Material Efficiency & Resource Conservation

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Cooperative Roadmapping as a Tool for Innovation-Orientied Resource Policy

Early Detection and Development of Resource Efficiency Potentials, using the examples of Roadmapping Initiatives in Photovoltaics and Green IT

Executive Summary

Summary report of Task 9 within the framework of the Project „Material Efficiency and Resource Conservation“ (MaRess)

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1 Occasion and Background

With regard to material efficiency and resource conservation, the early detection of innovation opportunities and risks, new businesses and markets has great importance for the success of innovations. While the German Federal Environment Ministry (BMU) and the Federal Environment Agency (UBA) have already made some estimates of potentials, further substantiated and clarified in the UFOPLAN project “Innovative environmental policy in key areas of action (future markets)” (FKZ 206 14 132 / 05), the next logical step within the framework of the BMU-funded project “Material Efficiency and Resource Conservation” (MaRess) is to derive specific technological and market-based challenges, and to feed these results into state funding policy, activities of business associations, and into the innovation management of key players in the industry.

With view to this task, the Institute for Futures Studies and Technology Assessment (IZT) and the Borderstep Institute for Innovation and Sustainability have initiated dialogue processes with industry, consumer and academia representatives. In this context, so-called “Roadmaps” were developed collaboratively from summer 2008 to summer 2010 (cf. Behrendt 2010). The term “Roadmap” is understood here as a representation of a path of development along a timeline. Based on trend analysis, interviews and dialogue workshops, material efficiency and resource conservation potentials were determined, and objectives, milestones and concrete measures by which the identified potentials can successfully be developed were outlined subsequently. This systematic process of developing a roadmap is called “Roadmapping”. Roadmaps were developed exemplarily for two important resource-related fields: firstly, for photovoltaics as a young, dynamic field of technology, and secondly, for information and communication technology (ICT) as a particularly significant cross-sectional technology. Within the ICT roadmap, the main focus was on the most important and rapidly growing area of workplace computer solutions. Analysis has shown that ICT as a cross-section technology holds major, as yet undeveloped, resource efficiency potentials.

Roadmapping allows for the formulation of a “map” that bundles various individual issues, identifies courses of action and names priorities. Early detection of resource efficiency potentials, as well as development of future markets including the associated challenges of market development, is based on the analysis of trends and the identification of driving forces. The examination is directed not only towards the dynamics of technological and market developments, but also on efficient life cycle and system observations. The roadmap creates the necessary framework by facilitating intelligent networks and communications between important innovation protagonists and by integrating knowledge.

While the roadmapping method has already been used in the past for the development of “master plans” for federal institutions at the level of individual companies or industries, the systematic cooperation of stakeholders from business, politics, administration, and science does present a new form and quality of “cooperative roadmapping”, duly tested within the Task 9 of the MaRess project for the technology fields mentioned above. From a methodological point of view, one main question was how collaborative roadmapping processes need to be designed in order to support innovation-oriented environmental policy effectively in unlocking resource efficiency potentials.

2 Roadmap: Resource-efficient Photovoltaics

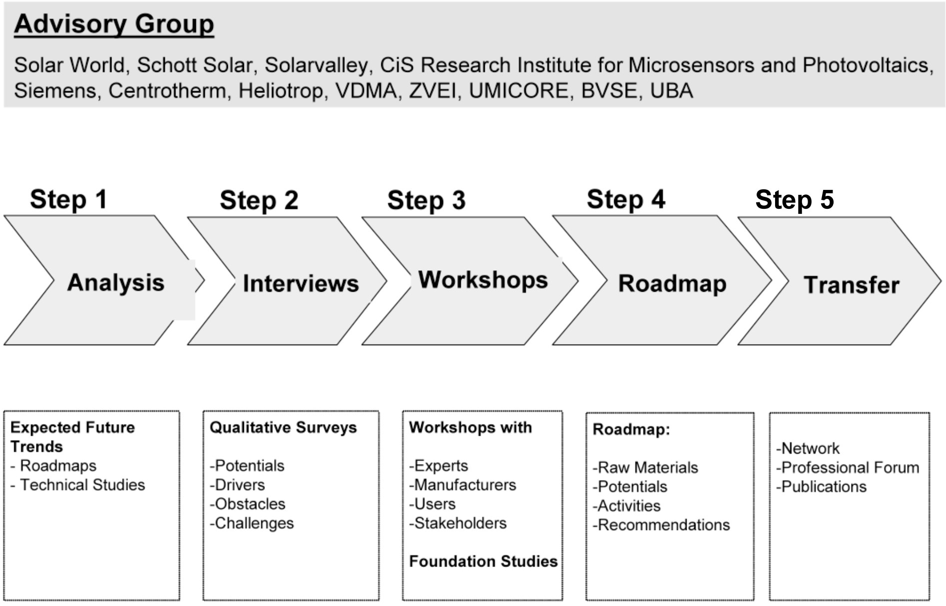
2.1 Initial Situation

Photovoltaics is a relatively young industry. It has in recent years been developed into a profitable, rapidly growing lead market. This is particularly true for Germany, the largest and most profitable photovoltaics market even ahead of the U.S. and Japan. The photovoltaic market has been growing faster than expected in the last years, and a worldwide total of 8.5 Gigawatt of newly installed capacity is expected for 2010. For photovoltaics to assume a globally significant position as future energy supplier, sustained high growth of the market is necessary in the decades to come. This does not only require a long-term, reliable political framework, but also continuous enhancement of solar technology, solar systems, and production technology. Important tasks are improving material efficiency, securing raw material availability and conservation of resources. Material efficiency is a main development objective in the photovoltaic industry, and the subject of numerous research and development activities, with the aim of improving the cost-performance ratio of solar cells, thus strengthening and securing the photovoltaic industry’s competitive position. The main challenge lies in increasing the degree of efficiency of solar cells, improving production yields and in optimizing their economic life-time and system reliability. Despite recent increases in efficiency, there are still significant untapped potentials and new challenges regarding material efficiency and resource conservation lying ahead. This makes process innovations targeting material and energy savings even more important. Furthermore, the solar industry is facing the challenge that in the near future, it will be necessary to recycle growing amounts of waste from of discharged solar modules and products in an economically viable and ecologically sound manner. In the relevant roadmaps that serve as strategic innovation routes for the solar industry, these challenges have only been touched upon so far. This is why the roadmap for resource-efficient photovoltaics was developed within the “Material efficiency and resource conservation” project MaRess, funded by the Federal Environment Ministry BMU and the Federal Environment Agency UBA. This was achieved in cooperation with key industries, organizations and academics from different areas of the solar industry, from mechanical and plant engineering, automation technology and the recycling industry.

2.2 The Dialogue Process

The creation of the roadmap is based on a broad dialogue with important stakeholders from the photovoltaics industry and their professional environment. Together with companies, associations and academics, main challenges were identified, assessments of potential made, and plans of action that consider material efficiency and resource conservation were reviewed.

Fig. 1: Dialogue process



Altogether, more than 60 experts from the photovoltaic industry participated in the process in two moderated workshops:

- Material Efficiency and Resource Conservation in Manufacturing, November 03, 2009, in Berlin
- End of Life Recycling, December 11, 2009, in Berlin

The workshops were supplemented by interviews with relevant experts from the photovoltaics industry, R & D institutions as well as business associations. The development of the roadmap was supported by an advisory group of representatives from different levels of the value chain: from photovoltaics companies (Solar World, centrotherm GmbH, Heliotop GmbH, Solar Valley Central Germany eV, Schott Solar, Umicore Precious Metals Refining), research institutions (CiS Research Institute for Microsensors and Photovoltaics, Borderstep Institute for Innovation and Sustainability), associations (the German association of machinery and plant manufacturers VDMA, the German association of the electrical engineering and electronics industry ZVEI, the German federal association of secondary raw materials and waste disposal BVSE), as well as the German Federal Environment Agency UBA.

