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# Synthesis Report

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## Executive Summary

One goal of ICT-ENSURE has been to enlarge and strengthen the European network of experts in ICT for environmental sustainability. To best achieve this goal ICT-ENSURE conducted expert studies, developed new ideas for SISE and a roadmap for future research in the field. The purpose of this document is to synthesize all of the work carried out in the ICT-ENSURE project and to look ahead to the future needs and requirements that emerge. The aim is not so much to add new material to the wealth of information already gathered and elaborated upon, but rather to provide a broad reflection on the potential value of what has been achieved overall.

ICT-ENSURE had an articulated structure of Work Packages that addressed the contribution of ICT to environmental sustainability from many aspects, structured according to the project's main network-building objectives. These actions can also however be mapped onto a *process* schema whereby the different activities all contributed to improve the coherence and inter-linking of on-going research, building a common research agenda in the context of the European Research Area (ERA).

The baseline consists of the census of on-going **research** projects and programmes and common literature library of work in the field carried out in Work Packages 6 "Literature Database" and 9 "Web-based Research Programmes Information System". From there, the key area surveys reviewed actual **practice** in Work Package 8 "Scientific Survey in Selected Fields". The analyses of the relevance of ICT and the research requirements that emerged developed through an iterative process of **community validation** in Work Packages 3 "Research Network", 4 "Enviroinfo 2008" and 5 "Enviroinfo 2009" including workshops, questionnaires, etc. In parallel, and to reinforce the understanding developed and its potential application, Work Package 2 "System Model" mapped the abstract structures of **knowledge** in the field, while Work Package 7 "SISE Concept Outline" dealt mainly with issues of **information** management. The end result was the definition of a **common agenda** (Deliverable 3.5, *ERA Recommendations Report*) for future research, from both the standpoints of ICT and environmental research that aims to further strengthen the ICT-ENSURE community and contribute to the structuring of ERA.

Throughout the work of ICT-ENSURE, a pattern of issues has emerged across the different activities that are a function of developments in ICT on the one hand, the increasing complexity and urgency of environmental sustainability on the other, and finally the interaction between these two processes. These trends are likely to drive and shape the whole ICT-ENSURE problem space in the years to come, raising entirely new issues and research requirements.

The process framework developed to describe the main activities carried out in ICT-ENSURE is thus re-mapped taking these trends into account, in order to produce a broader roadmap for future activities. This basically entails linking the emerging opportunities in ICT developments with the urgent needs of environmental sustainability, highlighting the role of: **communities of practice, open toolkits, social networking, complex system models, and strategic intelligence.**

This brief synthesis thus aims to provide a first glimpse of where to go next. ICT-ENSURE provides a solid baseline upon which to build this effort. Carrying these results forward into the future opens new possibilities for ICT for environmental sustainability research to achieve real societal impact in response to the challenge of environmental sustainability.

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# 1 Introduction

## 1.1 Purpose of this document

The purpose of this document is to synthesize all of the work carried out in the ICT-ENSURE project and to look ahead to the future needs and requirements that emerge. The aim is not so much to add new material to the wealth of information already gathered and elaborated upon, but rather to provide a broad reflection on the potential value of what has been achieved overall.

## 1.2 Scope of this document

This document first provides an overview of all ICT-ENSURE activities carried out, viewed within a process-oriented framework whereby the project has aimed to move from a rich but fragmented set of research issues and initiatives to a networked community with a shared research agenda. On this basis, a brief summary of all project activities is presented.

At this point, two broad issues are raised that have reappeared from time to time throughout the project's work:

- From the ICT standpoint, the profound changes that are occurring in the field, such as the emergence of Web 2.0 and social networking.
- From the environmental standpoint, the increasing evidence of the serious consequences of current trends coupled with the lack of an adequate global response.

It has not been within the scope of the ICT-ENSURE project to address these issues, but any work building on the project's outcomes will need to do so. In order to identify some possible directions for the future, an attempt is made to map these trends and some of their consequences onto the key elements of the ICT-ENSURE process.

