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Resource efficiency of selected technologies, products and strategies

Executive Summary

Summary report of Task 1 within the framework of the „Material Efficiency and Resource Conservation“ (MaRes) project



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**“Material Efficiency and Resource Conservation”
(MaRes) – Project on behalf of BMU | UBA**

Project Duration: 07/2007 – 12/2010

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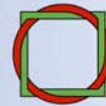
More information about the project

“Material Efficiency and Resource Conservation” (MaRes)

you will find on www.ressourcen.wupperinst.org

The project is funded within the framework of the UFOPLAN
by BMU and UBA, FKZ: 3707 93 300

The authors are responsible for the content of the paper.



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Resource efficiency of selected technologies, products and strategies: Executive summary

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Abstract

In order to successfully provide companies with political support in the implementation of resource efficiency, we need to know where to start best, thus, where the highest potentials are to be detected.

Unlike with energy efficiency, only few substantiated data about resource efficiency potentials were available when the MaRes project started. The project took the first necessary steps to fill this gap.

The most interesting technologies, products and strategies for increasing resource efficiency were identified in a broad, multi-staged, expert-driven process. Thereafter, their concrete potential was determined. The potential analyses were carried out in a diploma thesis program in the framework of a network of experts and in an expert-based analytical process. Altogether, potential analyses were carried out with reference to 20 relevant topics (“Top20-topics”) that were expected to carry high resource efficiency potential. After their finalisation, the results of the single potential analyses were analysed in an intense discourse process in the framework of a cross-evaluation and issue-specific as well as overarching recommendations for action were concluded (see Tab. 1).

Tab. 1: Central fields of action with potential for increasing resource efficiency

Central fields of action with potential for increasing resource efficiency
<p>Technologies</p> <p>Cross-sectional technologies and enabling-technologies: “Door openers” for resource efficient applications</p> <p>Renewable energies facilitate substantial resource savings</p> <p>The growing ICT market needs a careful resource management</p>
<p>Product level</p> <p>Food – both production and consumption need to be considered</p> <p>Traffic – Infrastructure bears higher resource efficiency potential than drive systems</p>
<p>Strategies</p> <p>Integrating resource efficiency into product development</p> <p>Resource efficiency-oriented business models: product-service systems require rethinking</p>

Source: Own illustration

Foreword and acknowledgements

The contents of this paper are the results of an intensive cooperation process of a number of different persons:

We, as coordinators of this Task in the MaRes project, have been responsible for conceptual and coordinating tasks as well as for the comprehensive evaluations. In cooperation with other MaRes project partners of Task 1, we carried out a broad expert-driven diploma thesis program. The results of the potential analyses were included into the results of Task 1. With regard to several topics, other universities also supported the work by mentoring students' theses.

We would like to thank all project partners, all other mentors and all students who worked on the variety of different topics for their great commitment. At this point, especially, the many substantive debates and conversations during the different analysis, assessment, evaluation, and diploma student workshops need to be mentioned.

We extend our heartfelt gratitude to the ifu (Institute for Environmental Informatics Hamburg) and to Prof. Mario Schmid (University of Applied Sciences Pforzheim) for the cooperation regarding the software Umberto for Material Flow Analysis. To carry out the potential analyses, the respective licenses were made available to the students free of charge and mentors introduced to the software in a workshop.

We would also like to thank all persons and institutions that participated and supported us in the survey in spring and summer of 2008. This enabled us to integrate many new ideas and aspects into the selection process of the “Top20-topics” and into general considerations at an early stage of the analysis of the field of investigation.

Our special thanks also goes to the participants of the two expert workshops who intensively discussed and commented on the choice of topics and the contents. Their important suggestions and impulses were included into the overall project results and publications.

We would, furthermore, like to thank Dr. Claus Lang-Koetz (until October 2009) and Dr. Daniel Heubach (until July 2010) for the collaboration and co-chairing of Task 1.

Last but not least, we express our thanks to Dr. Kora Kristof (Project Co-ordination, Wuppertal Institute) and to Felix Müller and Kristine Koch (Federal Environmental Agency) for their very helpful comments and suggestions.

Holger Rohn und Nico Pastewski

1 Introduction

The need to increase resource efficiency has become a top issue in national and international politics in recent years. In this context, the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) and the Federal Environment Agency (UBA) entrusted 31 project partners with the research project “Material efficiency and Resource conservation” (MaRes, see <http://ressourcen.wupperinst.org>). The project has been coordinated and managed by the Wuppertal Institute for Climate, Environment and Energy. The project aimed at advancing knowledge with respect to central questions of resource conservation, especially the increase of resource efficiency with a focus on material efficiency.

This paper summarises the results of Task 1 regarding the potential analyses of identified technologies, products and strategies. It largely builds upon Resource Efficiency Paper 1.2 (Rohn et al. 2009) and Resource Efficiency Paper 1.4 (Rohn et al. 2010). The results presented in the following were gained in a diploma thesis program in the framework of a network of experts and an expert-based analytical process. Altogether, potential analyses were carried out with reference to 20 relevant topics (“Top20-topics”), which are expected to carry high resource efficiency potential. After their finalisation, the results of the single potential analyses were analysed in an intense discourse process in the framework of a cross-evaluation and issue-specific as well as overarching recommendations for action were concluded. In addition, Resource Efficiency Paper 1.5 (Rohn et al. 2010b) contains the summarised results of the potential analyses (10 pages each).

In a comprehensive form, the acquired results are going to be documented in a final report and central results shall be published in a book. Besides, the results of Task 1 are going to be made use of in other tasks of the MaRes project and in the Network Resource Efficiency.