2.3 Results and Outlook

Key results of the roadmap are:

New material-saving technologies and processes provide a way of meeting increasing cost pressure in the years to come. The solar cells’ base materials make up the greatest cost pool. Progress in resource efficiency and the availability of low-cost raw materials is therefore particularly relevant to the competitive environment of the solar industry and its further development. By utilizing the material efficiency potentials identified in the roadmap, costs could be halved in the medium term[1].

With the photovoltaic market growing, it is becoming more relevant to material flow. Currently, the output from photovoltaics is still significantly below the amounts of other products such as electronics, and so far does not represent a large material flow by comparison. However, the market penetration of photovoltaics will change this. In 2008, the global material flow for photovoltaic electricity was around 593 000 tonnes. This could be doubled in five years, and quadrupled by 2020. By 2030, it could increase globally by a factor of nine, growing to around 5.3 million tonnes.

Shortages are possible, and may become evident in delivery problems and high prices. Numerous future technologies are already competing for silver. The supply of silver cannot easily be expanded in the short term, mainly because silver is a by-product of less dynamically sought-after core products. In the case of tellurium for cadmium telluride (CdTe) solar cells, and indium for copper indium gallium selenide (CIGS) solar cells, a surge in demand is to be expected in the medium term that will exceed current production. Due to the relatively low amounts of the respective materials in the product, incentives for material-efficient economic activities are only to be expected with high prices for tellurium and indium. Potentials of increasing supplies lie mainly in the increased exploitation of bypasses of copper and zinc smelting, and in the subsequent treatment of residues. Whether there is an absolute scarcity of high-quality quartz for the production of metallurgical silicon cannot be assessed reliably at present, due to the lack of systematic surveys of pure quartz deposits. However, shortages of raw materials can always arise temporarily if the supply does not keep pace with the dynamic developments of demand. Apart from photovoltaics, the semiconductor industry is primarily decisive here.

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[1] Surveys and Evaluations by the authors, based on: Wim C. Sinke, Wijnand van Hooff, Gianluca Coletti, Boukje Ehlen, Giso Hahn, Stefan Reber, Joachim John, Guy Beaucarne, Emmanuel van Kerschaver, Mariska de Wild-Scholten, and Axel Metz: Wafer-based crystalline Silicon Modules at 1 €/Wp: Final Results from the crystal clear integrates project. 24th European Photovoltaic Solar Energy Conference and Exhibition, 21-25 September 2009

Tab. 1: Possible structural supply bottlenecks for the Development of Photovoltaics

Production Lines	**Begrenzende Materialien**	**Research Needs**
Silicon-PV (c-Si, Poly-Si)	Silver (n-Electrode)	Partial and complete substitution of silver, Minimizing the amounts of silver in products
	Indium (TCO)	Avoiding ITO, e.g. by using ZnO or ATO
Thin film PV		
CdTe	Tellurium (Cell material)	Minimizing layer thickness, increasing product yield, recycling of production waste
CIGS	Indium (Cell material)	Minimizing layer thickness, increasing product yield, recycling of production waste
Farbstoff	Indium (TCO)	Avoiding ITO, e.g. by using ZnO or ATO
	Tin, Platinum (TCO)	Increasing Material Efficiency
III-V PV (Heterojunction)		
MJC III-V	Germanium (Substrate)	Alternative Substrates
	Gallium (GaAs Substrate)	Lift-off, III-V/Si
MJC III-V, lift-off	Indium (Cell material)	In-free Heterojunction Cells
	Gold (Electrode)	Alternative Electrodes

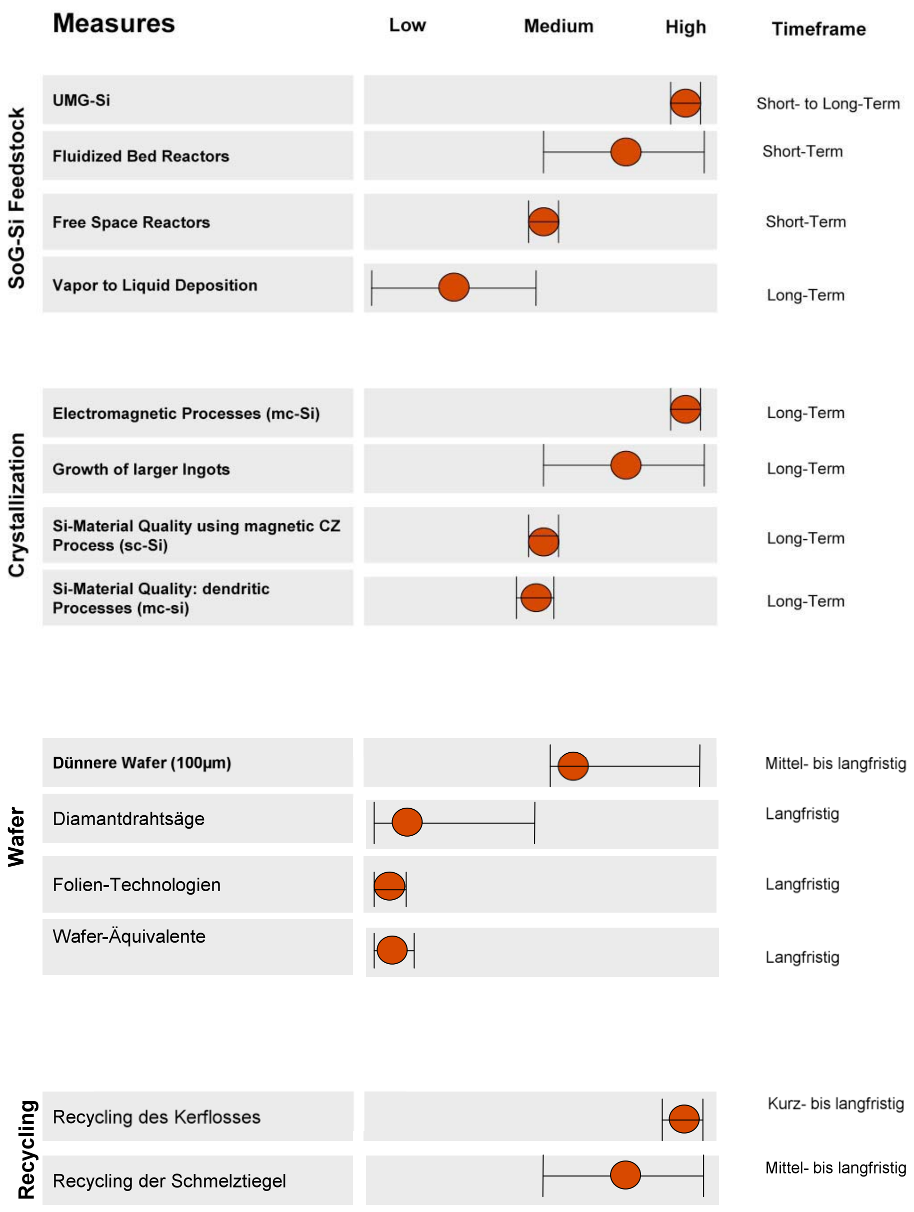
TCO – Transparent Conductive Oxides; ITO – Indium-Tin Oxide, ATO – Antimony-Tin Oxide; MJC – Multi-Junction Cells; Tin and Platinum are only potentially limiting factors for the development of Dye-PV if the Indium problem in TCOs can be alleviated.

Source: Evaluation of the IZT authors, based on: Andersson 2000, DoE 2005, Feltrin, Freundlich 2008, and Feltrin 2009, Hagelüken 2008, ISI / IZT 2009, Ökoinstitut 2009, Ökopol et al. 2007, Wadia et al. 2009, Wäger 2008.