## 1.3 Related Documents

All content-related ICT-ENSURE deliverables are related to this report and can be found at [www.ict-ensure.eu](http://www.ict-ensure.eu). Of particular interest are the following project deliverables:

- D2.3 Integrated Framework and Model
- D3.5 ERA recommendation report
- D7.2 Conceptual detailing SISE
- D8.2b Final reports
- Focus area surveys (climate, energy, biodiversity and natural resources and integrated report)

## 2 ICT-ENSURE Results

### 2.1 Overview

#### 2.1.1 Project Objectives

The goal of ICT-ENSURE has been to enlarge and strengthen the European network of experts in ICT for environmental sustainability. This network should stimulate the synthesis of a Single Information Space in Europe for the Environment (SISE), brought in by DG INFSO, to better structure the various national and international research programmes and communities.

ICT-ENSURE's operational objectives can be summarised as follows:

- *Network & Communicate*

In order to integrate Europe's leading experts from related communities and to explore research activities in individual countries, four regional workshops and two EnviroInfo conferences were conducted within the ICT-ENSURE project. These workshops addressed different aspects of the ICT-ENSURE project including: ICT and climate change, ICT for environmental risk management, ICT for agriculture and biodiversity, ICT for industrial ecology, ICT for sustainable use of natural resources and working towards SISE.

- *Inform & Support*

To foster the development of the European Research Area in the field of ICT for environmental sustainability, the provision of information on research activities and research results in the form of web based systems (literature database and research programmes information system) in the field of ICT for environmental sustainability was developed by ICT-ENSURE.

- *Survey & Analyse*

Through the involvement of a number of European experts in different fields of ICT for environmental sustainability, the importance and potential of different key areas were analysed with the aim of identifying the current state of research and of determining future research needs. Key areas addressed within the ICT-ENSURE project in relation to ICT use included: Energy consumption and efficiency, climate change, sustainable use of natural resources, biodiversity, agriculture, industrial ecology, quality of life, sustainable urban development, health and environmental risk management.

#### 2.1.2 ICT-ENSURE as a Process

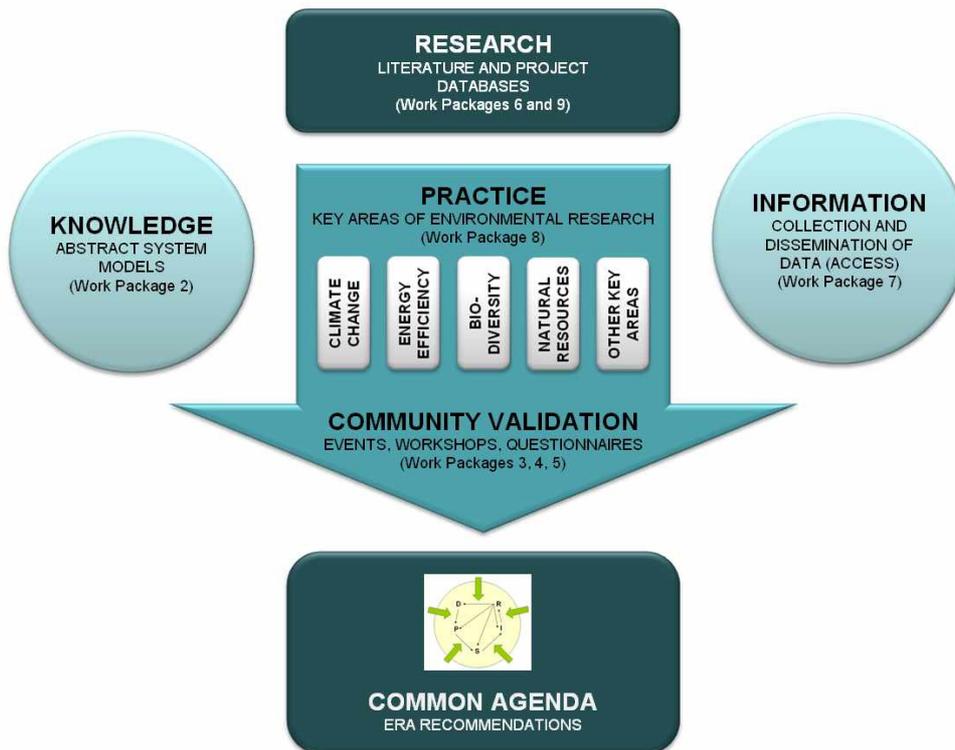
ICT-ENSURE had an articulated structure of Work Packages that addressed the contribution of ICT to environmental sustainability from many aspects, structured according to the networking objectives listed above. These actions can also however be mapped onto a *process* schema whereby the different activities all contributed to improve the coherence and inter-linking of on-going research, building a common research agenda in the context of ERA (European Research Area). When reviewing the future prospects for development of the ICT-ENSURE problem space, such a process of improving the effectiveness of ICT-based environmental sustainability research is the main interest.