2 Methodology

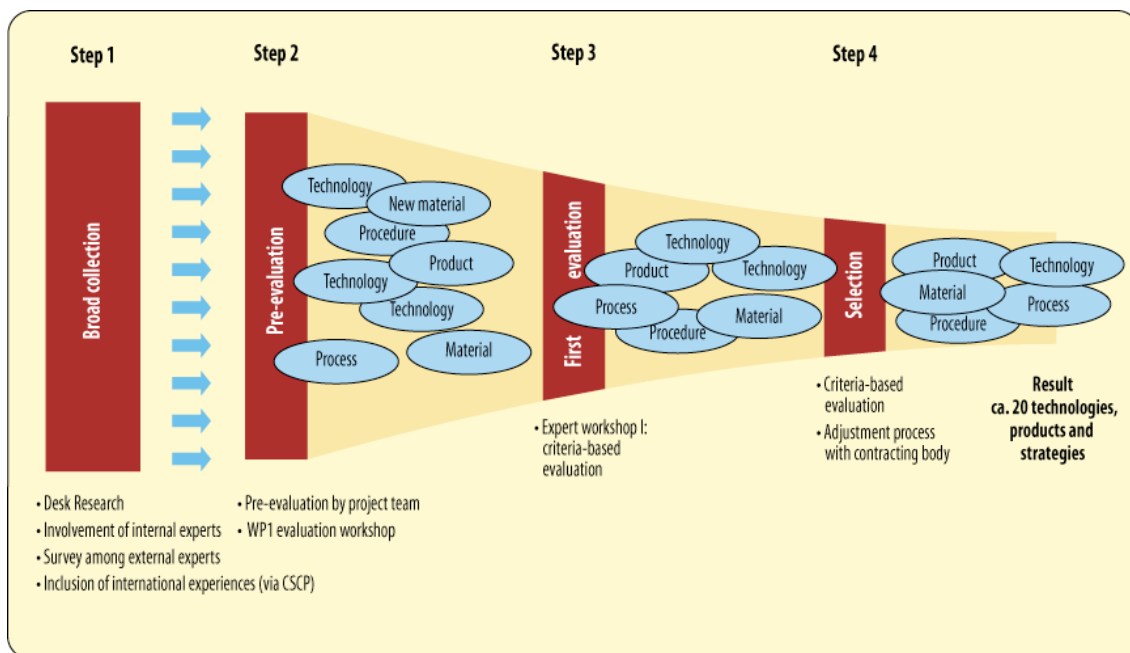
2.1 Selection of topics

The process of topic selection aimed at the identification of technologies, products and strategies which are expected to carry high resource efficiency potential in Germany. In this respect, a complex expert-based methodology for evaluation and selection was developed including four steps (see Fig. 1). For a detailed explanation of the methodology and proceedings see Rohn et al. 2009.

In a first step, the topics that had been identified via desk research and in a survey were structured in a topic list including about 1000 proposals. The survey was carried out on the basis of desk research results and was aimed at enriching the topic list with

the support of experts. The primary addressees of the survey were experts from research institutes, associations, related initiatives and networks (e.g. PIUS-Network, environmental alliances) and enterprises. This way, approximately 15.000 persons were contacted.

Fig. 1: Criteria-based selection of technologies, products and strategies with high resource efficiency potential



Source: Rohn / Lang-Koetz / Pastewski / Lettenmeier 2009

In a second step, the topic list was further elaborated and pre-evaluated. The aim was to evaluate the given 1000 proposals along three criteria: resource input, resource efficiency potential and economic relevance to end up with a focussed topic list of about 250 nominations (“Top250-topics”).

In a third step, an expert evaluation was carried out along seven criteria (presented in Tab. 2) to obtain a ranked topic list. The criteria on resource efficiency were complemented by criteria significant for the implementation. In the course of a workshop with internal and external experts (Expert workshop I) a revised topic list with about 50 proposals (“Top50-topics”) was derived.

On this basis and in a fourth step in cooperation with the Federal Environment Agency, the final selection of the “Top20-topics” took place. In a later stage, these topics were addressed in detailed potential analyses. Thus, the selection of the “Top20-topics” was a result of all previous working steps (see Fig. 1). For details with regard to the “Top20-topics” see Rohn et al. 2009.

Tab. 2: Criteria for the evaluation of technologies, products and strategies

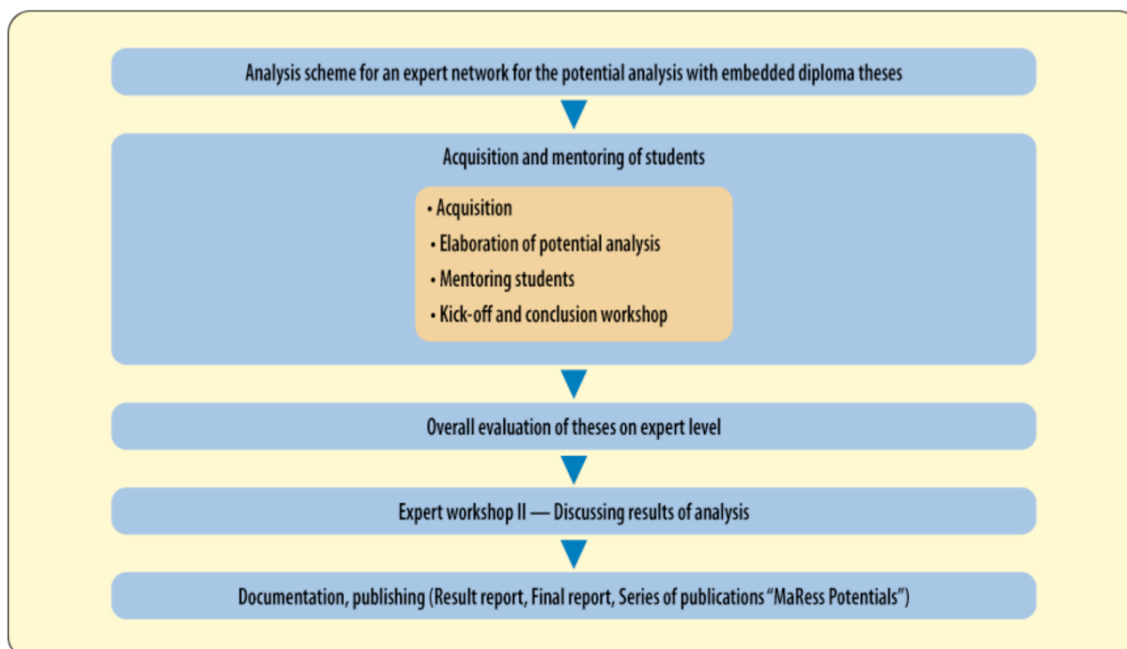
Criteria for the evaluation of technologies, products, strategies
Resource input in terms of mass relevance
Resource efficiency potential of the specific application
Other environmental impacts
Feasibility
Economic relevance
Communicability
Transferability