In the course of the dynamic development of the photovoltaics market in recent years, significant improvements in material efficiency have already been achieved. The “low hanging fruits” in manufacturing have in fact largely been picked. But the possibilities of production with less material and resources are by no means fully exploited. The remaining short-term potentials for the crystalline silicon technology mainly lie in the production of solar grade silicon (SoG-Si) from metallurgical grade silicon (MG-Si), as well as the use of fluidized bed reactors and free-space reactors for the production of SoG-Si. Frameless modules can be realized in the short term, the reduction of glass thickness in the short to mid term, whereas electromagnetic methods of manufacturing silicon in sufficient quality and at acceptable costs are more relevant in the long term. In thin-film technology, the optimization of plasma-enhanced chemical vapour deposition (PECVD) for the production of amorphous silicon (a-Si) absorber layers and the reduction of absorber layers in copper indium selenide (CIS) technology are particularly promising. Entirely novel cell and module concepts that efficiently combine material efficiency demands with the requirements of industrial production are only to be expected in the long-term perspective.

The analysis of raw material requirements has shown that the most effective material efficiency strategies today are minimizing the gross amounts of material in products, and improving process yield and production waste recycling. In the short and medium term, concrete measures in production waste recycling and material efficiency, for instance by increasing production yield or reducing the amount of raw materials, are especially effective. Nevertheless, the foundations for the recycling of discharged modules need to be laid today as the waste flows are of high latency (“Design for Recycling”). In the long term, the recovery of raw materials from recycled modules will also prove effective (“Urban Mining”). As soon as material efficiency is increasingly implemented in manufacturing, the amount of production waste and module recycling will decrease.

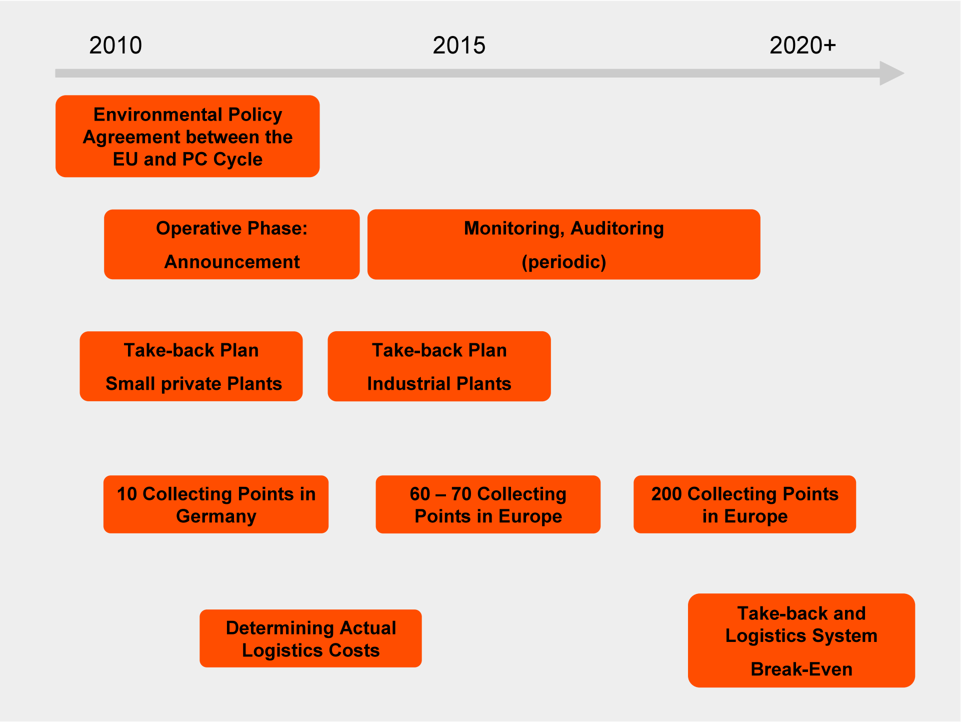
Fig. 2: Relevant Measures and Timeframe for the Manufacturing of c-Si Modules



Source: Workshop "Material Efficiency and Resource Conservation in PV Production", IZT, Nov. 03, 2009.

In future, there are adequate structures to be set up for end-of-life recycling, as well as bulk procedures for joint recycling of faulty modules to be developed. After further examination it may be required to concentrate on specific materials, e.g. glass, steel, aluminum, or copper, with special regard to the decreasing amounts of raw materials actually used in photovoltaics products. Further questions to be addressed include an ecologically sound recycling which not only covers mass materials, but also ensures that rare and special metals essential to future technologies are recovered. Quantity-based recycling ratios, as laid out in the European Union’s Waste Electrical and Electronic Equipment (WEEE) Directive, are not sufficient because they do not account for those functional materials used solely in small amounts.

Fig. 3: Milestones for a Comprehensive Take-Back and Logistics System



Source: Workshop End-of-Life Recycling, Berlin, Dec. 11, 2009.

The unlocking of resource efficiency potential involves overcoming a number of hurdles. Refashioning production units makes higher investment costs necessary, and there are questions regarding the technological complexity of certain processes and quality issues (such as the purity of solar-grade silicon) still to be resolved. Although the potential for recycling production waste is notably high, the assessment of this aspect remains the most uncertain and, accordingly, the most demanding to implement. There is no “silver bullet” for resource-efficient photovoltaics in the foreseeable future. In fact, it is rather more important to individually test singular cases in order to balance differing expectations. This involves specific systemic innovations through interdisciplinary R & D that includes product developers as well as plant, construction and process engineers. Several areas in which further improvements are most pressing and fit to be targeted with appropriate R & D activities have been identified in the roadmap for different areas of solar technology. These include standardized analytical methods for measuring contamination and for the quantification of key material figures; development of flexible wafers to simplify the very fragile wafers’ handling; hydro-metallurgical and chemical procedures for recycling production waste from thin film technologies; and the development of alternatives to silver as contact materials.

Benchmarking: A broad informational base is required to encourage the development of resource efficiency potentials, for instance in the shape of a classification figure system for material and energy efficiency. These types of reference numbers can be used to condense large amounts of data into a manageable form of meaningful information. One particular benefit of these figures is that they highlight weaknesses and optimization potentials at the same time. Direct comparisons may help in disclosing opportunities for improved material efficiency. Various companies in the photovoltaics industry already use such figures as part of their environmental management, to regularly record waste, water use or energy consumption at the enterprise level, for example. But so far, they have rarely been systematically employed at the process level or used to uncover optimization potentials.

Initiating beacon projects for “Smart Integrated Manufacturing”: Resource efficiency would be greatly facilitated if there was clear progress in integration, automation and upscaling of production units. New automatic manufacturing concepts are becoming more and more important for increasing operational capacities and improving overall quality. While production was restricted to “custom-made” unique pieces made with considerable amounts of manual labor a few years back, today there are fully automated, ready-made production lines for manufacturing of ingots, solar cells and modules available. Vertically integrated automatic production facilities may be state of the art, but have nevertheless hardly been practically realized so far. Automation can benefit yield, cost reduction, high quality and standardization of manufacturing. The demand is high enough to render efficient and consistently automated manufacturing and testing procedures for solar cells appealing. By using intelligent systems controls, the rejection rate can be reduced, process quality increased, and error sources eliminated or at least compensated. Automated processes in which the possibilities of control are nevertheless transparent provide some leverage to resource-efficient and therefore economic mass production of solar cells. Here, a lot can be drawn from concepts like the “gigawatt factory” or “grid parity factory”. The German photovoltaics company centrotherm AG has presented some of these ideas under the heading “grid parity factory” and shown how the integrated production of ingots, cells and modules provides opportunities for saving energy and resources. These concepts focus on the integration of production under one roof. One the one hand, this saves in transport, packaging, and the margins of intermediate levels. Wear, aging and fracturing of materials can be reduced by direct processing. On the other hand, by optimization of the production process and recycling, the amount of water used, the process chemicals required, and the energy consumed can significantly be reduced. Hence, the larger the production plant, the easier – and more economic – its water recycling will become. Possible savings in water consumption could be up to 60 percent. In addition, the company M + W Zander has calculated that the scale benefits that these one-gigawatt plants offer for wafer manufacturing can reduce capital investments by 25 percent, while investments could be reduced even further in thin film manufacturing. However, the industrial manageability of solar factories of this size has not yet been satisfactorily established. Altogether, concepts of scaling and vertical integration have been very successful in comparable industries such as semiconductor or flat panel display production, and have significantly contributed to cost reduction. For these concepts to be applicable to photovoltaics, landmark projects for “Smart Integrated Solar Factories” are required that have a similarly high signalling effect and multiplicator function in order to facilitate and accelerate a similar wave of innovation in the photovoltaics sector.