Such a schema can be constructed starting from the baseline of the census of on-going **research** projects and programmes and common literature library of work in the field carried out in Work Packages 6 "Literature Database" and 9 "Web-based Research Programmes Information System". From there, the key area surveys reviewed actual **practice** in Work Package 8 "Scientific Survey in Selected Fields". The analyses of the relevance of ICT and the research requirements that emerged developed through an iterative process of **community validation** in Work Packages 3 "Research Network", 4 "Enviroinfo 2008" and 5 "Enviroinfo 2009" including workshops, questionnaires, etc.

In parallel, and to reinforce the understanding developed and its potential application, Work Package 2 “System Model” mapped the abstract structures of **knowledge** in the field, while Work Package 7 “SISE Concept Outline” dealt mainly with the issues of **information** management.

The end result was the definition of a **common agenda** (Deliverable 3.5, *ERA Recommendations Report*) for future research, from both the standpoints of ICT and environmental research that aims to further strengthen the ICT-ENSURE community and contribute to the structuring of ERA.

The work of ICT-ENSURE overall can thus be schematically represented as follows:



## 2.2 Synthesis of results

### 2.2.1 Research

In order to provide an overview of and access to current research and activities in the area of ICT for environmental sustainability a common information basis is a necessity. Work Packages 6 and 9 both contributed to reinforcing the baseline of research available as regards the ICT-ENSURE problem space. Work Package 9, “Web-based Research Programmes Information System”, developed a web-based information system for acquisition, storage and retrieval of the meta-information on research programmes in Europe in the field of ICT for environmental sustainability. The resulting information system, available at <http://is.ict-ensure.eu> allows to search for EU and national research programmes, projects, and organisations and to navigate by ICT fields, sustainability fields, target groups, and focal topics.

Work Package 6, “Literature Database”, developed an online literature database to enable free access to full text paper resources of the ICT for environmental sustainability community, available at <http://lit.ict-ensure.eu>. The database can be searched for articles, chapters and volumes or conference proceedings by specifying author, institution, year, etc. Conference proceedings include EnviroInfo



since 1997, the Towards eEnvironment conference in Prague 2009, and the workshops “AK Umweltdatenbanken” since 2005.

### **2.2.2 Practice**

Taking a step towards applied research and towards the requirements of the related actor groups, Work Package 8 “Scientific Survey in Selected Fields” analysed the importance and potential of different key areas through the involvement of a number of European experts in different fields of ICT for environmental sustainability. This followed the aim of identifying the current state of research and of determining future research needs. In a first round of surveys, key areas addressed within the ICT-ENSURE project in relation to ICT use included: Energy consumption and efficiency, climate change, sustainable use of natural resources, biodiversity, agriculture, industrial ecology, quality of life, sustainable urban development, health and environmental risk management.

A first synthesis document identified common features across these surveys, including a stakeholder analysis to identify common needs and requirements for ICT research. A second round of surveys was then conducted focusing on four key fields – Climate Change, Energy Efficiency, Bio-diversity and Natural Resources – with a common methodological framework. In the identification of research demand, the highest priority emerged for the educational and training tools. Improved accessibility and usability followed, being in the first position for biodiversity, in the second position for energy and climate change, and in the third position for natural resources. Data exchange and networks followed with a second position in biodiversity, a third position in the ranking in energy, and a fourth position in natural resources. In climate change research, instead, this category was given a low priority. E-participation tools ranked in general in a lower position, except for natural resources where they are considered of higher priority. GIS tools were surprisingly given the lowest position in the ranking for all sectors (apart from biodiversity).

The outcomes of these surveys were then incorporated in a second version of the comparative analysis and a questionnaire aiming to prioritise both the user requirements and the ICT research needs. The results of the questionnaire highlight the level of complexity of ICT research needs in environmental sustainability, confirming the importance of interoperability, from an ICT perspective, but also from a social and policy perspective.

