Borderstep Institute for
Innovation and Sustainability

Energy-efficient Cloud Computing Technologies and Policies for an Eco-friendly Cloud Market

Recommendations for Future RTD Policy

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Publishing information:

Part of the study "Energy-efficient Cloud Computing Technologies and Policies for an Eco-friendly Cloud Market" (SMART 2018/0028)

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ENVIRONMENT AGENCY AUSTRIA

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1 Introduction and background of the recommendations

The Borderstep Institute and the Environmental Agency Austria are preparing a study about "Energy-efficient Cloud Computing Technologies and Policies for an Eco-friendly Cloud Market" for the European Commission.

The partners already prepared calculations about the energy consumption of the cloud computing data centres (Task 1) and a description of all relevant technological elements (hardware and software) from the edge device to the data centre that are needed to provide fully fledged cloud services (Task 2).

Based on the research in Task 2 the following six areas of research and technical development have been identified and described as promising for fostering the energy efficiency of cloud computing:

- IT equipment: from edge devices to hyperscale data centres (server, storage, network)
- Infrastructure for IT environments (cooling, ventilation, power supply)
- Communication networks (wired, mobile, core)
- ICT energy metering, control and analytics for precise allocation of consumption
- Efficient cloud (scaling) management
- Efficient cloud application software

An online survey with experts who have worked on this topic confirmed the relevance of all six areas for energy-efficient cloud computing.

Even though the online consultation and the expert interviews for the development of recommendations on further RTD policy options are still ongoing, preliminary results for the need for RTD in each of the six identified key technological areas have been identified on the basis of the online consultation (Figure 1).