With regard to utilizing potentials for material efficiency and resource conservation in the solar photovoltaic industry, trade associations are especially important. They are crucial to providing a platform for moderated, structured search procedures, and for exchanging experience and business results (best practice, benchmarking, etc.). In addition to those initiatives and associations of the solar industry already in place (Glottertal forum, EPIA, BSW), the German engineering federation VDMA offers an independent trade platform called “Means of production for photovoltaics” (Produktionsmittel für die Fotovoltaik) that draws on the results of the roadmap and uses it to develop strategies for further resource efficiency challenges. For the automation technology sector, the German association of electrical and electronics industries ZVEI was brought on board. This kind of cooperation results in opportunities for more effective exchange relationships that go far beyond strictly business-oriented market signals and technology forecasts and help identifying opportunities and risks.

3 Roadmap Workplace Computing Solutions 2020: Development of a Lead Market for Green Office Computing

3.1 Initial Situation

In our contemporary information and knowledge-based society, information and communication technology (ICT) forms the technical base and as a dynamic field of innovation, significantly contributes to economic development. ICT can make an important contribution to saving natural resources in various economic and social contexts, for example through intelligent control of power grids and buildings, or through facilitating telephone and video conferences. However, environmental relief potential aside, the production of ICT equipment (personal computers, laptops, televisions, etc.) and infrastructure (data centers, mobile networks, etc.) and of course their use is generally associated with high energy and resource consumption rates that have in the past been rising steadily. For example, the ICT-generated power consumption in Germany has risen from about 38 TWh in 2001 to approximately 55 TWh in 2007 (Cremer et al. 2003), currently representing approximately 10.5 percent of the total power consumption in Germany. The strongest growth is being recorded in the infrastructure segment, i.e. servers, data centers, mobile and telephone networks. Even so, at present consumer devices still account for the greatest part of ICT-related power consumption. The approximately 26.5 million desktop computers currently in use in German business, government, and educational institutions (schools and universities) make up the largest fraction of this with an annual consumption of about 6.5 TWh (Fichter / Clausen / Hintemann 2010, P. 10) – more electricity than two medium coal power plants produce in a year. Currently, the inventory consists of 50 percent PCs, 41 percent notebooks, 8 percent “Thin Clients” and 1 percent “Mini” or “Compact PCs”, a new generation of computers that has only been available on the market just over two years (Ibid., p. 17). In terms of energy and material consumption, notebooks, Thin Client and server-based computering as well as Mini-PCs perform a lot better than PCs. While an average office PC requires 698 kWh of primary energy per year (not including the monitor), notebooks, Mini PCs and Thin Clients (including server share) need only around half of that. Averaged over the different types of devices, the average workplace computer has a primary energy consumption of currently around 500 kWh. As the following table shows, the amounts of materials used in different devices also reveal a similar picture. Given the growing importance of the service sector, the increasing computerization of industries with little computer equipment so far (trades and crafts, for instance), as well as the national policy of improving computer access in schools and universities, current forecasts estimate that the number of workplace computers will increase to around 37 million devices in 2020 (Fichter, Clausen, Hintemann 2010, p. 18). Despite all improvements in energy efficiency, the ongoing high use of computers means that the total energy consumed by desktop computers in Germany is likely to continue to grow in the years to come. Using more devices from energy-saving device groups like notebooks, thin clients and mini-PCs – their performance generally being quite sufficient for regular office applications – could significantly contribute to saving energy and material. Therefore, the objective should be the advancement of sustainable structural changes to workplace-related computer solutions in Germany till 2020 and the development of a lead market for “Green Office Computing”.

Tab. 2: Different Types of Workplace Computers in Comparison

	Workplace Computers in Germany 2010				
	PC	Mini PC	Notebook	Thin Client	Total
Terminal Devices					
Number of Devices	13.000.000	300.000	11.000.000	2.200.000	26.500.000
Furnishing structure, in percent	49,1	1,1	41,5	8,3	100,0
Energy Consumption					
Annual Energy Consumption per Device (without monitor etc.) p.a. (in kWh)	201	74	65	43	
Cumulative Energy Demand (CED) of Devices (in kWh)	549	202	177	117	
Production Energy (CED) for Devices (in kWh)	584	285[2]	340	141	
Service life (in years)	5	5	4	8	
Production and Operation Energy (CED) per Device p.a. (in kWh)	666	259	262	135	
Total Cumulative Energy Demand (CED) divided by Use of central IT resources per Workplace Computer p.a. (in kWh)	32	32	32	249	
Production and Operation Energy (CED) per Workplace Computer p.a. (in kWh)	698	291	294	384	499
Materials Used					
Total Weight in kg	8	2	2,4	1,5	
Pro-Rata Weight of Terminal Server (25 kg) per Workplace Computer (in kg)[3]	0,07	0,07	0,07	0,55	
Weight of Device and Terminal Server shares per Workplace (in kg)[4]	8,07	2,07	2,47	2,05	5,18
Environmental Effects					
Greenhouse Gas Potentials through Energy Consumption in CO2-equivalent p.a. per Workplace Computer (in kg)	122,9	49,4	44,1	75,4	85,4

Source: Calculation and compilation of data by the Borderstep Institute, 2010.

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[2] For the calculation of the Cumulative Energy Demand (CED) of Mini PCs, corresponding data was used from notebooks without Monitor, as notebook parts are generally used in Mini PCs.

[3] As a Terminal Server serves several workplaces, the weight is allotted proportionately.

[4] This refers to the weight of the devices needed for one single workplace. Not only does this include the weight of the end devices, but the proportionate weight of the terminal server utilized as well.

3.2 The Dialogue Process

Based on the Borderstep Institute’s initial scientific analysis from 2008, and the resource savings potentials for ICT and for workplace computing in particular determined therein, the area “Thin Client & Server Based Computing” (TC & SBC) was chosen as the primary field of examination for the roadmapping process, in agreement with the funding authorities, the Federal Environment Ministry and the Federal Environment Agency UBA. In order to continuously incorporate different perspectives and interests surrounding the value chain of workplace-related IT solutions into the roadmapping project and involve those stakeholders crucial to subsequent implementation of the roadmap at an early stage, a control group was set up that met every two months from September 2008 to September 2010. This steering committee has supported and professionally accompanied the Borderstep Institute’s analytical work. Additionally, the steering committee designed and adopted the roadmap. Members of the roadmapping control group were:

- IT manufacturers and software producers: Fujitsu Technology Solutions, Igel Technology, Sun Microsystems Inc., Citrix Systems
- System houses and IT consultants: Accentrix IT Consulting, Computacenter
- IT users: Finanz Informatik (Financial Computer Science), the German savings bank Sparkasse’s IT service provider, and Federal Environment Agency UBA
- Associations: German Federal Association of Information Technology, Telecommunication and New Media BITKOM
- Science: Borderstep Institute, Fraunhofer Umsicht
- Monitoring: UBA

The two-year roadmapping process consisted of the following steps:

- Ecological evaluation of different workplace computing solutions
- Selection and analysis of the industries and sectors relevant to the development of resource efficiency in office computing
- Analysis of the selected priority sectors (small service providers, federal authorities, schools, home offices)
- Case studies and identification of best-practice applications of resource-efficient workplace computing (TC & SBC, etc.)
- User surveys, including all federal agencies and a number of system houses and retailers, regarding the constraints in using TC & SBC
- Technological, market-based and social trend analysis
- Realization of four Delphi surveys for the evaluation of future trends
- Developing the business-as-usual scenario “Workplace computing solutions 2020”

- Developing the “Resource-efficient workplace computing solutions 2020” roadmap, adopted by the steering committee in July 2010
- Deriving a Green IT scenario based on the roadmap, and determining the resource saving potentials outlined in the roadmap
- Editing the results for publication (Roadmap, best practice, etc.), and organizing transfer workshops.