Among the main identified limitations the issues of data availability, accessibility, quality and sustainability were again mentioned, together with (open) access to data and technologies. Integration and interoperability issues were more strongly stressed, as were usability and cost issues. It can be noted that in few cases the limitations are purely technological in nature, but that in most cases they strongly concern more social aspects such as communication, participation, motivation and usability.

Areas of future potential were also identified, largely also repeated by the results from the analysis of the research programmes and projects. It seems that the future of ICT for sustainability probably lies in the online, direct use of applications and databases to support more sustainable lifestyles and decision making, so that in general future research should focus on “green” economic solutions for balanced social development with direct advantage for normal citizens and other stakeholders.

### **2.2.3 Community validation**

Three ICT-ENSURE Work Packages aimed to integrate Europe’s leading experts from related communities and to explore research activities in individual countries, through four regional workshops and two EnviroInfo conferences. The workshops (Work Package 3) addressed different aspects of the ICT-ENSURE project including: ICT and climate change, ICT for environmental risk management, ICT for agriculture and biodiversity, ICT for industrial ecology, ICT for sustainable use of natural resources and working towards SISE.

In Work Packages 4 and 5 (EnviroInfo 2008 and 2009), the ICT-ENSURE project contributed extensively to the conference and organised specific workshops “Sharing Environmental Information” for the 2008 edition and five workshops for the 2009 conference: “ICT for Risk Management”, “SISE – Shaping a Single Information Space for the Environment”, “ICT for Climate Change and Climate



Change Adaptation”, “ICT for Natural Resource Management” and “ICT-ENSURE and its Information Dissemination”.

In the organisation of the ICT-ENSURE workshops different approaches were used: the two regional workshops in Paris and Stockholm addressed a smaller number of selected and invited experts while focusing on specific key areas of the ICT-ENSURE project. Through this an extremely active and communicative setting was provided which allowed for intensive discussions and supported networking activities between all participants. The two other regional workshops were conducted in the course of two larger events and focused on the development towards a Single Information Space in Europe for the Environment (SISE). These events benefited from the larger expert community present while providing additional input through the other conference tracks. During the EnviroInfo conference the ICT-ENSURE workshops provided a strong focus point for the conference and fostered connections between different key areas of ICT-ENSURE and the development of a SISE.

All together over 250 experts (plus a larger number of additional participants) from 22 EU member states and 7 non EU states were actively involved in the ICT-ENSURE workshops. The workshop participants included experts from different professional backgrounds, from universities, research institutions, governments, NGOs, international networks and research programmes. National research results and projects were presented, international initiatives were highlighted and future development and cooperation opportunities were discussed.

#### **2.2.4 Knowledge**

In order to create a structural meta-model for the complex setting of ICT for environmental sustainability Work Package 2 “System Model” aimed primarily at:

- Assessing the opportunities and risks of ICT for environmental sustainability regarding among other things the larger socio-economic context (i.e. technical progress, economic growth, and social change)
- Developing a comprehensive framework for the role of ICT in environmental sustainability
- Identifying ICT applications and their interaction with the environment in a system model
- Locating the areas, where ICT can influence environmental sustainability (technologies, sectors, drivers and impacts)

Activities began with a first approach to systematise and evaluate ICT applications on the basis of effects of environmentally relevant ICT applications that are having an essential influence on sustainability including systemic effects of ICT. A Framework and System Model was then developed, dealing with the role of ICT in Environmental Sustainability. With this system approach the attempt is made to describe in more detail the heterogeneous areas of environmental sustainability research under the perspective of ICT application on a meta-level.

This basic conceptual generic model separates the “environment” in a natural and man-made part and emphasises the closed loop control aspects on environmental monitoring for environmental protection with the feedback function of environmental information, for which ICT plays a dominant role to gather, process, store, distribute, and communicate. For demonstrating an exemplary use of the proposed Meta-model for structuring the information space, the areas air, water and industry were agreed on. As a fourth application field “market dynamics”, which had not been foreseen within the contract topics, was considered in addition as an essential pillar for sustainability research.

Oriented on the Meta-model, nine experts/scientists provided their specific perspectives of systemic view approaching the idea of semantic access to relevant information in the selected areas with regard to an IT implementation. As a result of this work it was recommended to include specific submodels under a Meta-model umbrella as an additional component in information services for the purpose of semantic enrichment for an access to a Single Information Space in Europe for the Environment.