Source: Own illustration (Details s. Rohn et al. 2009)

2.2 Potential analyses

The potential analyses were carried out in a Diploma Thesis program in the framework of a network of experts along defined consistent guidelines (see Rohn et al. 2010a). The general procedure is illustrated in Fig. 2. Those of the “Top20-topics” were worked on for which qualified interested candidates were found in the given period of time.

Fig. 2: Overview of the potential analysis process



Source: Own illustration

At the beginning of the process, the topic field was analysed and relevant fields of application were identified. The potential resource consumption for the study area was

assessed based on at least one case study, assessing and comparing the current status of resource use in the relevant life cycle phases with a possibly more resource efficient alternative.

Methodologically, the resource efficiency potentials were quantified according to the concept “Material Input per unit of Service (MIPS, see Schmidt-Bleek 1994 and Schmidt-Bleek et al. 1998). Therefore, regarding the examined potential analyses, results are largely – depending on data availability – available as life cycle wide resource use in up to five resource categories (abiotic and biotic material, earth movement, air and water, see Ritthoff et al. 2002 and Lettenmeier et al. 2009) as well as the respective concrete potential for increase in resource efficiency.

Where possible, the results were scaled up to the national level to calculate the resource efficiency potential for Germany in the end. Further environmental implications like green house gas emissions were captured in individual cases.

Besides the assessment along quantitative results, a qualitative evaluation was carried out to capture, among other things, possible rebound effects and constraints of a dissemination of the application. To guarantee a uniform and comprehensive assessment, the results were presented according to the outlined criteria (see Tab. 2). These qualitative evaluations are based on publications, statistics and expert opinions.

Beyond intense individual support, interim results were documented, presented, critically discussed and pre-evaluated along consistent guidelines in the framework of four students’ workshops, improvement measures were taken if necessary.

After the finalisation of the potential analyses carried out by the students, the advisors pre-evaluated the theses. Furthermore, an internal evaluation workshop was carried out to assess the pre-evaluated potential analyses of the Task 1 partners according to the seven criteria outlined in Tab. 2 and the guidelines for potential analysis in an overarching frame. The results of each individual thesis were discussed and specific and overarching recommendations for action were concluded. For a further validation of the results the “Expert workshop II” took place on July 1st 2010. Alongside Task 1 partners, further external experts were involved.

2.3 Lessons learned

The selection of essential topic areas with reference to the increase of resource efficiency in the form of technologies, products and strategies is an extremely complex enterprise. This showed in all working steps from the detailed development of the proceedings to the implementation of the individual working steps. One central reason is the broad scope of the investigation which was not restricted to specific products, branches, fields of need or the like beforehand. In addition, quantitative estimates of the deployed resources and resource efficiency potentials are usually not available or difficult to determine which is one of the reasons for the qualitative expert evaluation.

The developed proceedings and the methods to identify the chosen topic areas and “Top20-topics” have, on the whole, proven to be efficient and target-aimed and were validated via the targeted participation of experts in the respective working steps.

Extensive desk research facilitated the identification of central individual topics and topic fields. In the described broad, multi-staged, expert-driven process the most interesting technologies, products and strategies for the increase in resource efficiency were identified. Among these, 20 relevant topics (“Top20-topics”) were chosen which are expected to bear high resource efficiency potential. Due to the response rate of the additional survey and the naturally restricted number of participants of the expert workshops, the choice of relevant topics possibly reveals a certain over- or under-representation of individual topic fields. Integrating experts from a wide range of different professional backgrounds faced this challenge. There are further relevant topics among the „Top250-topics“ that deserve further analysis and evaluation in the future. The “Top20-topics”, thus, are the result of the selection process undertaken with the professional support of the Federal Environmental Agency under the temporal, financial and organisational conditions of Task 1.

Working on the potential analysis one challenge, among others, was to facilitate a uniform assessment of a huge variety of topics. In this context, the described process based on extensive exchange between the participants resulted, all in all, suitable. At the same time, the high number of participants increased the coordination needs. The recruiting process of qualified candidates for the potential analyses in the diploma thesis program was difficult as well in a few cases as the assigned topics were not all in line with the curricula of the participating universities. This is why for a few topics no candidates were found (e.g. micro reactor technology, textile). Furthermore and as expected beforehand, a few of the chosen topics did not end up in the final presentation of results due to a lack of quality or the dropout of the students (nanotechnology, algae, cross-sector technology). The development and use of individual unifying guidelines as well as the systematic scheme of analyses and specific templates for the elaboration of the potential analyses showed to be helpful.