3.3 Results and Outlook

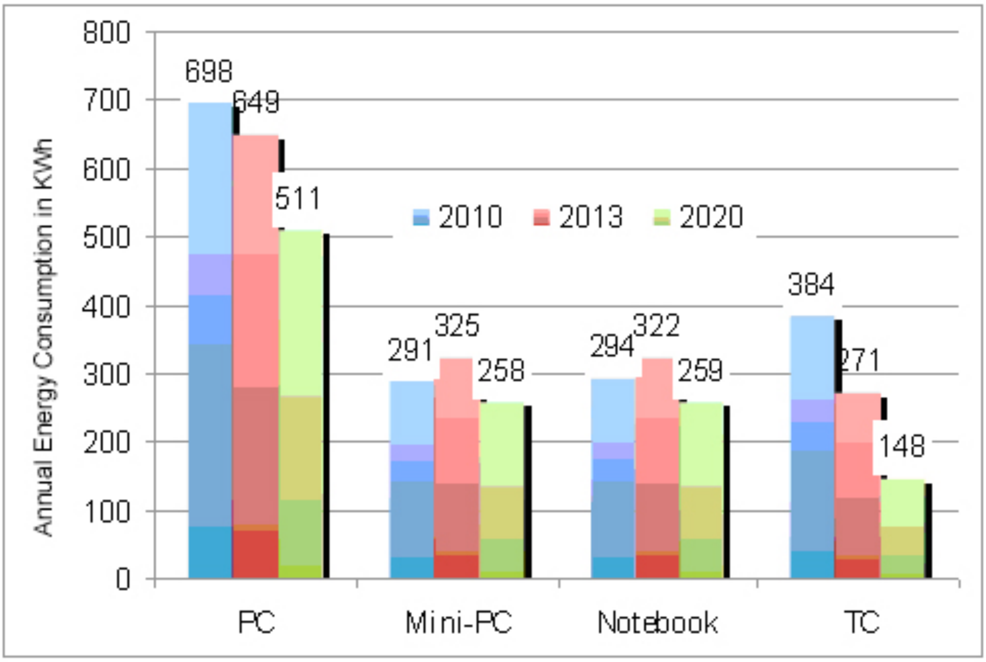
Based on the analysis carried out as part of the roadmapping process (trends and existing obstacles for the implementation of energy and material-efficient computing solutions like TC & SBC, case studies on best practice applications, etc.), and on the Delphi surveys, the roadmap “Workplace computer solutions 2020” was first developed using the basic “business as usual” scenario (BAU scenario). In this basic scenario, current trends are continued and extrapolated (increasing energy efficiency of devices, growing number of mobile devices, etc.), thus representing the future impacts of an undisturbed “business as usual”. The BAU scenario also shows where there is most need for action in future in order to tap material efficiency and resource savings potentials in workplace computing. This was the foundation for determining the objectives of the roadmap and for articulating concrete measures for resource saving potentials to be realized. The “Green IT” scenario developed subsequently picks up the measures from the roadmap and shows what happens when it has been completely implemented. So the difference between the “BAU” scenario and the “Green IT” scenario is that, in the latter, the roadmap has already been implemented.

In both scenarios, the number of computer workstations has been equalized, but the additional energy and material efficiency measures from the roadmap account for the differences in the “Green IT” model, i.e. shifting ratios of computer device groups (more TC & SBC, compact PCs, etc. in comparison to regular desktop PCs), an accelerated improvement of energy and material efficiency, as well as a greater life expectancy of equipment.

Selected results of the BAU scenario

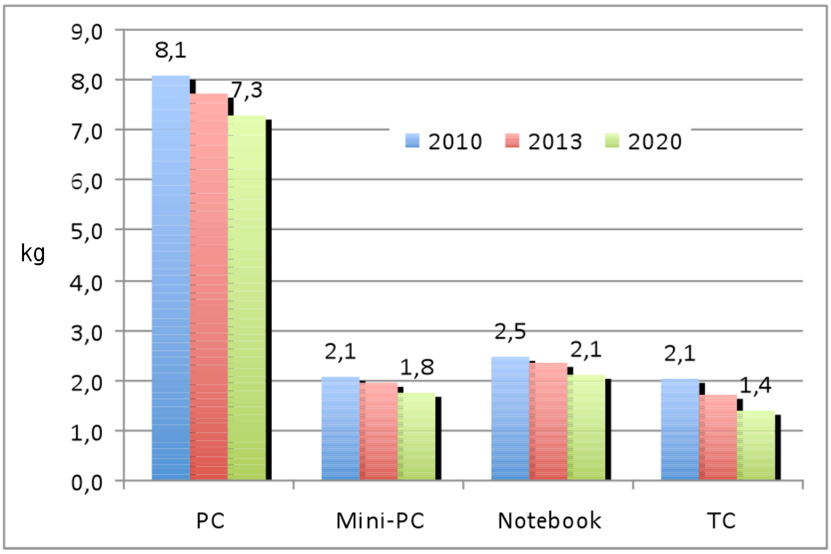
As the two following charts show, despite substantial increases in the efficiency of desktop computers, Mini PCs, notebook and TC& SBC will still have distinct advantages regarding energy and material consumption in future. The figures also show that as of today, Mini PCs, notebooks, and thin clients (including their terminal server shares) are more or less equally resource-efficient. But Thin Client & Server-based Computing will play the lead role from no later than 2013 onwards from an ecological point of view. The reason is that when using Thin Clients, the application software runs exclusively on terminal servers, and the efficiency of servers, data centres and required software is increasing much faster than that of end devices.

Fig. 4: Development of Annual Energy Consumption per Workplace Computer in kWh in Germany (including production and terminal server share, not including monitor) in the BAU Scenario



Source: Calculation by the authors, Fichter/Clausen/Hintemann (2010).

Fig. 5: Development of Material Use per Workplace Computer in kg in Germany (including terminal server share, not including monitor) in the BAU Scenario



Source: Calculation by the authors, Fichter/Clausen/Hintemann (2010).

Advantages of Thin Client & Server-Based Computing

As the BAU scenario illustrates, a resource-saving strategy for desktop computers mainly needs to address two points: Firstly, the respective devices need to become distinctly more energy- and material-efficient, and secondly, “structural changes” regarding the types of devices used are necessary. The desktop PC as an “allrounder” will still be important in the future for some individual applications; for the largest part of office and desktop applications however, Mini PCs, notebooks, and especially Thin Client & Server-Based Computing will clearly be better alternatives from an ecological point of view.[5] Apart from energy efficiency, TC & SBC has other benefits as well, such as reduced administration, greater security, and lower total costs of ownership.

Obstacles regarding Thin Client & Server-Based Computing

Against this background, the question is why TC & SBC is that slow to spread. This is primarily due to the fact that the transition from a desktop PC to a server-based computing system constitutes a fundamental shift in IT, with major impacts on work flow and the workplace in general. The significance of such a system change already indicates that it may be connected with a variety of barriers. That being said, there are also numerous prejudices about server-based computing, originating mostly from experiences with the first generation of Thin Clients, but influencing the formation of opinions even today. As the case analysis and barrier analysis within the roadmapping project have shown, the following obstacles regarding the use of TC & SBC play an important role:

In many cases, decision-makers in business, administration and organizations are not well informed. This is not only due to the fact that the information provided by manufacturers and suppliers of TC & SBC leaves room for improvement, but also because the marketing for traditional PC solutions often promotes prejudices towards TC & SBC. The amount of misinformation with decision makers regarding possible cost reduction effects is particularly crucial.