### 2.2.5 Information

Public authorities face challenges in managing and disseminating the ever growing quantity of environmental information, an issue which has become even more urgent since the reporting burden has been laid upon the EU member states by European legislation.. To offer guidance in this regard, ICT-ENSURE developed the Work Package 7 “SISE Concept Outline”. With the Communication *Towards a Shared Environmental Information System (SEIS)* the European Commission set out an approach to modernise and simplify the collection, exchange and use of the data and information required for environmental policy. This project in turn relies on the integration of European environmental information into a single information space (SISE).

SEIS with its strong support from the Commission is fostered more by EEA, JRC and Eurostat, guided by DG Environment, whilst the origin of SISE can be identified in DG Information Society and Media, with the objective to improve IT tools and infrastructures. The first step in WP7 was thus to analyse the state of the art in both action lines, SEIS and SISE, to watch their progress and to develop recommendations for further needs in realisation of an environmental segment of a Single European Information Space. This led to a preliminary screening of critical requirements for the “Single Information Space in Europe for the Environment” (SISE).

On this basis, the possible building blocks of an integrated information space in Europe were identified, concentrating on information sources held by or destined to public authorities in the Member States. A reflection on the nature of environmental information and the legislative and regulatory basis for giving access to it, including quality factors and the development of eEnvironment, set the stage for an identification of user needs and target groups in the context of existing and “historic” initiatives and organisations making environmental information available.

A broad specification for SISE was then developed according to the main IT aspects: Interoperability, shared low level protocols, data exchange patterns, cross-domain communication and semantic interoperability, as well as metainformation and multilinguality. Examples of best practice include the German PortalU system, the running FP7 GS Soil programme, and the Environmental Information System Baden Württemberg (EIS-BW).

### 2.2.6 Common Agenda

In order to move from analysing the current state of the art and from network building towards a future agenda in this field, one of the final activities of Work Package 3 “Research Network” was to deliver recommendations for the European Research Area (ERA), in line with one of the main aims of the project itself. Indeed, this work analysed the results generated within the ICT-ENSURE project through scientific surveys (WP8) and networking events (WP3, 4 and 5) in the context of frameworks developed within system model of WP2 and the SISE framework of WP7, to contribute to the structuring of the European Research Area “ICT for environmental sustainability”.

In order to understand the European Research Area “ICT for environmental sustainability” it is necessary to take the different actors and initiatives (including research programmes, projects and actions) into account. Results from the scientific surveys and the networking events within the ICT-ENSURE project show that the importance of inter-disciplinary exchange and communication between different user groups has been repeatedly stressed. The integration of information sources and to facilitate access to and exchange of information between actor groups is one of the main challenges for ICT in the context of environmental sustainability.

Based on the scientific surveys and the networking events of ICT-ENSURE it has become evident that there is a need for following the vision of a new research community that overcomes the distinction of developers of ICT and environmental scientists and serves to integrate the exchange between different actor groups. This can be supported by using ICT in an integrated, multi-disciplinary community by “co-designing” new approaches to integrate the development of new methodologies in environmental sustainability research with new ICT tools and services.

Starting from the user requirements identified within the scientific surveys and the workshops, a structure was developed using the DPSIR (Driving Force, Pressure, Impact, State, Response)

framework to serve as a common basis for cooperation and discussion between actors in a multi-disciplinary context. The process dimension extracted from the DPSIR model identified the role of ICT in terms of the sequential links between each of its five main elements, in order to generate a common research agenda structured according to five areas as follows:

1. *ICT supporting environmentally sustainable human behaviours and economic activities (Driving Forces – Pressure)*
2. *ICT supporting our understanding of the environment and the impacts of human activity on it (Pressure – State)*
3. *ICT supporting our ability to assess the impact of climate and environmental changes on human livelihood (State – Impact)*
4. *ICT supporting the formulation and evaluation of strategies and policies to address environmental challenges (Impact – Response)*
5. *ICT supporting the implementation of strategies and policies for environmental sustainability (Response – Driving Forces)*

### 3 Emergent Issues

Throughout the work of ICT-ENSURE, a pattern of issues has emerged across the different activities that are a function of developments in ICT on the one hand, the increasing complexity and urgency of environmental sustainability on the other, and finally the interaction between these two processes. These trends are likely to drive and shape the whole ICT-ENSURE problem space in the years to come, raising entirely new issues and research requirements.