By use of the MIPS-methodology, comprehensive results as life cycle-wide resource use were gained for the majority of topics. This way a quantitative database was built which in many cases allowed to frame possible target-aimed courses of action. One basic problem of quantitative analyses is the availability and validity of the database and the indicators. MIPS is an indicator that allows for life cycle wide analysis with reasonable effort. With reference to the data base and similar to other indicators and methods many analyses faced the problem of unavailable (or only available with unjustifiable effort) upstream-processes of individual materials and intermediate products. This problem needs and has to be resolved on a superior level (e.g. in international committees for ecobalance and in software development), e.g. by the improved integration of life cycle wide resource uses in the advancement and updating of databases. Beyond quantitative analysis and assessment, reflecting on the results in a broader framework and detecting further critical aspects was facilitated by the application of qualitative criteria (see Tab. 2). A correlation of different indicators was found in several cases. In the potential analysis of server-based computing, e.g. external costs correlated with MIPS results.

Alongside this evaluation process, the close monitoring by universities, the Task 1 management as well as by external experts ensured the quality of the acquired results. It showed that this proceeding was very helpful throughout the whole process. Building on the experiences gained, the methodology is to be developed further and reflected on in the light of new insights.

3 Results and recommendations for action

In the following, the central results of the conducted potential analyses are presented in an overview and summarised in seven fields of action. For a more detailed presentation of the results see Resource Efficiency Papers 1.4 and 1.5 (Rohn et al. 2010a und 2010b).

3.1 Overview of results

Seven fields of action were worked out in the course of the criteria-based cross-evaluation in which central results and recommendations for action for the individual potential analyses merge. Each field of action summarises several closely interrelated topics from the potential analyses. The selective assignment of the topics is not always possible and there are complex interdependencies between the individual fields of action. Tab. 3 gives an overview of the fields of action and the potential analyses.

Tab. 3: Overview of fields of action and potential analyses

Fields of action and assigned potential analyses
<p>Cross-sectional technologies and enabling technologies: “Door openers“ for resource efficient applications</p> <ul style="list-style-type: none"> • Assessment of resource efficiency in grey water filtration using membrane technologies • Resource efficient energy storage: comparison of direct and indirect storage for electric vehicles • Resource efficiency potential of energy storage – resource efficient heat storage • Resource efficiency potential of insulation material systems
<p>Renewable energies facilitate substantial resource savings</p> <ul style="list-style-type: none"> • Resource efficiency potential of wind and biomass power • Resource efficient large-scale energy production: potentials of Desertec • Resource efficient energy production by photovoltaics
<p>The growing ICT market needs a careful resource management</p> <ul style="list-style-type: none"> • Green IT: Resource efficiency potential of server based computing • Green IT: Resource efficiency increase with ICT – comparison of displays • Resource efficiency potential of recycling small electric and electronic appliances by recoverage from household waste using an RFID labelling of primary products
<p>Food – both production and consumption need to be considered</p> <ul style="list-style-type: none"> • Resource efficiency potential in food production – Example: Fish • Resource efficiency potential in food production – Example: Fruits

<ul style="list-style-type: none"> • Resource efficiency potential in food production – Example: Vegetables • Resource efficiency potential of intelligent agricultural technologies with the example of the use of nitrogen sensors for fertilization
<p>Traffic – Infrastructure bears higher resource efficiency potential than drive systems</p> <ul style="list-style-type: none"> • Assessment of resource efficiency potential in freight traffic • Resource efficiency potential of electric vehicles
<p>Integrating resource efficiency into product development</p> <ul style="list-style-type: none"> • Consideration of resource efficiency criteria in product development processes • Resource efficiency potential of the implementation of light-weight construction using new materials • Resource efficiency potential of high-strength steel
<p>Resource efficiency-oriented business models: product-service systems require rethinking</p> <ul style="list-style-type: none"> • Resource efficiency potentials of new forms of “using instead of possessing” in assembly facilities • Resource efficiency potential of production on demand

Source: Own illustration

3.2 Cross-sectional and enabling technologies: “Door openers” for resource efficient applications

Due to the manifold possibilities of application in different branches, cross-sectional technologies in part carry very high resource efficiency potential. Furthermore, in many systems resource efficiency potential can only be (fully) explored with the help of assistive technologies, which, therefore, can be called ‘enabling technologies’. With reference to renewable energies (see Chapter 3.3), e.g. suitable storage media often are the prerequisite to secure energy provision meeting the demands. Even if the individual use of the technology, in part, only generates low saving potential the huge variety of possible applications opens up manifold ways to resource conservation.

Results: The resource efficiency potential of using membrane technologies was analysed with reference to municipal sewage plants of a certain plant size. With respect to the approximately 1.000 existing plants of this type in Germany the potential was estimated to be remarkable, especially for new but also for refit plants. Furthermore, there are 9.000 plants of a different type for which additional resource efficiency potential is to be expected. Additionally, there is number of other fields of application, e.g. drinking water purification (e.g. desalination and softening), food production or grey water processing for which product integrated environmental protection is relevant. Membrane technology as well offers great possibilities for export as modern technologies for water treatment are in high demand in countries with rapid economic growth like China and India or with limited existing capacities regarding drinking water purification and supply (e.g. Africa).

To guarantee a better extensive use of central developments like renewable energies and to realise resource efficiency potential, enabling technologies increasing resource efficiency need to be easily available. However, as the comparison of electric vehicles with fuel cell cars shows this potential is only fully revealed by taking into consideration complete life cycles. The production process of the energy storage system for the fuel cell car is notably more resource efficient than that of the “classic” electric vehicle. This,

however, is more than offset during the use phase (due to the extremely energy consuming generation of hydrogen by means of electrolysis). In comparison to conventional drive systems (e.g. diesel car), the efficiency potential of the electric vehicle is only viable by changing the composition of the electricity mix (high percentage of renewable energy).

Minor differences between possible alternatives often have major effects. With reference to the analysed insulation materials made of EPS hard foam, e.g., a minor change of the composition of the insulation material (by adding graphite) resulted in resource savings of about one third. Considerable differences in resource consumption could also be detected with regard to different types of thermal energy storage.