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[5] Clear environmental benefits can be found throughout the entire product life cycle, in energy consumption, avoidance of pollutants and the use of material (weight) in the end product. As extensive research within the roadmapping project has shown, the available data regarding the (cumulative) raw material use throughout the product life cycle of computer terminals and servers is fragmentary at best. There is a notable lack of detailed and scientifically sound data about electronics components, the consumption of raw materials in the manufacturing process, and the younger generation of devices such as Mini PCs in particular. Assessing the resources used in the devices examined with the indicator "Cumulative raw material Usage" would have been desirable, because it is undoubtedly more meaningful to examine than material weight and material composition in terms of prioritizing prospective ecological benefits. However, due to the lack reliable data this could not be accomplished. Therefore the idea was dropped, in consultation with the Federal Environment Agency UBA expert panel, so the analysis concentrates on identifying the material weight of end devices (weight in kg) and their respective composition (proportion of electronic components, metal, plastic and power supplies, in kg). The Roadmapping project has revealed some considerable research needs with respect to (cumulative) raw material usage.

The complexity of a TC & SBC project is often perceived as high, leading to a certain degree of uncertainty with the responsible staff. Also, in many larger organizations and authorities, IT management responsibilities are split up into central IT maintenance (data centers, key central services, etc.) and decentralized IT tasks (responsibility for end devices, applications for individual departments, etc.). This further complicates the implementation of integrated TC & SBC solutions, since there are issues of losing responsibilities and decision-making power.

TC & SBC is also associated with a number of changes to the workplace itself. Employees usually do not know anything of the benefits or downsides beforehand. Hence, there is also a certain degree of resistance to the implementation of TC & SBC on the part of the employees themselves. Probably the most widespread bias against TC & SBC is that graphics and media services are estimated as poor. The reason for this is that the first generation of Thin Clients in parts indeed did not have sound cards, making them unsuitable for applications such as language teaching in schools for example, even though there is excellent and widespread software on offer for exactly these purposes.

But for specialist software with low sales figures in particular, terminal server-capable applications are still largely missing. So many companies, including scientific users, cannot make the transit to server-based computing just yet. These kinds of barriers may be overcome by so-called “Desktop Virtualization” in future.

However, the interplay of terminal, terminal server and network infrastructure that TC & SBC requires not only challenges and sometimes overburdens many users, but system houses that are not yet that familiar or often lack knowledge, experience and qualified personnel for TC & SBC as well. This significantly increases decision-makers’ uncertainty on the corporate side, as they often rely on long-standing, stable and good relations to their system houses. Mostly they want to perform important and risky system changes with a partner who knows their business well. So ultimately, it is the expertise of system houses that presents one of the main obstacles.

Roadmap “Workplace computing solutions 2020” - Development of a lead market for Green Office Computing

The aim of the roadmap is the advancement of sustainable structural change for work-related computer solutions in Germany by 2020. With the roadmap, a leading market for “Green Office Computing” shall be developed, contributing to the following economic and environmental goals:

1. Increasing the fraction of energy- and material-efficient desktop computer solutions from 50 percent today to 60 percent in 2013 and 85 percent in 2020.[6]
2. Reducing the cumulated energy demands (CED) of workplace computers in Germany from 500 kWh per year today (including production and terminal server shares, but not including the monitors) to 400 kWh by 2013 and 200 kWh by 2020.
3. Reducing the average product weight per workplace computer (including server share) from 5.2 kg today (without monitor) by 20 percent by 2013 and at least 50 percent by 2020.

The 39 practical measures listed in the roadmap are intended to achieve those objectives. The implementation of the roadmap by 2020 would lead to savings of 29.4 TWh of primary energy, which translates to savings in electricity costs of around 2.75 billion Euros, a reduction of carbon dioxide emissions of 5.5 million tonnes, and savings of around 245,000 tonnes of material. Furthermore, with the implementation of the roadmap, the rapidly growing market for “green” future technologies can successfully be developed, and Germany can be positioned as a Green IT pioneer in the international competition environment.

The wide range of measures and the resources necessary to implement them make it clear that the implementation of the roadmap can only be accomplished in a concerted action of ICT producers and users, politics and science. Therefore, the formation of a “Green Office Computing” initiative in the form of a public-private partnership has been proposed for the execution of the roadmap. As a network of partners that advances and promotes resource-efficient computing solutions in business, government and education institutions, the initiative serves as an institutional platform devoted to the development of strategic partnerships and the coordination of measures to be implemented from the roadmap. The initiative should be supported by the federal governments, ICT services and users (Council of IT officers, the German CIO Colloquium, etc.), industry associations such as BITKOM, and scientific institutions.

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[6] „Energy- and material efficient“ computing solutions are understood here as devices that use at least 20 percent less energy, or are at least 20 percent lighter in total, than an average workplace computer in the year 2010.

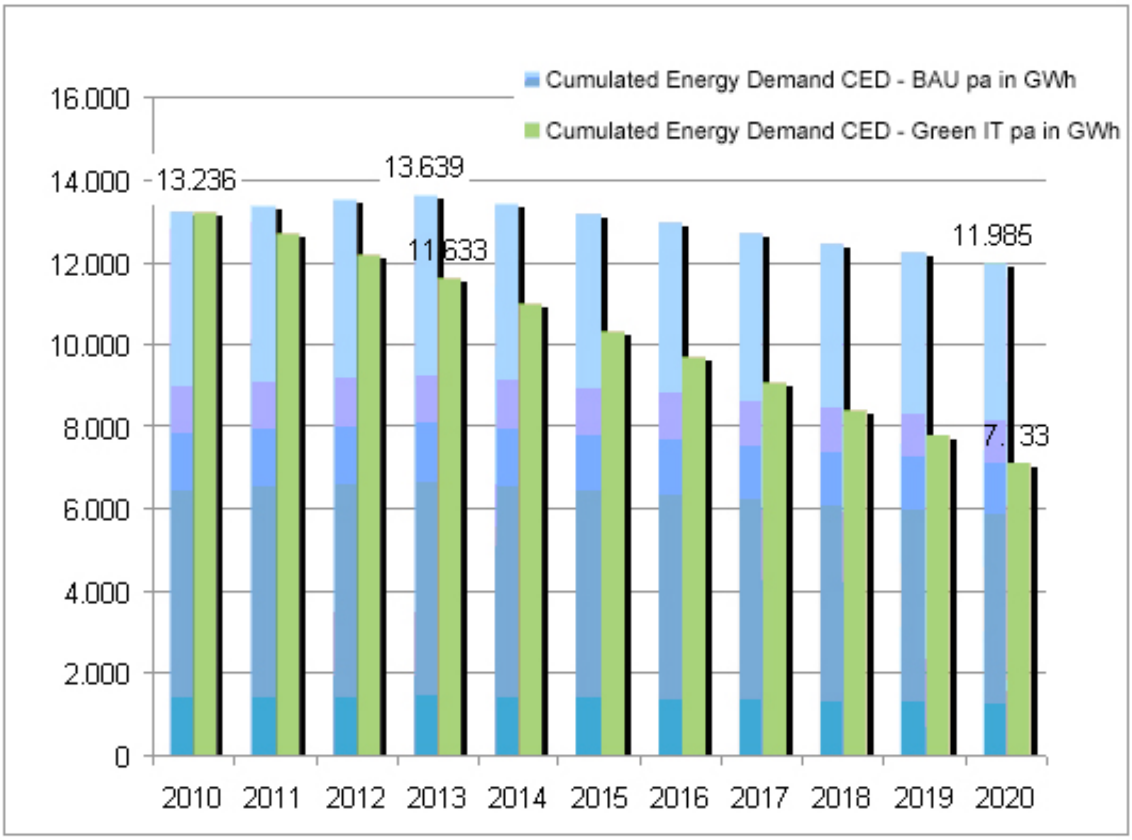
Tab. 3: Selected Measures from the Roadmap “Workplace Computer Solutions 2020“