We can sum them up in seven key points.

1. *ICT and Environmental Sustainability Research is emerging as a research field in its own right.*

The specific interrelationship between ICT and its fields of application can often lead to the development of new paradigms where the two become inextricably intertwined. As an example, e-commerce developed as a fully new form of doing business that was driven by innovative web applications. Environmental research has to date “used” ICT in order to make its activities more efficient and effective, but the signs are appearing that important changes in the way environmental research is carried out will soon become increasingly evident, driven by a range of new approaches based on, for example, sensor networks, data mining, and social networking.

2. *The walls of closed gardens, both disciplinary and among stakeholders, are coming down.*

As was particularly evident in the surveys of key research areas, environmental sustainability research is becoming increasingly inter-disciplinary, often at a far more rapid pace than the organisation of research itself (University departments, research institutes, etc.). New forms of collaboration are being experimented with, often however meeting the resistance of existing structures. A similar dynamic is apparent in stakeholder relations, where the roles of the public and private spheres as well as those of academia, individual citizens etc. are shifting and interacting in new ways.

3. *A mechanistic view still predominates in much of environmental research, with a need to incorporate social and market dynamics into a view of the environment as a complex system.*

The founding disciplines of environmental sustainability research, such as biology, are based on traditional scientific methods of observation, where the observer is “outside” of the system being analysed. This has led to a somewhat mechanical understanding of the dynamics that shape the environment, especially when trying to construct computer-based models to predict trends and impacts. While these models prove of fundamental value in managing the environment and environmental policy, it is becoming increasingly clear that they fall short of capturing the full complexity of the social, economic, cultural and political dynamics that affect sustainability.

4. *The quantity of raw data is increasing exponentially, raising not only technical issues of storage and processing but also setting new requirements for the role of the public sector and for public access to data.*

This trend is evident in all spheres of life but particularly so for data related to the environment, climate, biodiversity etc. with the increase of sensors and multimedia monitoring on the one hand and the production of information in relation to governmental regulations on the other. It is also even more so as the scope of environmental sustainability research continues to expand, to encompass an ever broader range of disciplinary fields. While for many this appears as a problem (so-called information overload), what is emerging at least in other fields is a paradigm shift from an emphasis on processed and “relevant” information towards data mining techniques that extract knowledge in real time from raw data. If anything, this shift leads to new challenges for public administrations and other “producers” of raw data.

5. *New forms of social innovation are emerging through the so-called Web 2.0, Living Labs etc. with a significant potential for environmental sustainability research.*

Social innovation driven by web 2.0 based internet applications is becoming one of the driving forces of research in ICT to promote and steer changes in individual and collective behaviour in the direction of sustainability. As an example, the CIP ICT PSP Save Energy project uses the Living Lab methodology (user-driven co-design of new applications and services) in defining mobile dashboards linked to smart metering networks that allow distance monitoring and control of energy consumption. The most influential component of the architecture, however, is the use of Serious Games to induce positive awareness and attitude changes, leading to a real impact in terms of behaviour shifts and real energy savings.

6. *In the face of an increasing situation of global emergency, there is a startling lack of public action.*

Perhaps the first use of ICT for environmental sustainability research with any real impact was the use of Unix-based CRIMP modelling software for the Club of Rome's *The Limits to Growth* report in 1972, nearly 40 years ago. The situation in the meantime has only gotten worse, and the evidence is clearly in front of us from the shrinking of glaciers to the significant increase in climate change related natural disasters. These trends are well reported in many of the ICT-ENSURE surveys, also as a demonstration of the wide diffusion of information on the environmental emergency. What continues to be ever more startling is the inadequacy of the response to the challenge, both at the level of individual lifestyles and behaviours and at the political level of, inter alia, the failure to reach agreement at the recent Copenhagen summit. For all the extensive research carried out by ICT-ENSURE and the wealth of information available to document the seriousness of the situation, there is no logical explanation for this lack of ability to react.