Recommendations for action: The analysis of membrane technologies shows that the resource efficiency potential determined with regard to grey water filtration is transferable. This technology is principally suitable to be broadly applied in this as well as in other branches. Still, obstacles like the reluctance to innovate need to be overcome, as the suitable technology is already available for many uses.

Currently, recharging batteries is the most resource efficient form of temporary electricity storage. Lithium ion cells as marketable commodities are characterised by a higher energy density and few losses compared with other types of accumulators. Long charging times, overheating and continuous losses of capacity, however, are the disadvantages. Additionally, as of today, the geological potential of lithium is restricted to few producing countries with a focus on South America and subjected to competing uses (medicine, pharmaceuticals etc.). Besides increasing the efficiency of accumulators, high-quality recycling of lithium ion accumulators needs to play a central role in the process of resource use. For this purpose, research and development in this regard need to be promoted and product responsibility of manufacturers and distributors with reference to recycling needs of lithium ion accumulators need to become legally binding. Currently, disproportionately large and heavy accumulators are necessary to drive vehicles on long-range distances simply by use of electricity. Besides the promotion of Research and Development of electric storage technologies that overcome these disadvantages, alternative concepts of direct electricity storage such as NaNiCl₂-(Zebra)-accumulators, Redux-Flow-Batteries and alternative network solutions such as Smart Grids need to be further explored and developed to attain marketability. Generally, the perspective of resource efficiency needs to receive more attention besides climate protection.

Hydrogen being used as indirect electricity storage medium in electric vehicles with fuel cell drive, as of today, can only be generated by means of electrolysis with enormous energy losses. Still, with regard to scope and field of application in the traffic sector (public transport, freight traffic) hydrogen is of considerable advantage as mobile energy source. Based on the results of this analysis, the further optimisation of fuel cell technology and hydrogen production is to be promoted, as well as research and development and the launch of these technologies in the efficient fields relevant to the use of hydrogen.

As all analysed heat accumulator alternatives are potentially resource saving, a further dissemination and promotion is useful. With reference to paraffin latent heat accumulators, it needs to be analysed whether paraffin can be synthetically produced in great quantities as it has merely been a by-product in crude oil processing so far. In addition to the regarded options, additional forms of latent heat accumulators and sorption storage with their diverse storage media and possible uses need to be taken into account and advanced. Generally, the transferability of the technology is to be examined more intensely as heat storage systems are not only relevant to the buildings sector but as well to the transport of heat and cold or to the use of waste heat in industrial processes.

Due to energy saving potentials in existing buildings by measures of insulation, there is going to be great need for remediation throughout the next decades. This is going hand in hand with considerable resource consumption but it is also possibly accompanied by saving potentials depending on the used insulation material and compound system. Corresponding additional analyses ought to be carried out to compare further variants of insulation material resp. systems (e.g. also based on renewable raw materials).

The overall resource conservation potential of cross-sectional technologies is difficult to assess on the base of the analysed case studies as the diversity of the fields of application needs to be specifically calculated.

As enabling technologies support resource efficient overall solutions in resource intensive demand areas, their potential ought to be broadly made use of. Many more fields of application ought to be analysed with reference to their breadth and their limits. As minor changes of enabling technologies can have great effects which was shown in the analysis of insulation material – further research endeavours are useful to, possibly, systematically reveal such potential.

3.3 Renewable energies facilitate substantial resource savings

In this section, the results of the potential analyses carried out in the field of “renewable energies“ are presented.

Results: In comparison to the electricity mix 2008 all explored renewable energies such as wind energy (offshore & onshore), biomass, photovoltaic and solar thermal energy (Desertec concept) offer possible increases in resource efficiency with reference to electricity generation. The specific use of resources of all analysed variants is comparably small, uses of abiotic materials and water make up only a fraction of those necessary for coal-fired power or for the electricity mix 2008. With regard to the consumption of biotic materials and air, biomass in the form of renewable raw materials is the only alternative that shows poorer results than the electricity mix 2008.

The specific use of resources is also determined by the build-up of an appropriate infrastructure. With regard to offshore-wind farms this concerns basically grid connection to the mainland as well as resource consumption for the manufacture of the plants (head mass, tower and foundation) in all analysed resource categories. Regarding other forms of renewable energies (Onshore-Wind farm and biomass), capacities are

restricted by a lack of space or in part already exhausted or they compete with other uses such as agriculture or are in conflict with nature conservation. In this respect, the repowering of existing plants/farms is the central option.

As to the examined biogas plant, it shows that especially the nature of the applied substrate, the use of fertilizers as well as the transport distances of the substrate have a relevant influence on the overall resource consumption of the plant. The size of the plant matters as well as the possibilities of using the waste heat of electricity production (e.g. with the help of heat grids).

The Desertec concept is an extraordinary project for the development of a globally applicable solution for the large-scale use of solar thermal power plants. Based on the current results, the technology option of the solar tower offers the highest resource efficiency among the solar thermal plants in comparison to parabolic plants and Fresnel collectors.

By building up new wind farms and solar thermal power plants high resource efficiency potentials can be realised.

Photovoltaic offers a high potential because of its decentralised use (see also the results of Task 9 of the MaRes project, e.g. in Fichter et al. 2010). As the results of the analysis show, the use of thin layer technology offers a considerable resource conservation potential in comparison to multicrystalline silicon thick-film modules. The resource efficiency potential can be significantly increased by the choice of suitable locations and the orientation of the system. The optimal orientation of a photovoltaic system is defined by the available surface (roof area, facade, open land) and its south-facing position.