Roadmapping Measures	**Timetable**
“Green Office Computing” Initiative	
Founding of a “Green Office Computing“ Initiative as a Public-Private Partnership	Foundation 2010 - 2011, Continuation 2011 - 2020
“Green Office Computing” Information Campaign	
Best-Practice Information Packs for different target groups (SME, administration, etc.)	2010 - 2012; Regular Updates
“Green Office Computing” Information Campaign in cooperation with business media (Target group: Senior management, not IT specialists)	Main phase: 2010 - 2013, Continuation 2014 - 2020
“Green Office Computing” Information Campaign in cooperation with IT specialist media (Target group: IT decision-makers and experts in enterprises)	2010 - 2013
“Green IT Truck“ for local presentation of innovative Green IT solutions	2012 - 2015
Showroom “Green Office Computing” in Berlin	From 2012
Beacon Projects “Thin Client & Green Cloud Computing“	
Beacon Project **–** Small service providers, Medical Practices, Crafts, etc.	2011 – 2015
Beacon Project **–** Engineering Jobs	2011 – 2015
Beacon Project – Estate Housing	2011 – 2015
Business Models	
Development of Software as a Service (SaaS) and Desktop as a Service Applications; attractive Margins for System Houses; Hardware and Service Bundles (similar to mobile phone flat rates); offers for private households and small companies on a monthly basis; Thin Client-compatible software licensing (and possibly data licensing, e.g. e-books)	2010 – 2015
Education and Qualification	
Information and training for system houses and resellers: “Future Market Green Office Computing“	2010 - 2011 planning, 2011 - 2013 implementation
Including TC&SBC and Green Computing in higher education curricula (Computer Science, etc.)	Pilot project 2011– 2014, Transfer 2014 – 2020
Endowment Chairs “Server-based Computing“ and “Green Office Home Computing“	Exploration 2011 – 2012, Appointments from 2013
Including TC&SBC and Green Computing in school education curricula (Computer Science lessons, etc.)	Pilot project 2011 – 2014, Transfer 2014 – 2020
Trade Unions, Staff Associations and HR	
Survey on effects and acceptance of server-based workplace computing	2011
Developing a model company agreement on server-based workplace computing, and dissemination of the survey’s results	2011
Dialogues with trade unions, technology consultants, staff associations and councils	From 2012
Technology Development and Standards	
R&D for increasing energy and material efficiency of Thin Clients	From 2010
High-performance servers and high-performance bandwidth for engineering and graphics users	From 2011
Development of software solutions for increasing the client per server ratio in server-based computing and SaaS	From 2011
Facilitating the diffusion of Mini PCs	From 2010
Measures to increase the average energy efficiency (PUE or power usage-effectiveness) of data centre infrastructure in Germany from 1.9 (present) to 1.6 in 2013 and 1.3 in 2020	From 2010
The Government as a patron and IT user	
“Green Office Computing“ as part of the German goverment’s ICT Strategy, as well as integration into the government’s Green IT action plan	2010
Innovation Alliance “Energy-Saving Application Software“	Realization: 2012 - 2015
Adaptation of directives and framework agreements in public procurement	2010 - 2012
Establishing an eco-label (“Blauer Engel”) for Thin Clients and Mini PCs	2011 - 2012
“Green Office Computing“ as a funding priority in the BMU project “IT goes green“	2010 - 2020

Savings Potentials through Implementation of the Roadmap: Green IT Scenario

The Green IT scenario differs from the BAU scenario in that it assumes that the roadmap measures presented above have already been implemented.[7] The effect of the roadmap is therefore immediately represented in the difference between the BAU scenario and the Green IT scenario. Not all of the effects of the roadmap can be quantified, so only those actions were taken into account whose impact could be plausibly estimated on the grounds of expert judgments and workshops. The implementation of the roadmap is represented in the "Green IT" scenario and would lead to the following effects:

Fig. 6: BAU and Green IT Scenario in Comparison: Energy Consumption of Workplace Computers in Germany (including production and terminal server share, not including monitor)



Source: Calculations by the authors, Fichter/Clausen/Hintemann (2010).

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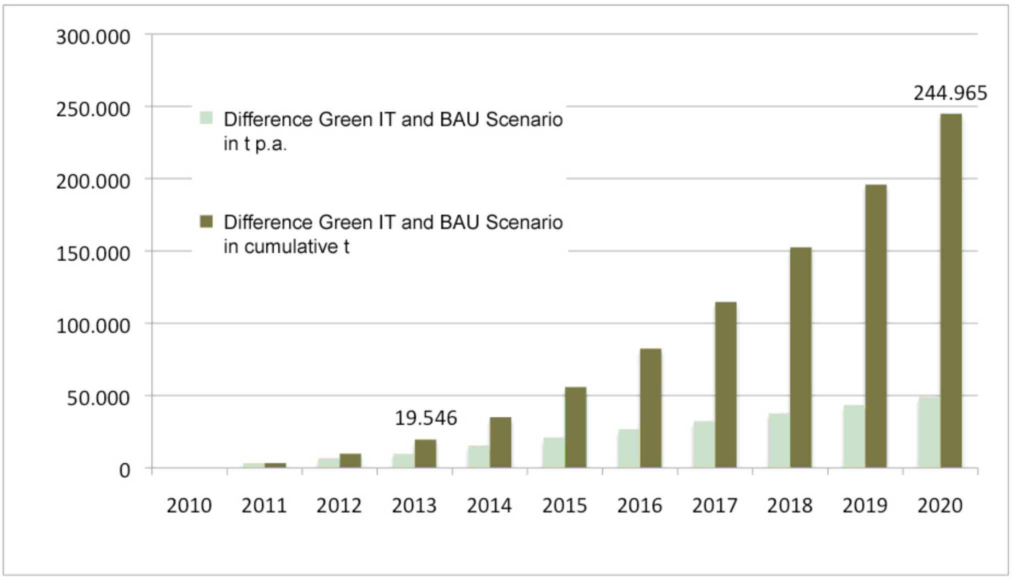
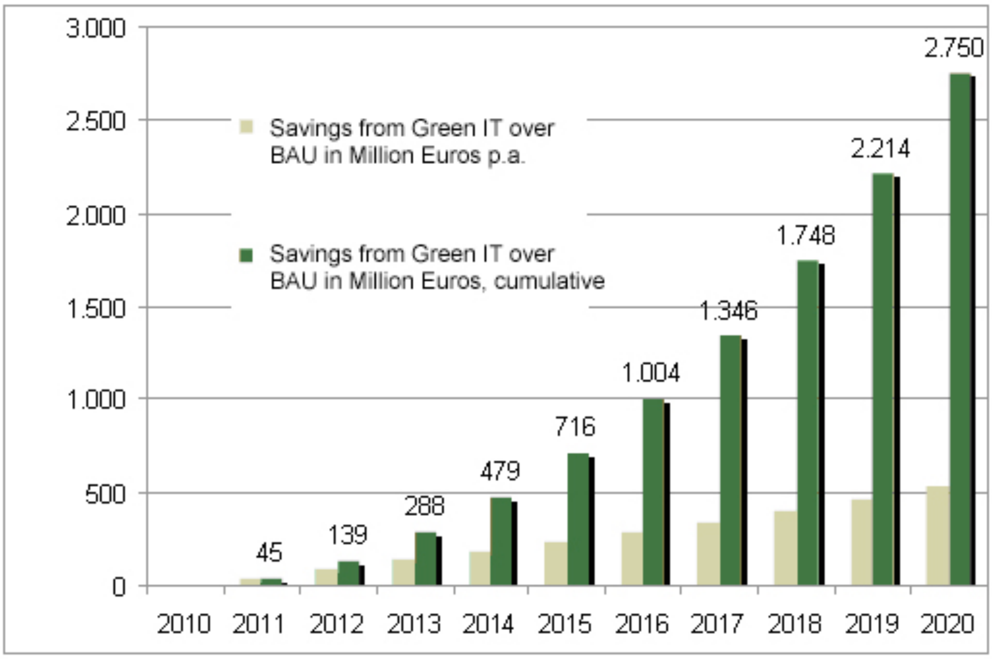
[7] While a "Scenario" refers to the situation at a specific time in the future (e.g., for the year 2020), the "Roadmap" shows the path of development towards that point.