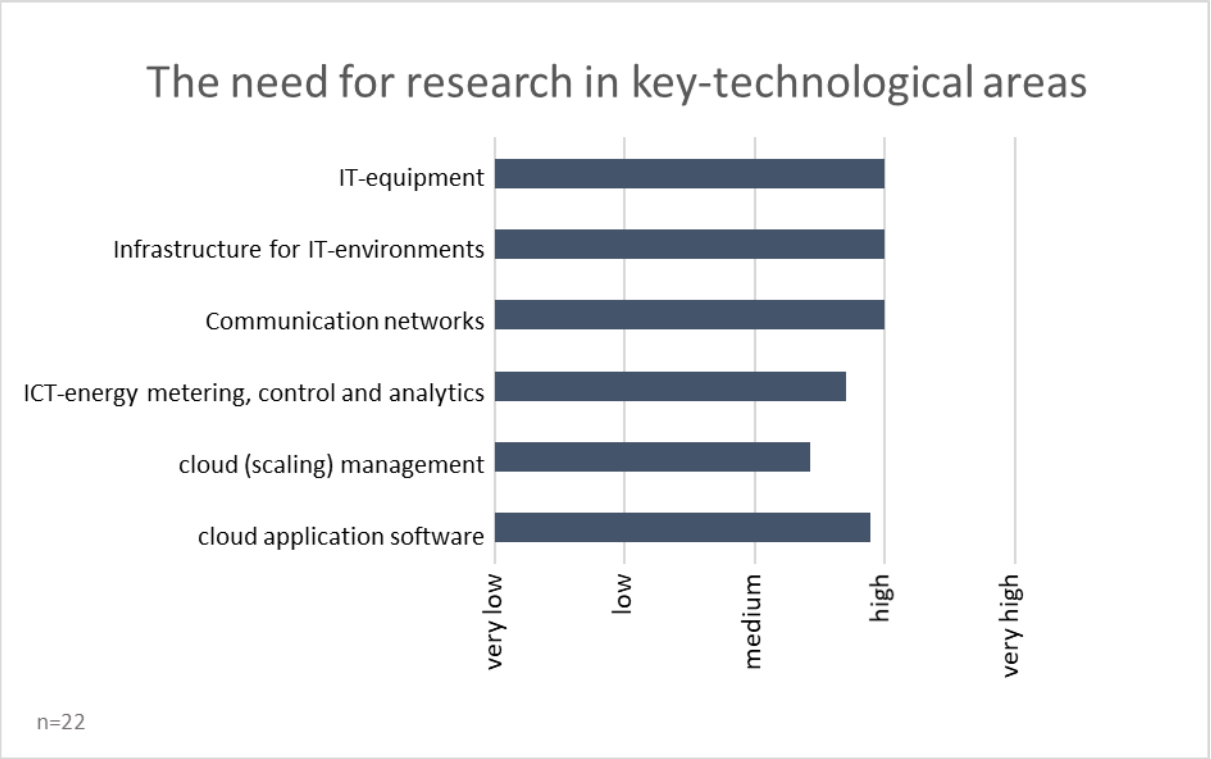

Figure 1: Need for RTD in key technological areas - result of the online consultation

Additionally, policy recommendations for research and technological development (RTD) are prepared and presented in this document, that are expected to contribute to energy efficiency of cloud computing in the EU-28. The main contributions of RTD for energy efficiency in cloud computing can be grouped in four characteristic areas:

- Transparency, data availability, allocation of energy consumption and standards
- Improvement of management and operation optimization in cloud computing
- Improvement of energy efficiency in individual technological components
- Improvement of software efficiency

The below presented ideas and suggestions are based on telephone interviews with various experts of various stakeholders like data centre operators, ICT manufacturers, software developers, cloud providers and scientific institutions. Also, in a two staged online survey, various stakeholders could suggest recommendations which were included as well. Similar recommendations were combined. Most of the recommendations were assessed in their importance from the experts; but some were added within the process so the preliminary rating is not available for all of them yet.

2 Workshop to validate the RTD recommendations

In a validation workshop on 10th of September 2019 the suggestions shall be validated and rated regarding their importance. Appropriate instruments for the implementation of these proposals will be selected and critically discussed. Potential instruments are for example:

- supporting excellent science, e.g. fund collaborative research, funding of research infrastructures, provide researchers with excellent training
- funding/supporting industrial research, e.g. investment in key industrial technologies, facilitate access to risk finance, supporting SME,
- incentivize cross-disciplinary, cross-sectoral, cross-policy and international collaboration, bring together resources and knowledge across different fields, technologies and disciplines,

In addition to such RTD instruments in the narrower sense, other instruments that are part of RTD policy in the broader sense may also be considered. Such instruments could be, for example:

- public procurement,
- the organisation and financing of the discourse (long-term visions, technology assessment, awareness measures, planning cell),
- Education and training (initiating and promoting the development of study courses and the development of training occupations)
- Regulatory policy (competition policy, regulatory policy, influencing private demand).

3 Overview of expert suggestions

In the following section, the recommendations that were suggested by the experts are presented short in a list. The recommendations are sorted according to a preliminary assessment of importance. The elements that have already emerged as important in the online survey are given the addition "strong recommendation". A more detailed version with descriptions can be found in the same sequence and numeration in the appendix.

Expert suggestions

Main focus on "Transparency, data availability, allocation of energy consumption and standards"

1. Development of KPI for the energy efficiency of cloud computing (STRONG RECOMMENDATION)
2. Detailed management system and sensing to gather data to use those for adjusting the runtime environments (STRONG RECOMMENDATION)
3. Research of the influence of 5G and edge computing on the energy demand of cloud computing (STRONG RECOMMENDATION)
4. Metering tool for software applications regarding their energy consumption / Development of dedicated library for accounting at the OS level.
5. New energy measurement/monitoring solutions for existing DCs with moderate installation cost/lead time.
6. Development of standards to describe the energy efficiency of individual components of the cloud computing ecosystem
7. Investigation of necessary transparency requirements of energy related data for cloud providers (information relevant for research) / Integration of cloud products in online benchmark platform
8. Public information about life cycle of cloud products + Comparison of alternatives

Main focus on "Management and operation optimization"

