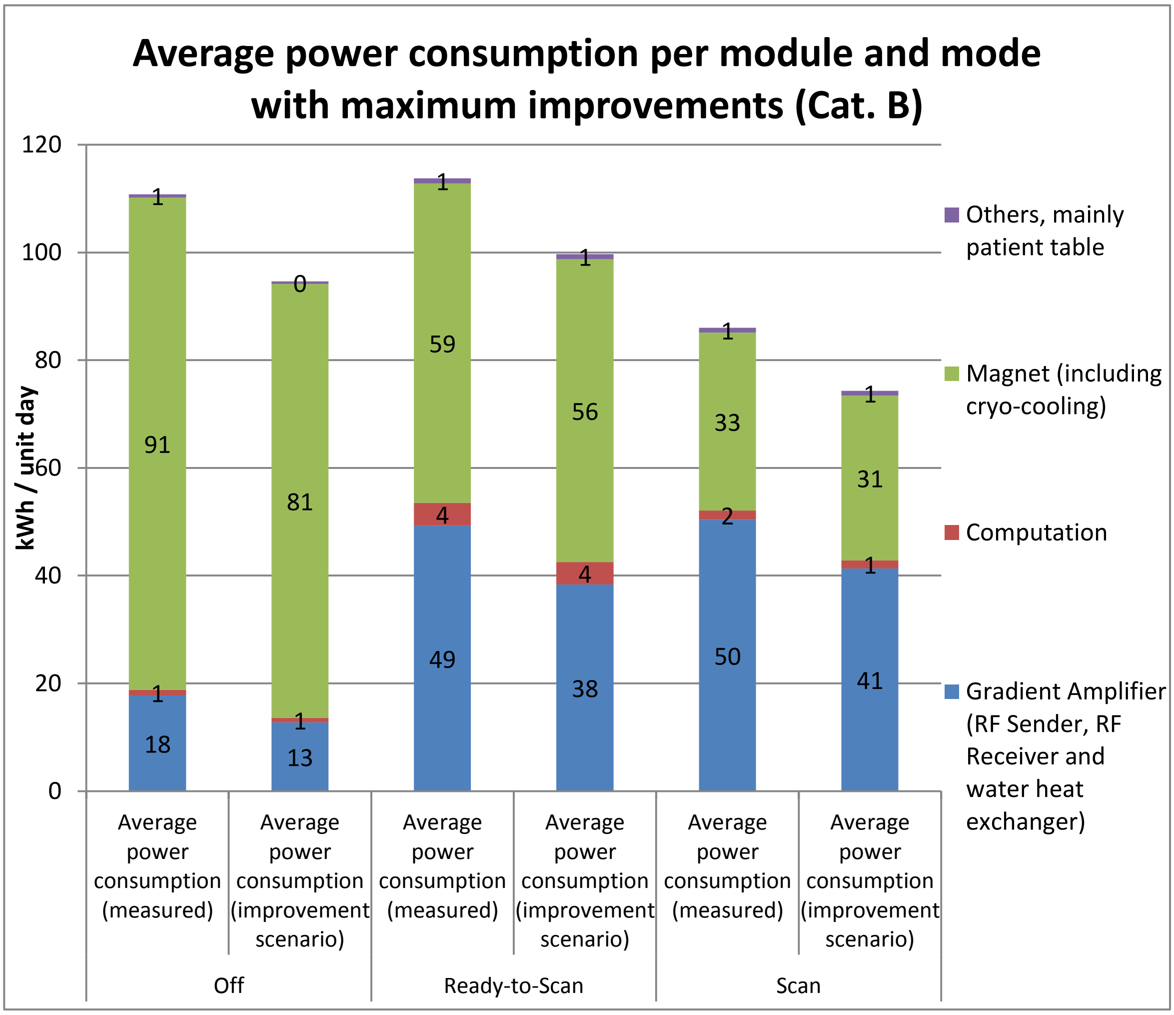

Figure 4: Average power consumptions and improvements scenario (cat. B products and improvements), in kWh

It can be easily derived from figure 4 that between 7% and 22% reduction is possible for modules per mode.

In detail the following overview provides the results in a confidential manner, since future developments must be understood as highly competitive in the MRI market.