Recommendations for action: In conclusion, the results reveal that a renewable energy mix carries high resource efficiency potential. With respect to all examined variants, an accelerated expansion of renewable energies can principally be recommended for the shown options even though further integrated analyses regarding resource aspects are necessary. From the point of view of resource consumption per kWh, an increase of wind energy in the provision of electricity is highly recommended. Biogas plants can also contribute to a more efficient provision of electricity even though this is not the case for all kinds of biogas plants. Resource consumption, in this case, needs to be individually evaluated depending on the nature of the used substrates and fertilizers and the interrelated cultivation method, transport distance and plant type and size. The Desertec concept ought to be promoted as resource efficient provider of base load power taking into consideration critical factors such as competition, development policy, dependency on imports, land use or questions concerning its decentralised location. Furthermore, due to the manifold technical uncertainties with regard to environmental impacts and resource efficiency the technical options ought to be continuously evaluated. This way, possible problems of the intensive expansion of particularly resource efficient variants of individual technologies can be addressed. Concerning photovoltaic systems resource efficiency of solar laminates ought to be primarily

achieved by a lifetime extension and by greater efficiency especially with regard to thin layer technology.

The expansion of renewable energies especially in the field of electricity provision demanded by politics and society involves a general change of our current supply structures which is going to increasingly develop from dominant centralisation to small-scale and local units in combination with large scale industrial renewable electricity generation (e.g. Offshore wind farms). Due to the unsteady availability of renewable energies from sun and wind and due to the focus of political funding on a local or personal use of the energy produced, direct and indirect power and heat storage accumulators are going to become indispensable and have a considerable influence on the resource efficiency of the overall system (see Chapter 3.2). In order to materialise efficiency conservation through the increased use of renewable energies, further research and development endeavours need to be made. Among others these are:

- Efficiency increases of plants and modules,
- Improvement of transmission networks, e.g. less resource intensive wires and improved transmission rates of wind energy, smart-grids and smart-metering as intelligent interface between power grid and consumers,
- Efficient storage systems for electricity and heat,
- Recycling-possibilities, e.g., for thick-film modules in photovoltaics or for water treatment to clean the mirrors for Desertec-electricity,
- The orientation of the systems to guarantee the optimal use of this infrastructure.

3.4 The growing ICT market needs a careful resource management

In this section the results of the potential analyses carried out in the field of “information and communication technologies“ (ICT) are presented.

Results: Due to rapid growth and the short life span of products on the information and communication market as well as on the electric and electronics market overall, the annual consumption of resources in this sector rises continuously. In comparison to PCs, in server-based computing reduced terminals are used (so called “thin clients“) that being connected to a central server show the same performance. A comparison of the two systems reveals that the server-based variant is considerably more efficient in all resource categories. This is in line with the results from Task 9 of the MaRes project (see Fichter et al. 2010). The potential analysis also showed that the more resource efficient variants according to MIPS are often also the more economical with regard to strategically interesting metals such as silver, gold, palladium, tantalum, copper, nickel, chrome and iron.

With the switch from tubes to LC-displays, the resource efficiency potential of Liquid Crystal Displays (LCD) has been largely exploited. The analysis revealed a high efficiency potential for the extended dissemination of OLED displays (Organic Light Emit-

ting Diode). Resource efficiency in comparison to LC and plasma displays can be increased three- to six fold in different material categories during the use phase.

With respect to mobile phones, design can spare resources. Resource efficiency potentials can be realised with longer life spans or with reduced versions of mobile phones. Forms of zero-energy-mobiles using the human energy harvesting methods (which make use of the human body as primary source of energy) are still in the development stage. The use as smartphone carries high savings potential provided it does completely substitute other appliances and their purchase / manufacture. It depends on the buying and usage patterns whether this potential can be exploited.

The disposal of ICT appliances proves to be the most problematic part of the life cycle with regard to resource efficiency due to several reasons. On the one hand, from an economical perspective, as of today, it is almost impossible to recycle LC and plasma displays. On the other hand, many old smaller electric and electronic appliances are disposed of in the household waste for convenience. This way, they are often energetically recovered instead of being recycled or reused. Marked with passive RFID labels, old electric and electronic appliances could be more easily identified and, therefore, utilised in recycling management, which could save resources.

Recommendations for action: To increase resource efficiency potentials and to counter market instabilities of rare metals, a targeted resource management is necessary – from the design of ICT products factoring in the continued and reuse at the end of the life cycle to totally new utilisation concepts. In this process, questions central to IT like data security need to be taken into account as they are of central importance for the question of acceptance.

Consumer acceptance is a sensitive issue especially on the ICT market and might turn out to be a serious obstacle, e.g., to market penetration with resource conserving mobiles. The analysis of the diverse development opportunities of the mobile shows that a change in mentality of providers and users is necessary which ought to be politically initialised. Currently, the actual life of mobiles declines. Product-service systems can counter this development. However, their market introduction as well requires a new awareness in the fields of production, sales and consumption. Generally, the high relevance of the phase of use needs to be more strongly addressed.

Recycling is a central issue for the realisation of resource efficiency and has dimensions in relation to design, procedures and users. With reference to recycling passive labels facilitate the identification of old electric and electronic appliances and, therefore, its utilisation in recycling management. Additional incentives possibly need to complement the existing legislation in the field of old electric and electronic appliances. Moreover, utilisation possibilities of resource intensive rare metals in IT components need to be improved.

Measures should include communication, funding and legal elements. These serve to promote market penetration, efficiency and technical maturity as well as the integration of resource efficiency in product design and ways of thinking in product life cycles and reflection on the perspective of product use. At the same time, and especially with re-

gard to the short-lived ICT market, rebound effects for all measures need to be separately addressed and analysed.

3.5 Food – both production and consumption need to be considered

In this field of action resource efficiency potentials of food production were analysed with the examples of fish, fruits and vegetables as well as agricultural technologies with the example of the use of nitrogen sensors for fertilization.

Results: On the supply side, resource efficiency potential was identified regarding more sustainable farming and fishing methods as well as more efficient irrigation methods and a safer use of pesticides. This means, e.g., reducing by-catches in fishing, reducing energy consumption in greenhouses or using waste heat from greenhouses. A further interesting approach is the use of nitrogen sensors to save pesticides and to increase yields.