9. Optimized load and resource management to increase utilization of data servers and data centres (STRONG RECOMMENDATION)
10. Artificial intelligence to optimize cloud performance and reduce power consumption (STRONG RECOMMENDATION)
11. Self-organising self-managing heterogenous cloud architectures and extending this paradigm to the edge./ Development of new architectures from Cloud to Thing with self-management and self-optimization (STRONG RECOMMENDATION)
12. Development of new data centre concepts for the reduction of data traffic (less cloud, more fog) (STRONG RECOMMENDATION)
13. Improve cloud performance analysis tools to evaluate cloud performance and energy consumption
14. Development of integrated power measurement and energy management systems for cloud architectures
15. Communication aware application to decrease data transfers.
16. Development of software that is able to control its service quality in comparison to energy consumption
17. Cloud native programming (provisioning, runtime, logging)
18. Decentralized pre processing of data

Main focus on "Improvement of energy efficiency in individual technological components"

19. Reuse of heat generated by data centres (STRONG RECOMMENDATION)
20. Use of artificial intelligence to optimise data centres, in particular to reduce the energy consumption of cooling systems (STRONG RECOMMENDATION)
21. Hardware acceleration and new SoC design (STRONG RECOMMENDATION)
22. New communication strategies such as on-device machine learning and analog transmission
23. "Standby ready" equipment and architectures
24. Modular computing (multiprocessing computer system where processing, memory, and peripheral units can be added or removed without disrupting its operation)
25. Efficient chip cooling
26. Water cooling of servers, storage systems and network components
27. Use of quantum computers for dedicated applications
28. General research about the positive and negative aspects of edge computing

Main focus on „Software efficiency"

29. Energy efficient programming (in general) (STRONG RECOMMENDATION)
30. Developer guidelines for energy efficient programming (STRONG RECOMMENDATION)
31. Training of software developers, Increase awareness of energy-efficient programming (STRONG RECOMMENDATION)
32. Slim/efficient design of hypervisor
33. New programming languages for coding energy efficient cloud application
34. Development of dedicated library for accounting at the OS level
35. Develop tools that can easily assess the energy consequences of variations of programming (use of accelerators, data locality, data movements, ...).

Appendix 1: Suggested Recommendations

Main focus on "Transparency, data availability, allocation of energy consumption and standards"

Idea/suggestion from the expert consultations
1. Development of KPI for the energy efficiency of cloud computing (STRONG RECOMMENDATION)
Type of contribution
Improvement of transparency, data availability, allocation of energy consumption and standards
Short description (interpretation of the study authors)
A simple comparison of energy efficiency of cloud computing products is not possible today, a suitable KPI has yet to be developed.
Impact on specific technological areas

IT-equipment	Infrastructure for IT-environments	Communication networks	ICT-energy metering, control and analytics	cloud (scaling) management	cloud application software
indirect impact	indirect impact	indirect impact	indirect impact	indirect impact	indirect impact

Idea/suggestion from the expert consultations
2. Detailed management system and sensing to gather data to use those for adjusting the runtime environments (STRONG RECOMMENDATION)
Type of contribution
Improvement of transparency, data availability, allocation of energy consumption and standards
Short description (interpretation of the study authors)
The configuration of the runtime environment has a high impact on how efficiently software can be operated in it. Dynamic adaptation based on monitoring data enables the runtime environment to be better adapted to the requirements of the application, thereby increasing energy efficiency.
Impact on specific technological areas

IT-equipment	Infrastructure for IT-environments	Communication networks	ICT-energy metering, control and analytics	cloud (scaling) management	cloud application software
no impact	no impact	no impact	indirect impact	indirect impact	medium impact

Idea/suggestion from the expert consultations
3. Research of the influence of 5G and edge computing on the energy demand of cloud computing (STRONG RECOMMENDATION)
Type of contribution
Improvement of transparency, data availability, allocation of energy consumption and standards
Short description (interpretation of the study authors)
For 5G mobile radio it is already clear that the energy consumption per GB will be considerably lower than in previous generations, but the side effects of very small radio cells and edge services cannot yet be quantified.
Impact on specific technological areas