Improvement potentials of MRI with respect to kWh

The percentages expressed in the chapter below are referred to the energy consumption of the module, not to the energy consumption of the whole equipment.

Off Mode

Gradient amplifier, RF Receiver, RF Sender, Water heat exchanger	20-25%	Possible BAT/BNAT

Technical measures:

- measures as given in ready-to-Scan mode and which refer to switch off technologies are also applicable for this module in off mode leading to given percentages of improvement
- 5%: Improvement of the frequency converter of the water heat exchanger

Computation	20-40%	Possible BAT and applied BAU from IT market

- 40%: Switch off while not used (e.g. at nights, weekends, depends on the hospital)

Magnet (cryo-cooler)	20-25%	Possible BAT/BNAT and influence on supplier due to combined market power

Technical measures:

- 20%: Cryo-coolers are mostly bought by all Companies from one supplier from Japan, Sumitomo Corporation. On the efficiency of the module the healthcare sector can take influence to some degree (e.g. through the SRI as a concrete action).

  The efficiency of the cryo-cooler system decreases over time. Therefore a surplus of performance towards a still reliable performance level after about 3 years life time could be compensated by e.g. speed controlled motor system, which adapts the power demand to the efficiency change over time. In other words: low speed at fresh system and performance level controlled by an increase of speed to compensate decreased efficiency over time. Power saving level potentially 20% (acc. to Sumitomo). If the market put pressure on the supplier of cryo-coolers, the whole product would be more efficient.

  Starting and stopping the cryo-cooler is not a viable option as this will wear out the system. It must be guaranteed that the magnet is PROPERLY cooled. If the cooler stops working the helium boils off and the MRI system is lost.
- 25%: such reduction level could be achieved if technical measures could be developed which allow to switch the cryo-cooler off for certain times during 24h
- 20%: a control loop taking into consideration the liquefying demand could lower cryo-cooling demand mostly in the time when MRI is off (less heat development, only cryo-cooling demand due to losses through isolation); gains take place continu-

ously since system works less in average, but the percentage refers only to off times.

Helium condensation plays a priority role in the functioning of MRI systems. The evaporated helium during the scan phases has to be re-condensed during the ready-to-scan and off time. Energy consumption can be reduced by not re-condensing the helium and refilling it when necessary (old models) but that would imply a greater energy consumption as the helium would need to be condensed and transported anyway. Moreover helium is a very limited resource and when released in the atmosphere it gets dispersed into outer space.

Ready-to-Scan Mode

Gradient amplifier, RF Receiver, RF Sender, Water heat exchanger	5-50%	Possible BAT/BNAT

Technical measures:

- 20-25% (RF Receiver and RF Sender): smart shutdown. Improvements in power supply (from analogue to digital power supply). RF senders and receiver are very sensible devices therefore the stability of the systems would be compromised by switching on and off. Feasibility of this measure is actually under investigation.
- 15-20% (Gradient amplifier): Efficiency of power supply. The introduction of switch mode power supplies is subject to certain restrictions, e.g. introduction of additional noise. This measure would probably not be applicable for the next 5 years.
- 10-15% (water heat exchanger): Smart switching of cooling system down to lower consumption during times of less cooling demand. Saving could be considerably lower according to how the MR is used. Intense use would require the heat exchanger to fully work in ready-to-scan mode to eliminate the excess heat generated during scan.
- 30% (power supplies): fast switch to off outside of scan sequences. The feasibility of this measure is under investigation as at the moment, switching off power supplies affects system stability.
- 5% (Water heat exchanger): Improvement of the frequency converter.

Computation	20%	Applied BAU from IT market

Technical measures:

- 20%: Improvement, innovation and efficiency of computation depends to 100% on BAU and the given developments in their sector. Healthcare devices cannot take influence due to a non-significant market share.

Magnet	10-20%	Possible BAT and influence on supplier due to combined market power

Technical measures:

- 10-20%: Cryo-coolers are bought by all Companies from one supplier from Japan, Sumitomo. On the efficiency of the module the healthcare sector can take influence to some degree (e.g. through the SRI as a concrete action).

  The efficiency of the cryo-cooler system decreases over time. Therefore a surplus of performance towards a still reliable performance level after about 3 years life time could be compensated by e.g. speed controlled motor system, which adapts the power demand to the efficiency change over time. In other words: low speed at fresh system and performance level controlled by an increase of speed to compensate decreased efficiency over time. Power saving level potentially 20% (acc. to Sumito-mo). If the market put pressure on the supplier of cryo-coolers, the whole product would be more efficient.