Fig. 7: Material Savings[8] in Workplace Computers in Germany (including terminal server share, not including monitor) through the Implementation of the Roadmap (Green IT Scenario)



Source: Borderstep Institut 2010.

Fig. 8: Power Costs Saved[9] in Operation of Workplace Computers in Germany through the Implementation of the Roadmap (Green IT Scenario, Source: Calculations by the authors, Fichter/Clausen/Hintemann, 2010)



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[8] Here, only the weight reduction of the end devices was considered. If the associated shifts in usage of materials and raw materials throughout the product life cycle had been considered additionally, the figures would be much higher.

[9] Calculations of future power costs were based on average electricity costs of 0,18 € per kWh for commercial customers in 2010 and an increase of prices of 5 percent p.a..

4 Lessons learnt: What can cooperative Roadmapping accomplish?

Co-operative roadmapping can achieve the following:

- *Long-term perspective*: Early identification of opportunities and risks (e.g. raw material shortages in photovoltaics, environmental and economic opportunities for the development of a lead market for Green Office Computing).
- *Assessment of potentials*: Identifying material efficiency and resource conservation potentials (e.g., through increased use of “lean” devices like Thin Clients in workplace computing, or in photovoltaics, adaptations in manufacturing and recovery of PV products)
- *Accelerating and facilitating the dissemination of existing efficient technologies*: Better understanding of existing obstacles preventing the implementation of resource-efficient future solutions (e.g. replacement of IT systems), and clarifying how to best tap material efficiency and resource conservation potentials in the short, medium and long term (e.g. in the production of photovoltaic products).
- *Integration of different stakeholder perspectives*: Resource efficiency from the point of view of different protagonists involved. In the photovoltaics field (e.g., photovoltaics industry, mechanical engineering and plant engineering, automation technologies, recycling companies and related business and trade associations), this is achieved for instance by determining how new production concepts in mechanical and plant engineering or automation technology can support the development of efficiency within the value chain. In the workplace computing field, this applies to groups like IT manufacturers, software vendors, system houses, IT users (e.g., SMEs, large companies, government agencies or schools), and scientific institutions.
- *Innovation Timetable*: Development of concrete measures for material efficiency and resource conservation potentials (as presented in the Roadmap “Workplace Computer Solutions 2020”) with specific objectives, milestones and responsibilities.
- *Supporting and establishing the “Ecological Industrial Policy” of the German Federal Environment Ministry*, particularly the initiative for material and energy efficiency and the development of future “green markets” through industry-oriented roadmapping procedures.
- *Identifying technology requirements, standardization needs and areas requiring further research*: Qualification requirements, user demands and other conditions for developing relevant future resource efficiency markets.
- *Combining skills and knowledge*: The roadmapping process bundles specific know-how from research institutions, companies, associations and social forces, something that cannot be achieved by individual firms, SMEs in particular, alone.

Participants are given access to interdisciplinary knowledge and professional know-how.

- *Involvement of business associations*: Sensitization, activation and integration of pertinent industries and professional associations into a platform for the development of coordinated innovation roadmaps for resource efficiency, as potential disseminators for the transfer of results into companies’ innovation management (pilot scheme).
- *Market opportunities*: Identifying opportunities and strategies to create and expand markets for efficient technologies, as well as identifying pilot projects for German companies in key future markets for efficiency technologies.
- *Innovation incentives for companies*: Impulses for linking the roadmap with operational activities in innovation policy and management for the development of resource efficiency potentials.

The experience from the roadmapping projects can also be transferred to other areas of technology and used as an essential element of innovation-oriented environmental policy. For future use of the cooperative roadmapping method, there are however a number of important aspects to be noted to help design the process efficiently and activate high resource savings potentials:

- Involving independent, market- and technology-neutral process moderators with technical expertise and methodological skills
- Selecting areas of examination with high potential for resource savings and “hidden” opportunities (e.g., cross-sectional technologies)
- A certain extent of political will within government ministries and authorities to follow the roadmap in cooperation with industry and science
- Government representatives actively involved in the process of drafting the roadmap
- Involving committed industry experts and senior decision-makers
- Expanding technological perspectives, user and operator integration
- Generating knowledge from different perspectives (e.g., with the Delphi method)
- Not suppressing possible side effects and risks (e.g., rebound effects)
- Involving social stakeholders
- Target group-geared and active transfer of results
- Securing continuity, for example by institutionalizing alliances.

5 References (German)

Behrendt, S. (2010): Integriertes Roadmapping. Heidelberg, Berlin, New York: Springer.

Cremer, C. et al. (2003): Der Einfluss moderner Gerätegenerationen der Informations- und Kommunikationstechnik auf den Energieverbrauch in Deutschland bis zum Jahr 2010 – Möglichkeiten zur Erhöhung der Energieeffizienz und zur Energieeinsparung in diesen Bereichen. Project No. 28/01 (Summary of the Final Report to the German Federal Ministry of Economics). Karlsruhe/Zürich.

Fichter, K., Clausen, J., Hintemann, R. (2010): Szenarien „Arbeitsplatzbezogene Computerlösungen 2020“, Arbeitspapier im Rahmen von AP 9. Roadmap-Dialoge des Vorhabens „Materialeffizienz und Ressourcenschonung (MaRess)“. Berlin.

6 Glossary

ATO: Antimony-Tin Oxide

CdTe: Cadmium telluride is one of several semiconductor materials that are used to produce thin film photovoltaics modules.

CIGS: Solar Cells based on Copper indium gallium selenide

CIS: Copper indium selenide

c-Si: Monocrystalline solar cells

Dendritic Processing (mc-Si): Dendritic growth is a form of crystal production based on precise knowledge of crystal growth mechanisms for controlling micro-structure and defects of the crystal.

Electromagnetic Processing: Silicon is melted by a magnetic field produced by induction coils. The electromagnetic forces keep the material in the heart of the reactor, so that a crucible is no longer required, and the inclusion of oxygen is mostly largely avoided.

EoL: End-of-life Recycling

Fluidized bed Reactors: E.g., for Silicon Production.

Free-Space Reactor: This technology allows the production of silicon powder out of monosilane. Impurities in the silicon resulting from contact with the walls of the reactor can be avoided with this method.

Ingots: Blocks of semiconductor material such as silicon. The growth of larger Ingots can potentially increase throughput and reduce specific energy consumption.

ITO: Indium-Tin Oxide

Kerf Loss: There is high saving potential associated with minimizing kerf loss, material wasted by saw cuts.

Lift-off process: A microstructuring procedure using adhesive layers that are washed out later on.

Magnetic CZ Process: With the magnetic Czochralski process, oxygen can be kept away from the silicon when growing crystals.

MG-Si: Metallurgical grade silicon,

MJC: Multi-Junction Cells

PECVD Process: Plasma-Enhanced Chemical Vapor Deposition

Poly-Si: Poly- or Multicrystalline Cells (mc-Si)

Slurry: A slurry made of fluid glycol or oil and silicon carbide is used to separate bars of silicon with wire saw technology.

SoG-Si: Solar grade silicon.

TCO: Transparent conductive oxide.

UMG–Si: Upgraded metallurgical grade silicon.

Vapor-to-Liquid Deposition: Similiar to the Siemens process, except in that the tubular reactor precipitates silicon as fluid using induction heating.