IT-equipment	Infrastructure for IT-environments	Communication networks	ICT-energy metering, control and analytics	cloud (scaling) management	cloud application software
medium impact	no impact	big impact	indirect impact	no impact	no impact

Idea/suggestion from the expert consultations
4. Metering tool for software applications regarding their energy consumption / Development of dedicated library for accounting at the OS level.
Type of contribution
Improvement of transparency, data availability, allocation of energy consumption and standards
Short description (interpretation of the study authors)
Which application / which process consumes which amount of energy? A metering tool for the energy consumption of applications, potentially integrated into operating systems.
Impact on specific technological areas

IT-equipment	Infrastructure for IT-environments	Communication networks	ICT-energy metering, control and analytics	cloud (scaling) management	cloud application software
no impact	no impact	no impact	medium impact	indirect impact	impact

Idea/suggestion from the expert consultations
5. New energy measurement/monitoring solutions for existing DCs with moderate installation cost/lead time.
Type of contribution
Improvement of transparency, data availability, allocation of energy consumption and standards
Short description (interpretation of the study authors)
It is much more effort to integrate monitoring technologies into existing data centres than in new buildings. To this end, further technological approaches are to be researched.
Impact on specific technological areas

IT-equipment	Infrastructure for IT-environments	Communication networks	ICT-energy metering, control and analytics	cloud (scaling) management	cloud application software
indirect impact	indirect impact	indirect impact	medium impact	no impact	indirect impact

Idea/suggestion from the expert consultations
6. Development of standards to describe the energy efficiency of individual components of the cloud computing ecosystem
Type of contribution
Improvement of transparency, data availability, allocation of energy consumption and standards
Short description (interpretation of the study authors)
Through standardization, the complex components of cloud ecosystems can be evaluated in a uniform scheme in terms of energy efficiency.
Impact on specific technological areas

IT-equipment	Infrastructure for IT-environments	Communication networks	ICT-energy metering, control and analytics	cloud (scaling) management	cloud application software
indirect impact	indirect impact	indirect impact	medium impact	indirect impact	indirect impact

Idea/suggestion from the expert consultations
7. Investigation of necessary transparency requirements of energy related data for cloud providers (information relevant for research) / Integration of cloud products in online benchmark platform
Type of contribution
Improvement of transparency, data availability, allocation of energy consumption and standards
Short description (interpretation of the study authors)
In order for independent science to be better able to research cloud related energy issues, it would be important for cloud providers to publish certain minimum information.
Impact on specific technological areas

IT-equipment	Infrastructure for IT-environments	Communication networks	ICT-energy metering, control and analytics	cloud (scaling) management	cloud application software
indirect impact	indirect impact	indirect impact	indirect impact	indirect impact	indirect impact

Idea/suggestion from the expert consultations
8. Public information about life cycle of cloud products + Comparison of alternatives
Type of contribution
Improvement of transparency, data availability, allocation of energy consumption and standards
Short description (interpretation of the study authors)
The energy consumption of operating physical hardware represents only part of the footprint of using cloud services. More knowledge must be available about the entire life cycle of manufacturing, transport, disposal, water consumption, etc.
Impact on specific technological areas

IT-equipment	Infrastructure for IT-environments	Communication networks	ICT-energy metering, control and analytics	cloud (scaling) management	cloud application software
medium impact	medium impact	medium impact	indirect impact	no impact	indirect impact

Main focus on “Management and operation optimization”

Idea/suggestion from the expert consultations
9. Optimized load and resource management to increase utilization of data servers and data centres (STRONG RECOMMENDATION)
Type of contribution
Improvement of Cloud management and operation optimization
Short description (interpretation of the study authors)
Server utilization has long been an important issue, as many servers are often idle and although they do not do any work, they still consume power.
Impact on specific technological areas

IT-equipment	Infrastructure for IT-environments	Communication networks	ICT-energy metering, control and analytics	cloud (scaling) management	cloud application software
indirect impact	indirect impact	indirect impact	medium impact	big impact	indirect impact