  Starting and stopping the cryo-cooler is not a viable option as this will wear out the system. It must be guaranteed that the magnet is PROPERLY cooled. If the cooler stops working the helium boils off and the MRI system is lost.
- 25%: such reduction level could be achieved if technical measures could be de-veloped which allow to switch the cryo-cooler off for certain times during 24h

The savings deriving from the above mentioned measures are strongly dependent on the use of the MR. Intensive use, as assumed in the SRI use scenario implies that the cry-cooler has to work most of the time in ready-to-scan and off mode to re-condense the he-lium evaporated during scan. In such cases the saving deriving from a variable speed motor are far lower. Nonetheless the re-condensation of helium is a top priority in MRI systems.

Patient Table	2-5%	Applied BAU from e-motor market

Technical measures:

- 2-5% improved efficiency of table motors

Scan Mode

Gradient am-plifier, RF Re-ceiver, RF Sender, Water heat ex-changer	2-25%	Possible BAT/BNAT

Technical measures:

- 2% (Gradient amplifier, RF sender): Increased efficiency. Absolut energy use might increase because the amplifier will have more technical elements than before, so it will be more efficient but at the same time more total energy will be consumed. The power amplifiers are already highly optimized therefore very limited improvement is expected in the next 5 years.

Computation	20%	Applied BAU from IT market

Technical measures:

- 20%: Improvement, innovation and efficiency of computation depends to 100% on BAU and the given developments in their sector. Healthcare devices cannot take influence due to a non-significant market share.

Magnet	2-20%	Possible BAT and influence on supplier due to combined market power

Technical measures:

- 2-20%: Cryo-coolers are bought by all Companies from one supplier from Japan, Sumitomo. On the efficiency of the module the healthcare sector can take influence to some degree (e.g. through the SRI as a concrete action).
- The efficiency of the cryo-cooler system decreases over time. Therefore a surplus of performance towards a still reliable performance level after about 3 years life time could be compensated by e.g. speed controlled motor system, which adapts the power demand to the efficiency change over time. In other words: low speed at fresh system and performance level controlled by an increase of speed to compensate decreased efficiency over time. Power saving level potentially 20% (acc. to Sumitomo). If the market put pressure on the supplier of cryo-coolers, the whole product would be more efficient.

  Starting and stopping the cryo-cooler is not a viable option as this will wear out the system. It must be guaranteed that the magnet is PROPERLY cooled. If the cooler stops working the helium boils off and the MRI system is lost.
- 2-25%: such reduction level could be achieved if technical measures could be developed which allow to switch the cryo-cooler off for certain times during 24h

The savings deriving from the above mentioned measures are strongly dependent on the use of the MR. Intensive use, as assumed in the SRI use scenario implies that the cry-cooler has to work most of the time in ready-to-scan and off mode to re-condense the helium evaporated during scan. In particular during scan the cryo-cooler could be assumed to be working without any interruption, therefore the savings could be far lower than theoretically expected.

Patient Table	2-5%	Applied BAU from e-motor market

Technical measures:

- 2-5% improved efficiency of table motors

<u>Summary</u>

Summarizing from all the technical interviews and investigations it can be stated that the most important and most feasible improvements can be seen in a smarter switching to off mode of several modules. As the technology of MRI is highly matured, there are physical boundaries of improvements regarding the power consumption of the modules.

Moreover the applicability of most of the identified technical solutions depends on the specific technology and would need to be deeply investigated, whether it fits into the environment of the MRI technology and its specific technological requirements. For instance substituting the analog power supply with a switched one could cause disturbances during scan increasing the noise level in the generated image. A deep redesign of the whole technology would be required.