7. *It is becoming increasingly clear that a disruptive transformational shift is required.*

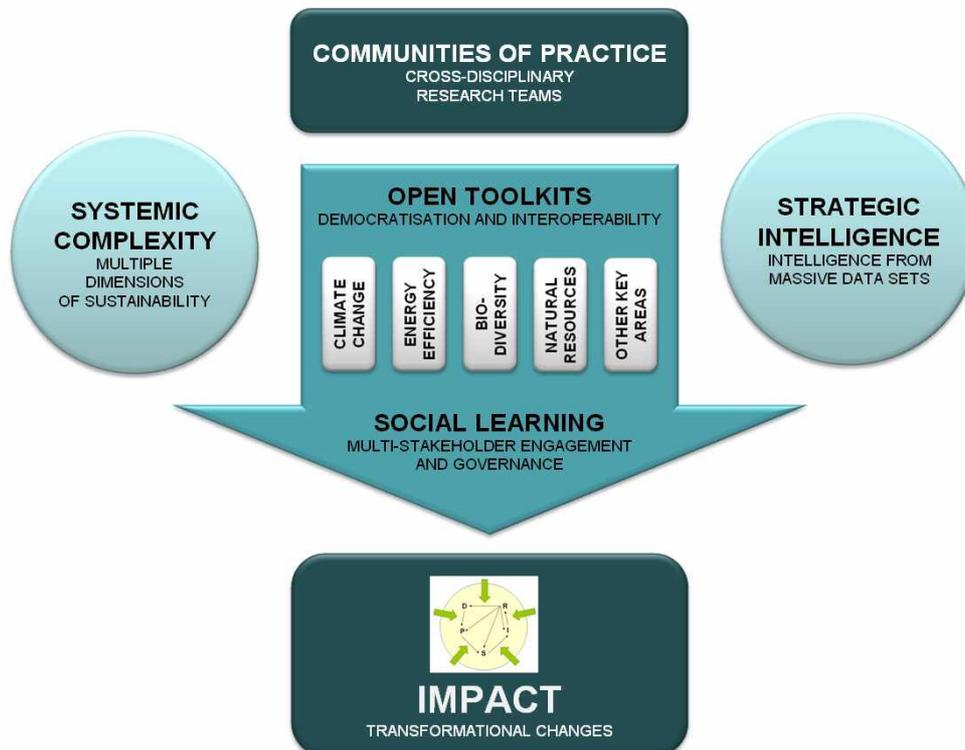
The lack of an adequate response and the worsening situation of the environment mean that incremental responses, including evolutionary changes in lifestyles, manufacturing processes etc. will no longer be sufficient to reverse the current trends. The large part of the analyses identified are based on linear models that fail to highlight where the tipping points are that will lead to permanent structural changes or system collapse. As it is becoming increasingly evident that only radical transformations in the way we live and work can assure the survival of our planet, it is clear that the most important potential for ICT to contribute to environmental research lays in its ability to support such transformational changes.

## 4 Future Directions

ICT-ENSURE has, over its two-year lifespan, carried out a thorough analysis of the state of the art of ICT in relation to environmental sustainability research. Within the framework of the research processes and the needs of the research community that carries it out, clear requirements for future research have been identified. At the same time, the general trends identified in the previous section point to the probability of significant changes in both the way ICT can be relevant to environmental research and the role in society of environmental research itself.

This paradox does not at all imply that the needs and requirements identified in ICT-ENSURE will soon become irrelevant, but that they will unfold in a changing context where the key issue will increasingly become reaching a real impact on societal behaviour. Some might argue that this goes beyond the mandate of environmental research, whose chief role remains understanding the dynamics of the environment and clarifying the options available, but the increasingly social dimension of ICT challenges this stance and blurs the distinction between observation and action.

The process framework developed to describe the main activities carried out in ICT-ENSURE can be re-mapped taking these trends into account, in order to produce a broader roadmap for future activities. In this way, the emphasis shifts from the “what” (the thematic emphasis) to the “how” and “why” or rather the methodological aspect.



These indications are developed individually in the following paragraphs.