Idea/suggestion from the expert consultations
10. Artificial intelligence to optimize cloud performance and reduce power consumption (STRONG RECOMMENDATION)
Type of contribution
Improvement of Cloud management and operation optimization
Short description (interpretation of the study authors)
Artificial intelligence offers great potential for the automatic optimization of cloud services in terms of performance and (energy) efficient operation.
Impact on specific technological areas

IT-equipment	Infrastructure for IT-environments	Communication networks	ICT-energy metering, control and analytics	cloud (scaling) management	cloud application software
medium impact	medium impact	medium impact	big impact	big impact	medium impact

Idea/suggestion from the expert consultations
11. Self-organising self-managing heterogenous cloud architectures and extending this paradigm to the edge./ Development of new architectures from Cloud to Thing with self-management and self-optimization (STRONG RECOMMENDATION)
Type of contribution
Improvement of Cloud management and operation optimization
Short description (interpretation of the study authors)
Cloud environments are usually operated self-organised. An efficient operation and selection of the optimum resource usage and the selection of best fitting equipment in heterogenous environments can massively improve energy efficiency of some applications.
Impact on specific technological areas

IT-equipment	Infrastructure for IT-environments	Communication networks	ICT-energy me-tering, control and analytics	cloud (scaling) management	cloud application software
no impact	no impact	no impact	medium impact	big impact	medium impact

Idea/suggestion from the expert consultations
12. Development of new data centre concepts for the reduction of data traffic (less cloud, more fog) (STRONG RECOMMENDATION)
Type of contribution
Improvement of Cloud management and operation optimization
Short description (interpretation of the study authors)
For many end-user applications, the proximity of the cloud service can help relieve traffic and thus power consumption in core and backbone networks. In certain cases, concepts of fog computing can be a favoured alternative to a central cloud.
Impact on specific technological areas

IT-equipment	Infrastructure for IT-environments	Communication networks	ICT-energy me-tering, control and analytics	cloud (scaling) management	cloud application software
medium impact	medium impact	medium impact	no impact	indirect impact	no impact

Idea/suggestion from the expert consultations
13. Improve cloud performance analysis tools to evaluate cloud performance and energy consumption
Type of contribution
Improvement of Cloud management and operation optimization
Short description (interpretation of the study authors)
In management of cloud resources, there is often a trade off between performance and efficient operation. For some applications performance features like reaction delay is of higher importance, for some applications it is less important. Analysis tools can help to fit the parameters better to the requirements and thus to improve energy efficiency.
Impact on specific technological areas

IT-equipment	Infrastructure for IT-environments	Communication networks	ICT-energy metering, control and analytics	cloud (scaling) management	cloud application software
no impact	no impact	no impact	big impact	big impact	medium impact

Idea/suggestion from the expert consultations
14. Development of integrated power measurement and energy management systems for cloud architectures
Type of contribution
Improvement of Cloud management and operation optimization
Short description (interpretation of the study authors)
A permanently installed energy measurement and management system in cloud architectures can be used to support live optimization with regard to energy efficiency.
Impact on specific technological areas

IT-equipment	Infrastructure for IT-environments	Communication networks	ICT-energy metering, control and analytics	cloud (scaling) management	cloud application software
indirect impact	indirect impact	indirect impact	medium impact	medium impact	medium impact

Idea/suggestion from the expert consultations
15. Communication aware application to decrease data transfers.
Type of contribution
Improvement of Cloud management and operation optimization
Short description (interpretation of the study authors)
Communication-aware software development can make a contribution to reducing data traffic on the Internet.

Impact on specific technological areas					
IT-equipment	Infrastructure for IT-environments	Communication networks	ICT-energy metering, control and analytics	cloud (scaling) management	cloud application software
no impact	no impact	big impact	medium impact	indirect impact	big impact

Idea/suggestion from the expert consultations
16. Development of software that is able to control its service quality in comparison to energy consumption
Type of contribution
Improvement of Cloud management and operation optimization
Short description (interpretation of the study authors)
Application-specific management for a comparison of the QoS with the energy consumption.