6.3 Expected BAU and Improvement Scenarios

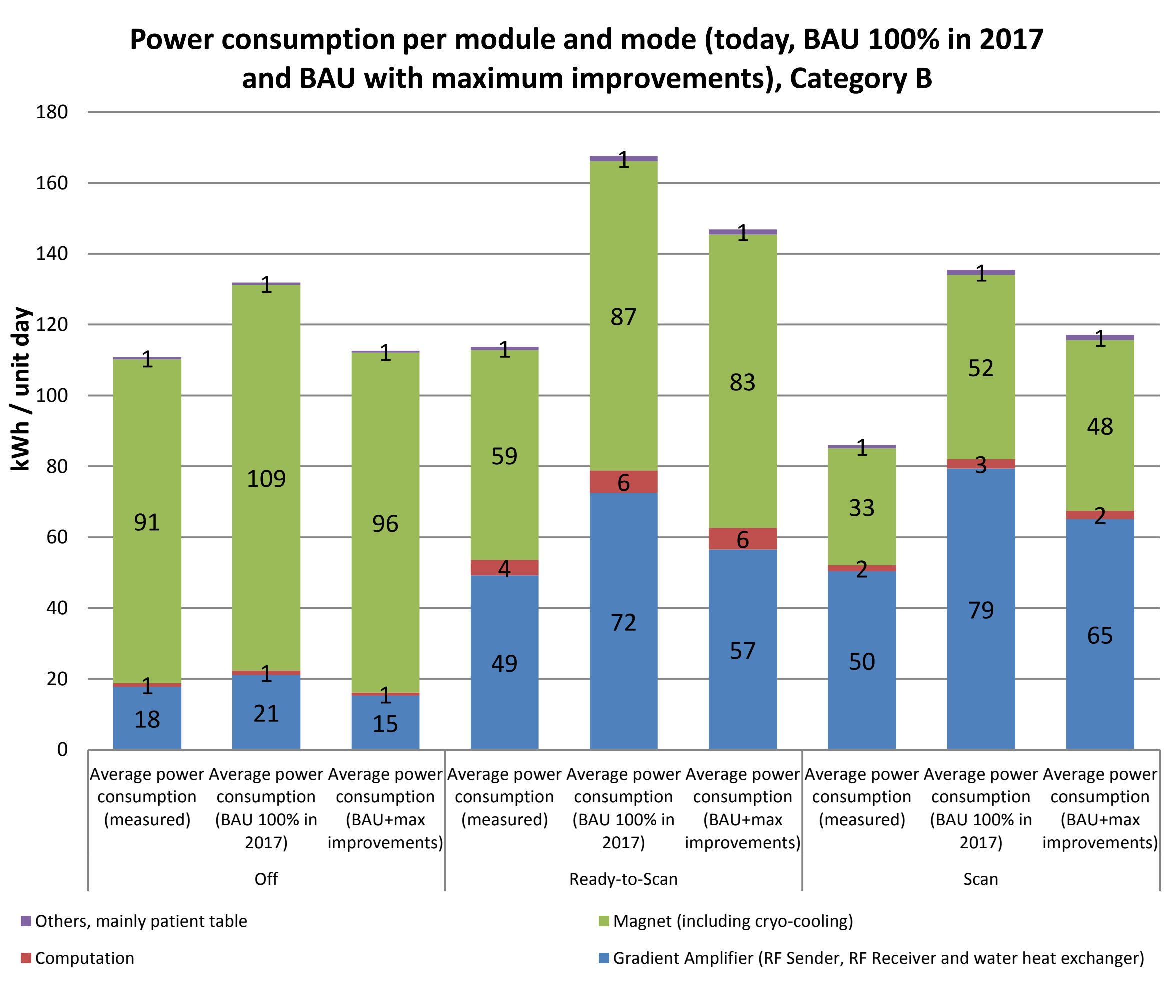

Figure 5: Power consumption (today, BAU in 2017 (100% category C), BAU 2017 with maximum improvements) for cat. B products per module and mode (in kWh)

Figure 5 shows the status of today per each mode. Values of left columns per mode are identical to left column of Figure 4. The central columns per each mode show the BAU scenario, which represents an expected change of power consumption by 2017. It is based on the following considerations:

- Trend in MRI goes towards a higher performance level and functionality. It can be said, that products tend to move in terms of energy consumption and functionality from category A to category B and from category B to category C.