The potential analyses show that different rather small measures in resource efficiency, in sum, can make a substantial contribution. However, the analyses also reveal that even though resource potentials can be realised in food production, there is most probably considerably higher potential on the consumer side. Only by the choice of his/her means of transport on the shopping tour, e.g., the consumer can realise substantial savings. It is known from other studies that savings potential can be increased in waste prevention on production and consumption sides. Furthermore, in consumption, the choice of food and the form of preparation are very relevant to resource use. The analyses also confirmed the finding that seasonal considerations in the choice of vegetables and fruits have a strong influence on resource conservation.

Recommendations for action: The food sector is one of the most resource intensive sectors. Based on the results of the analyses, policy focus ought to be oriented towards the following fields: As to the area of more resource efficient fishing, a central starting point is the implementation of more sustainable fishing methods causing less ground-movement and reducing by-catch. With respect to fruit-growing, water consumption and alternative cultivation techniques are central starting points. Regarding vegetable growing, the reduced consumption of energy and other resources around the greenhouses is a decisive factor apart from water use. As the case study showed, intelligent agricultural technologies and integrated cultivation systems can contribute to a decrease in the use of fertilizers and pesticides.

The consumer side ought to be systematically and broadly analysed with reference to resource efficiency potential, e.g., regarding food choice, preparation of meals and waste. As to overall consumption, the question arises how a long-term change of habits towards more resource saving and sustainable diets can be facilitated and which incentives are needed in this context. A possible starting point for influencing consumer behaviour might be to link the debate about “healthy diets“ with a debate about „diets oriented towards resource efficiency and environmental compatibility“. Public procurement can play an important role in this regard.

3.6 Traffic – Infrastructure bears higher resource efficiency potential than drive systems

This section deals with the results of the potential analyses carried out in the topic field “traffic”.

Results: Due to its high level of resource consumption and its central importance for all social and economical spheres, ‘vehicles and transport’ is an area of focus for endeavours to increase resource efficiency and reduce emissions. The academic discussion not only deals with alternative drive systems but also considers the development of infrastructures (see also the results of Task 2 of the MaRes project, e.g., in Steger et al. 2010).

With regard to a municipal commercial vehicle, the comparison of electric and diesel drive shows that the use of electric vehicles, on the one hand, reduces the emission of GHG emissions and, on the other hand, increases the independence from mineral oil. Still, certain limiting conditions need to be taken into account: The level of resource efficiency is primarily dependent on the electricity mix. This correlation can be transferred to rail traffic as well. Further measures reducing fuel consumption and, therefore, potentially increasing resource efficiency are lightweight construction and an intelligently controlled deployment of vehicles as facilitated by innovative telematics systems. The use of modern traffic telematics possibly contributes to the reduction of infrastructure needed and facilitates the exploitation of further potential.

Construction and maintenance of the infrastructure for the respective carriers are the major sources of resource consumption in rail traffic. Still, infrastructure has often been neglected in resource efficiency or sustainability considerations so far. However, it bears great potential even though the build-up of transportation infrastructure in Germany has been largely completed due to demographic reasons. The reduction of road width is a possible first step to increasing resource efficiency.

Recommendations for action: As infrastructure is a central factor for resource consumption in the traffic sector, solutions to increase resource efficiency not only ought to address energy consumption (resp. the emissions relevant to climate change) but overall resource consumption. Since avoiding the construction and expansion of infrastructure carries a high resource efficiency potential, measures to improve the utilisation of vehicles and infrastructure and maintenance solutions based on optimised resource consumption ought to be prioritised. Furthermore, global demand for resource efficient infrastructure (use) bears export potential.

To meet the so far steady growth in transport services, the development of drive systems needs to be paralleled by the development of more efficient vehicles and infrastructure use. In this process, logistics, traffic telematics and product-service systems (e.g. car sharing) can be useful. Still, in order to increase demand for these systems, offers need to meet target group needs better and demand patterns (of users) need to change. For long term infrastructure projects, changing future user needs ought to be given stronger consideration in planning.

3.7 Integrating resource efficiency into product development

In this field of action, resource efficiency criteria in product development processes were explored and potentials of several materials were analysed.

Results: From a number of previous studies we know that product development processes carry the potential to significantly reduce the environmental impact throughout the entire lifecycle of a product as there are many parameters that can still be influenced. Along the progression of the development process, product parameters are increasingly determined and, correspondingly, future environmental impact becomes more and more manifest. Therefore, attempts to increase resource efficiency throughout the entire lifecycle ought to be addressed at an early stage in the product development process. By integrating the MIPS concept and by defining universal criteria for resource efficiency a design methodology that accompanies the development process could be established which enables the designer to assess and reduce resource consumption of products throughout the entire lifecycle.

The relevance of the integrative lifecycle-oriented product development process was proven in the examination of a lightweight constructed seat shell. Using a textile-reinforced thermoplastic material combined with a consequent material-specific lightweight construction design and adjusted highly productive production processes could significantly reduce the lifecycle-wide resource consumption of the automobile seat shell. The lower mass of the newly developed light weight constructed seat shell contributes to a reduction of fuel consumption in the use phase. Since lightweight construction materials and strategies have a wide range of application, especially in automotive engineering, resource efficiency potential is considered to be high.

Further potential analyses showed that materials advancement is suitable for reducing resource consumption. The analyses of the use of higher- and high-strength steels (hss) for lightweight construction in automobiles reveal that fuel savings of 0.7 l / 100 km can be realised in comparison to conventional steel constructions. Further considerable resource consumption savings can only be realised in combination with innovative casting procedures.