Impact on specific technological areas					
IT-equipment	Infrastructure for IT-environments	Communication networks	ICT-energy metering, control and analytics	cloud (scaling) management	cloud application software
no impact	no impact	no impact	no impact	medium impact	big impact

Idea/suggestion from the expert consultations
17. Cloud native programming (provisioning, runtime, logging)
Type of contribution
Improvement of Cloud management and operation optimization
Short description (interpretation of the study authors)
Cloud environments offer very powerful tools for scaling individual application components, which enable, for example, different application parts to be scaled differently according to requirements. However, this requires cloud native programming, which is often not compatible with old application concepts (e.g. monolithic).

Impact on specific technological areas					
IT-equipment	Infrastructure for IT-environments	Communication networks	ICT-energy metering, control and analytics	cloud (scaling) management	cloud application software
no impact	no impact	no impact	no impact	big impact	big impact

Idea/suggestion from the expert consultations
18. Decentralized pre processing of data
Type of contribution
Improvement of Cloud management and operation optimization
Short description (interpretation of the study authors)
The IoT in particular will result in more and more data being generated decentral; complete processing in a central cloud would mean massive data traffic and thus increasing energy consumption in the communication networks. Decentralized pre-processing can massively reduce data traffic.

Impact on specific technological areas					
IT-equipment	Infrastructure for IT-environments	Communication networks	ICT-energy metering, control and analytics	cloud (scaling) management	cloud application software
medium impact	medium impact	big impact	no impact	no impact	medium impact

Main focus on “Improvement of energy efficiency in individual technological components”

Idea/suggestion from the expert consultations
19. Reuse of heat generated by data centres (STRONG RECOMMENDATION)
Type of contribution
Improvement of energy efficiency in individual technological components
Short description (interpretation of the study authors)
Although waste heat recovery does not reduce electricity consumption in the cloud itself, it can make a major contribution to saving energy and CO2 in nearby heat consumers.
Impact on specific technological areas

IT-equipment	Infrastructure for IT-environments	Communication networks	ICT-energy metering, control and analytics	cloud (scaling) management	cloud application software
no impact	no impact	no impact	no impact	no impact	no impact

Idea/suggestion from the expert consultations
20. Use of artificial intelligence to optimise data centres, in particular to reduce the energy consumption of cooling systems (STRONG RECOMMENDATION)
Type of contribution
Improvement of energy efficiency in individual technological components
Short description (interpretation of the study authors)
The control algorithms of cooling infrastructure in data centres still have a potential to be further optimized with artificial intelligence, especially machine learning, and for example to predict thermal situations in data centres. This will lower the PUE and save further energy in the infrastructure.
Impact on specific technological areas

IT-equipment	Infrastructure for IT-environments	Communication networks	ICT-energy metering, control and analytics	cloud (scaling) management	cloud application software
medium impact	big impact	indirect impact	big impact	no impact	no impact

Idea/suggestion from the expert consultations
21. Hardware acceleration and new SoC design (STRONG RECOMMENDATION)
Type of contribution
Improvement of energy efficiency in individual technological components
Short description (interpretation of the study authors)
Hardware acceleration is a noble path that often increases not only performance gains but also the energy efficiency of applications. Very versatile chips (ARM, x86, GPU, ASICS...) in cloud environments can be used under certain circumstances to use the perfect hardware for each application (component).
Impact on specific technological areas

IT-equipment	Infrastructure for IT-environments	Communication networks	ICT-energy metering, control and analytics	cloud (scaling) management	cloud application software
big impact	no impact	big impact	no impact	no impact	no impact

Idea/suggestion from the expert consultations
22. New communication strategies such as on-device machine learning and analog transmission
Type of contribution
Improvement of energy efficiency in individual technological components
Short description (interpretation of the study authors)
The energy consumption of communication technologies depends strongly on the technology used and its configuration. AI-based control and alternative transmission methods have the potential to significantly reduce energy consumption.
Impact on specific technological areas