- The development of MRI products will improve the functions and the performances and therefore an increase of the magnetic field strength and gradient and RF amplifiers is expected. For simplification and in order to apply a worst case scenario it is assumed that all category B products move by 2017 into category C products and thus the level of power consumption increases respectively according to the today measured data of category C products. For this reason the scenario is named “BAU 100% category C” meaning that all category B equipment sold in 2017 will have the same performances of category C today.
- Many predictions or scenarios are thinkable, how much more the BAU scenario will increase the power consumption or in other words how much more power the new performance and functions will require. There is no historical consumption data available to build a trend that can be interpolated to provide forecasts. The only solid reference is given by the measurements of products from the three categories during this project.

The right columns of Figure 5 per mode show the identified maximum improvement potentials, which represents the mix of a Best Available Technology (BAT) and Best not yet Available Technology (BNAT), since the improvement options partly refer to ideas and approaches, which are not yet fully developed. The improved power consumption is applied to the BAU scenario (central columns).

The power reduction used to generate the right columns follows the highest level of ambitiousness since all identified improvements mechanisms are applied at once to each module in each mode to all models, an assumption that would prove un-realistic due to technical feasibility as already presented. However, even in this scenario it seems not avoidable that an increase of power consumption takes place due to the newly and additionally integrated functions to and within MRIs.

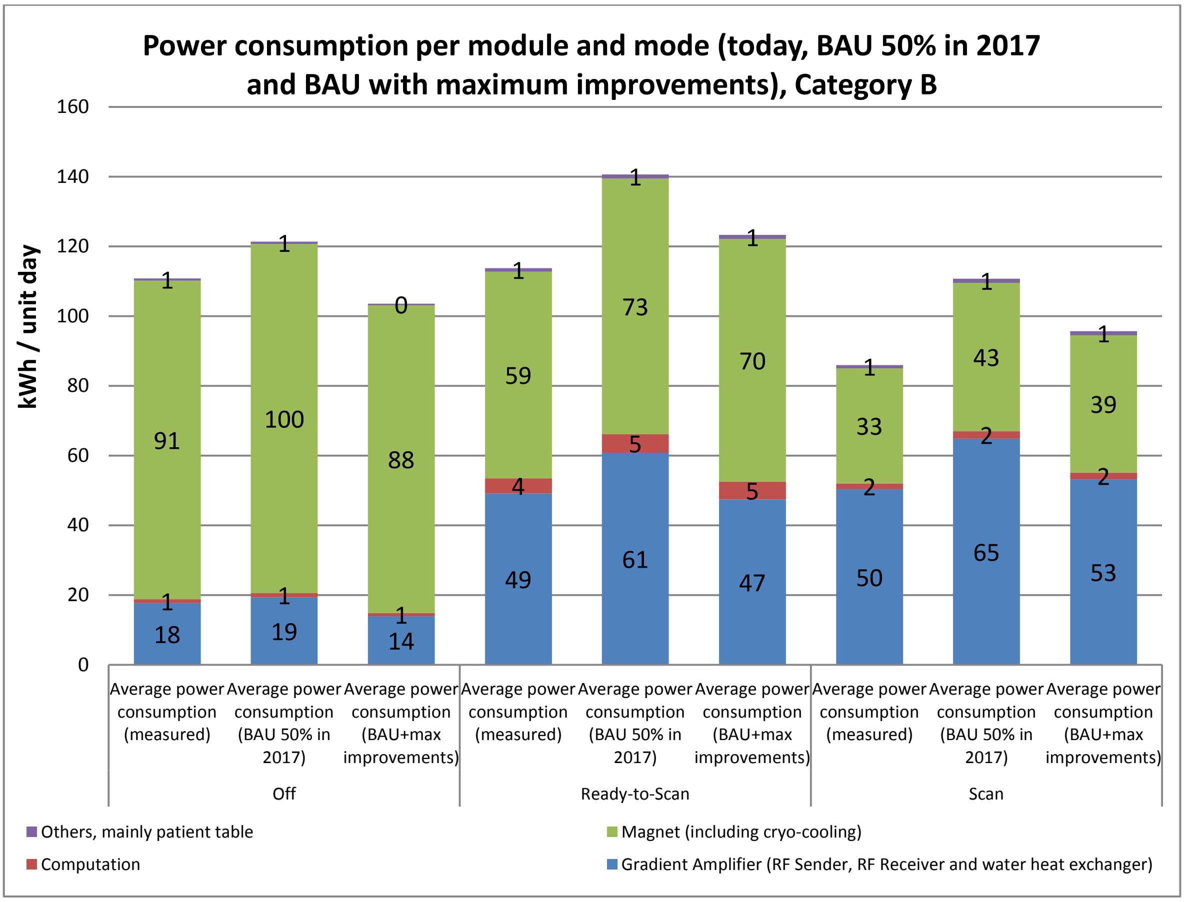

Figure 6: Power consumption (today, BAU 2017 (50% category C), BAU 2017 with maximum improvements) for cat. B products per module and mode (in kWh)