Recommendations for action: Acceptance on several levels is a central prerequisite for adjusting product development to resource efficiency. Along with relevant decision makers in management and construction, suppliers’ and customers’ awareness and motivation with regard to resource-related matters needs to be raised. Expert knowledge, hierarchical potential and personnel networks are necessary to promote the implementation of new directives in design.

The virtual integration of resource efficiency thinking in product development can be achieved in a multi-stage approach. In a first step, targeted communication raises awareness for the need to integrate resource efficiency. Publishing articles in management or construction journals can accomplish this, by integrating the new insights into engineering studies and in further training courses for designers. Furthermore, the means usually used in product development such as CAE programs, can be adapted

to the requirements of resource efficient design. In further steps, the consideration of resource efficiency can result in new ways of thinking such as product-service systems, which are explained in the following field of action.

3.8 Resource efficiency-oriented business models: product-service systems require rethinking

This section describes the results of the potential analyses in the topic field “product-service systems”.

Results: An approach to increasing resource efficiency is to understand resource orientation as integral part of the business strategy and to implement it in corresponding business models.

The concept “using instead of possessing” forces the suppliers to reorganise their sales-oriented business strategy towards service-oriented ways of thinking. This aims at accompanying the customers throughout the product use phase and at re-designing the product after the use phase.

“Production on demand” is the differentiation of “order-driven” production that has gone furthest and which, in the ideal case, equals the prevention of overproduction. Quantitative resource efficiency potentials were determined with the example of journals. The concept “production on demand” starts from the customer side: Customers need to order as early as possible because the quantities produced equal the quantities ordered. This results in longer lead times for customers compared with stocks-based storage. This rethinking can be identified as a chance for the realisation of resource efficiency potentials but, at the same time, as impediment to its concrete implementation.

The potential analysis of a robot according to the principle “using instead of possessing” revealed that by reusing the robot about half of the resource consumption during production could be saved. Since operating energy makes up the highest consumption share, increasing energy efficiency also bears savings potential.

Recommendations for action: With the example of assembly facilities in the “Business-to-Business” sector (B2B), it was shown that the principle “using instead of possessing” can result in saving potential outside already familiar fields like chemical-leasing or working clothes / garment hire services. Against this background, detailed analysis is suggested identifying further fields of application for B2B across the board and assessing possible potentials. In order to save resources, business models based on product-service systems need to be increasingly applied. These can only be realised, however, if actors change their thinking and new configurations of actors emerge – e.g., in addition to the actual user, the facility manufacturer or the equipment supplier can operate a facility as well. The target is to develop an understanding for these business models and to raise awareness for its benefits. E.g., stricter directives for environmentally sound disposal of production facilities could render reuse or further use of facilities more attractive to the respective companies.

For small and medium sized companies concepts for joint use ought to be developed and promoted as this would render the use of facilities more efficient. Innovation and innovation promotion, therefore, ought not only to be understood in terms of production and production technology but it ought to encompass (models of) product use as well.

4 Conclusion and outlook

In the framework of the MaRes project, concrete resource efficiency potentials for twenty selected topics (“Top20”) in the fields of technology, products and strategies were analysed and possible recommendations for action were drawn up. As estimated in the pre-selection process, the analyses provided interesting and resource-relevant starting points. The potential analyses, in part, identified substantial potential for resource conservation. In some cases, these go hand in hand with other aspects of sustainability and open up new perspectives. As a result, in our opinion, so far underrepresented recommendations for action in the sustainability debate were made (e.g. with respect to the relevance of infrastructure, see 3.3 and 3.6, or with regard to resource consumption of electric drives, see 3.2 and 3.6). These could be used for focusing policy measures.

To achieve substantial dematerialisation resp. increase of resource efficiency in our economy and society (keyword factor 10), different measures need to be taken with the participation of key actors to realise the identified potentials and to reveal further potentials. In addition to technologies, resource intensive fields and organisational and institutional innovations, the complete value chain including the use and utilisation phase needs to be integrated to realise actual effects throughout the lifecycle. Against this background, it becomes clear that additional activities beyond Task 1 and MaRes as a whole are necessary.

The topics worked on (“Top20”) ought to be understood as the beginning of a systematic and encompassing analysis of resource efficiency potentials concerning our social and economical activities. Even though representing central and resource intensive sectors, the analysed topics naturally represent only a small selection from the totality of identified topics that were also assessed by the experts during the first expert workshop. Furthermore, with regard to the addressed topics some questions remained open and new questions were raised. Moreover, those topics presented in the expert workshop but not chosen for further analysis (“Top250“, see chapter 2.1) and those chosen in the workshop (“Top50“) promise interesting potentials that ought to be analysed in the future.

There is a need to study focus areas based on further case studies (e.g. central fields such as construction, living or food and nutrition).

The analyses also demonstrate the need to make greater use of or build up suitable ways (such as networks) to involve industrial partners at an early stage. On the one hand, the existing network of the MaRes project needs to be strengthened, on the other hand, further forms and consortia need to be established (e.g. with a stronger

focus on individual topics). This is aimed at safeguarding the continuous direct link to the implementation and feasibility of analysed potentials.

Due to the broad range of topics and the possibilities for increasing resource efficiency in diverse sectors, the network of universities integrating the paradigm of resource efficiency in research and training ought to be considerably extended. It would be desirable to extend the circle of participating universities (e.g. all technical universities represented in the group of „TU9“ and, beyond that, schools of design and universities of applied sciences) for the further analysis of the topics identified in the Task 1 of the MaRes project.

So far, in university education, only few departments and specialist areas offer programmes (e.g., lectures, tutorials, projects) in the field of resource efficiency. Therefore, there is much room for a considerable extension of programmes offered that need to be integrated into the existing curricula. To foster the broad integration of resource efficiency into university training and research, activities for the establishment of a „Virtual Resource University“ (from innovation to implementation research) need to be started (see also the results of Task 13 of the MaRes project, e.g. in Kristof et al. 2010).

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