IT-equipment	Infrastructure for IT-environments	Communication networks	ICT-energy metering, control and analytics	cloud (scaling) management	cloud application software
medium impact	indirect impact	big impact	medium impact	no impact	no impact

Idea/suggestion from the expert consultations
23. "Standby ready" equipment and architectures
Type of contribution
Improvement of energy efficiency in individual technological components
Short description (interpretation of the study authors)
The energy consumption of ICT equipment in times of low utilization is still a big issue, even if the 2019 ecodesign regulation on servers and storage products will lower the idle consumption. Sending devices to complete standby and reactivating them on the basis of workload predictions has a huge potential for energy efficiency. A "standby-ready" standard or label could help to achieve this with defined wake-up times etc.
Impact on specific technological areas

IT-equipment	Infrastructure for IT-environments	Communication networks	ICT-energy metering, control and analytics	cloud (scaling) management	cloud application software
big impact	medium impact	big impact	no impact	no impact	no impact

Idea/suggestion from the expert consultations
24. Modular computing (multiprocessing computer system where processing, memory, and peripheral units can be added or removed without disrupting its operation)
Type of contribution
Improvement of energy efficiency in individual technological components
Short description (interpretation of the study authors)
Modular hot-pluggable systems facilitate the replacement of obsolete or error-prone components, especially in data centres. This can contribute to a faster renewal of hardware, which usually also has a positive effect on the CO2 footprint including production and disposal.
Impact on specific technological areas

IT-equipment	Infrastructure for IT-environments	Communication networks	ICT-energy metering, control and analytics	cloud (scaling) management	cloud application software
big impact	medium impact	no impact	no impact	no impact	no impact

Idea/suggestion from the expert consultations
25. Efficient chip cooling
Type of contribution
Improvement of energy efficiency in individual technological components
Short description (interpretation of the study authors)
Chip cooling is a critical application in ICT environments such as cloud computing. The transport of the refrigerant together with the generation of cold alone consumes the same amount of electricity as the chip itself. The limits of miniaturization in CMOS technology and thus a potential end to the Moore law make cooling all the more important.

Impact on specific technological areas					
IT-equipment	Infrastructure for IT-environments	Communication networks	ICT-energy metering, control and analytics	cloud (scaling) management	cloud application software
big impact	indirect impact	indirect impact	no impact	no impact	no impact

Idea/suggestion from the expert consultations
26. Water cooling of servers, storage systems and network components
Type of contribution
Improvement of energy efficiency in individual technological components
Short description (interpretation of the study authors)
Many examples have already shown that water is an excellent way to dissipate heat from ICT equipment. Current design of water cooling guarantees 100% tightness and can be operated in many regions without active chillers.

Impact on specific technological areas					
IT-equipment	Infrastructure for IT-environments	Communication networks	ICT-energy metering, control and analytics	cloud (scaling) management	cloud application software
big impact	big impact	big impact	no impact	no impact	no impact

Idea/suggestion from the expert consultations
27. Use of quantum computers for dedicated applications
Type of contribution
Improvement of energy efficiency in individual technological components
Short description (interpretation of the study authors)
First quantum computers are commercially available. This offers new possibilities in ICT and many applications will profit from it in performance but also in terms of energy efficiency.

Impact on specific technological areas					
IT-equipment	Infrastructure for IT-environments	Communication networks	ICT-energy metering, control and analytics	cloud (scaling) management	cloud application software
no impact	indirect impact	no impact	no impact	no impact	no impact

Idea/suggestion from the expert consultations
28. General research about the positive and negative aspects of edge computing
Type of contribution
Improvement of energy efficiency in individual technological components
Short description (interpretation of the study authors)
Supporting the research about the future impact on energy consumption of edge computing; and potential efficiency gains.