Figure 6 shows an alternative scenario, which represent a more realistic situation regarding the increase of power consumption of category B products. It assumes that only 50% of power consumption takes place between today's category B level and today's category C level. The reduction potentials are applied identically. It results into a lower level of power consumption. In off mode the maximum improvements create an absolute reduction compared to today. In modes ready-to-scan and scan the increase compared with today is significant lower than shown in Figure 5.

The magnet in scan mode and in ready-to-scan mode shows an increase in the energy consumption, which cannot be avoided due to energy requirements of higher field strength. The gradient amplifier module shows a reduced energy consumption in all modes except for scan mode, where the energy demand increase.

6.3.1 Increased Number of Patients per Day

Measurements show that there is a sort of linear relationship between the number of patients per day (related to scan speed) and the total energy consumption. The higher the scan speed, the higher the energy consumption (for additional information refer to the "Ecodesign target for MRI" report published on COCIR website).

Increasing the number of patients per day influences the power consumption in kWh/patient. In principle, it is possible to reduce the time per examination which increases the number of examined patients per day. Due to the physics of the process, the scan speed cannot be increased as such, but new sequences have to be developed which could produce the same results in a shorter time. This would result in the loss of comparability of power consumptions due to different functional unit. The reduction of the duration of the examination could also be achieved by reducing the “administrative time” i.e. patient preparation, data input and archiving etc. Such improvement is highly depending on the kind of use in the respective hospital and related circumstances from persons and examinations, therefore is not under the control of the manufacturer. For this reason an average value has been set for the administrative time for each examination.

However Table 2 gives some preliminary indications, how important time for examination is.

Table 2: Indicative calculation of variable examination times

Scenario	Category	Total energy consumption (kWh/d)	Number of patients	Energy consumption per patient (kWh/patient)
energy today (average patients)	B	311	21	15
energy BAU 50% future (average patients)	B	373	21	18
energy BAU 50% + improvements (average patients)	B	323	21	15
energy BAU 50% + improvements (max patients)	B	323	25	13

The calculation bases on following assumption:

- Today the average power consumption per patient is about 15 kWh.
- With the BAU 50% scenario it might increase to 18 kWh/ patient, if no examination time improvement takes place
- With the BAU 50% scenario and the improvements from the SRI it might decrease down to 15 kWh/ patient, if no examination time improvement takes place
- With the BAU 50% scenario and the improvements from the SRI, plus the application of 25 patients it might decrease down to 13 kWh/ patient. The patients are taken from the currently highest examination speed as investigated from category B products. A more detailed prediction is not possible today.

All the given figures do neither consider additional functionalities, nor the fact that an increase in the patient per day ratio could imply an increase in the energy consumption.

6.3.2 Summary of the Findings

The technical development towards MRI with more and improved functions has an impact on the possible environmental improvements. It changes the reference, i.e. functional unit, for comparisons of power consumption. However, many modules in each mode have options for technical improvement which lead to lower power consumption. But some modules clearly have to follow physical constraints in order to provide the intended functions appropriately.

The highest improvement potentials are buried in modules and modes, in which in principle no function is provided, i.e. off mode and partly ready-to-scan mode. A combination of increased efficiencies and smart switching off functions are therefore considered. Also, the more the modules are investigated separately and understood as individual sub-products or parts with individual improvement options the higher is the probability to reap the potential.

Overall there are two scenarios presented for category B products, in which an increase of power consumption is expected in case of BAU. The improvement potentials initiated from the SRI can lower these increases, but due to more functions and better examinations a low increase of the level of power consumption in absolute terms might occur. However the measures and improvement potentials are all proven to be ambitious and that the scenarios reflect the best possible situation. This is supported from action items, which would not work without the SRI for example the influence on the supplier of the cryo-cooler because of combined market power.