Impact on specific technological areas					
IT-equipment	Infrastructure for IT-environments	Communication networks	ICT-energy metering, control and analytics	cloud (scaling) management	cloud application software
indirect impact	indirect impact	indirect impact	indirect impact	indirect impact	indirect impact

Main focus on „Software efficiency”

Idea/suggestion from the expert consultations
29. Energy efficient programming (in general) (STRONG RECOMMENDATION)
Type of contribution
Improvement of software efficiency
Short description (interpretation of the study authors)
The general programming of applications has a high impact on energy consumption. Studies have shown that sometimes very similar applications cause completely different consumption of IT capacity (CPU load/RAM/network) and thus different energy consumption.
Impact on specific technological areas

IT-equipment	Infrastructure for IT-environments	Communication networks	ICT-energy metering, control and analytics	cloud (scaling) management	cloud application software
no impact	no impact	no impact	no impact	medium impact	big impact

Idea/suggestion from the expert consultations
30. Developer guidelines for energy efficient programming (STRONG RECOMMENDATION)
Type of contribution
Improvement of software efficiency
Short description (interpretation of the study authors)
A guideline for developers could be created to support the development of efficient applications.
Impact on specific technological areas

IT-equipment	Infrastructure for IT-environments	Communication networks	ICT-energy metering, control and analytics	cloud (scaling) management	cloud application software
no impact	no impact	no impact	no impact	big impact	big impact

Idea/suggestion from the expert consultations
31. Training of software developers, Increase awareness of energy-efficient programming (STRONG RECOMMENDATION)
Type of contribution
Improvement of software efficiency
Short description (interpretation of the study authors)
More efficient programming requires specific skills that are often not part of the training of software developers. Targeted training and sensitization to energy efficiency can make a contribution here.
Impact on specific technological areas

IT-equipment	Infrastructure for IT-environments	Communication networks	ICT-energy metering, control and analytics	cloud (scaling) management	cloud application software
no impact	no impact	no impact	no impact	big impact	big impact

Idea/suggestion from the expert consultations
32. Slim/efficient design of hypervisor
Type of contribution
Improvement of software efficiency
Short description (interpretation of the study authors)
The hypervisor is a central element in virtualized cloud environments. The larger and fuller the hypervisor is with pre-installed elements, the higher the specific power consumption is just to provide the virtual resources.
Impact on specific technological areas

IT-equipment	Infrastructure for IT-environments	Communication networks	ICT-energy metering, control and analytics	cloud (scaling) management	cloud application software
no impact	no impact	no impact	no impact	medium impact	no impact

Idea/suggestion from the expert consultations
33. New programming languages for coding energy efficient cloud application
Type of contribution
Improvement of software efficiency
Short description (interpretation of the study authors)
Completely new programming languages could be more oriented towards implementing applications more efficiently than is possible with previous programming languages and their methods.

Impact on specific technological areas					
IT-equipment	Infrastructure for IT-environments	Communication networks	ICT-energy metering, control and analytics	cloud (scaling) management	cloud application software
no impact	no impact	no impact	no impact	no impact	big impact

Idea/suggestion from the expert consultations
34. Development of dedicated library for accounting at the OS level
Type of contribution
Improvement of software efficiency
Short description (interpretation of the study authors)
A standard library in the operating system that enables monitoring and calculation of the resource consumption of applications.

Impact on specific technological areas					
IT-equipment	Infrastructure for IT-environments	Communication networks	ICT-energy metering, control and analytics	cloud (scaling) management	cloud application software
no impact	no impact	no impact	no impact	medium impact	big impact

Idea/suggestion from the expert consultations					
35. Develop tools that can easily assess the energy consequences of variations of programming (use of accelerators, data locality, data movements, ...).					
Type of contribution					
Improvement of software efficiency					
Short description (interpretation of the study authors)					
Simple tools can help to estimate the effects of variations in programming. However, these still need to be developed, especially to be available to cloud application developers.					
Impact on specific technological areas					
IT-equipment	Infrastructure for IT-environments	Communication networks	ICT-energy metering, control and analytics	cloud (scaling) management	cloud application software
no impact	no impact	no impact	big impact	medium impact	indirect impact