## 4.1 Communities of Practice

Interaction with the ICT-ENSURE research community demonstrated both the interest and the will to collaborate across new disciplinary borders and to consolidate the emerging field of research specifically linking ICT to environmental sustainability. The recommendation for a specific ERA “ICT for environmental sustainability” group makes a substantial contribution in this direction, building a community of practice through the further development of key ICT-ENSURE outcomes:

- *Extended EnviroInfo Community*: the long-term, real life platform for exchange between scientific experts to coordinate research in the field of environmental informatics
- *Research Programmes Information System and Literature Information System*: to support structuring of the national and international European research landscape while providing easy access to related information for different actor groups: researcher, stakeholder, networks, policy makers...
- *Social Web Community*: an online platform to facilitate exchange between involved actors. The XING network constitutes a lower access barrier to entering the community especially for the open public and also for actors from the industry.

Taking these aspects into account, ICT-ENSURE paves the way to an ERA that not only clarifies a potential strategic research agenda but also adds insights on the methodological approach towards dealing with convergent, multi-disciplinary challenges. In this context, we can say that ERA has been conceived primarily within a concept of “research efficiency”, with the important goal of coordinating research efforts and reducing overlap of programmes at different levels of governance. But a main challenge that ERA faces today is also one of “research effectiveness”, namely the capacity of capturing the full complexity of emerging research challenges and overcoming the frontiers and disciplinary boundaries that constitute the main barriers.

## 4.2 Open Toolkits

Throughout ICT-ENSURE, it became evident that there is a “heavy” presence of ICT legacy systems. While many of the ICT systems that currently support environmental research are highly sophisticated and in some aspects state of the art, they remain firmly embedded within the specific disciplinary or operational context for which they were conceived. Work in ICT-ENSURE demonstrated that in many cases the research approaches are evolving more rapidly than the ICT systems that support them.

Future work in ICT tools supporting environmental sustainability research will therefore need to be based on more open and flexible approaches, such as:

- Modular toolkit approach based on apps and mash-ups.
- Service oriented architectures based on the cloud computing paradigm.
- Full interoperability based on models such as INSPIRE spatial data infrastructures.
- Shift to open standards and open source platforms.
- Democratisation of specialised functions such as modelling through improved user interfaces

The emerging scenario thus foresees an opening up of ICT systems supporting environmental sustainability and the integration of modular services into a range of platforms. Examples could include services for monitoring the coastal environment build into navigation systems on fishing fleets, or the integration of climate change modelling into widely accessed e-participation platforms.

### 4.3 Social Learning

While ICT-ENSURE continuously encountered the concern for more effective ways to communicate and disseminate environmental information to decision makers as well as the broader public, the approach considered often remains within the “didactic” stance of informing others with “expert” knowledge. This is instead an area where ICT is significantly transforming approaches towards communication landscape, from collective learning platforms to participatory web 2.0 social networks, Living Lab co-design innovation ecosystems, and “serious games” for the viral diffusion of new concepts and shared values.

As the environmental research community embraces these new technologies and their underlying methods, the challenge will be not so much to keep up with the trends but to be able to profoundly re-think research approaches. Placing the user-citizen-consumer at the centre of the research process rather than as the final step of a value chain often implies a thorough revision of methodologies, the roles of the different players, and the means for the legitimisation of “scientific” knowledge.

This transformation has been an uncomfortable one for many industries, research centres and scientific communities alike. On the other hand, the potential benefits are not to be underestimated, especially in the area of environmental sustainability where the social norms that shape lifestyles and workstyles and individual and collective behaviour patterns can play a determining role.

### 4.4 Systemic Complexity

The system models developed in ICT-ENSURE demonstrate that it is possible to map the dynamics governing the environment and environmental systems, at least within the confines of the natural systems themselves and the impacts of human activity on them.

In order to fully understand how the social, economic and other dynamics shape these systems, it is necessary to broaden the scope to include the feedback loops within these “external” dimensions that are generated by interaction with environmental systems. Throughout the ICT-ENSURE surveys, there is a call for greater interoperability between models and modelling systems in different fields, but what is suggested here subsumes and goes significantly further. That this is possible is demonstrated in the final sections of the work of WP7 that map the relation between market dynamics and the environmental systems.

This shift towards a higher level of systemic complexity in framing environmental dynamics introduces a significant new dimension of complexity in the models that capture and describe these dynamics. On the other hand, it is possible that one of the key reasons for the lack of impact of much environmental research lies in the failure to link negative trends with the systemic rather than merely causal aspects of human activity. With the increasing sophistication of ICT complex system modelling tools, this broadening of scope is a reasonable objective with a potentially high impact.

### 4.5 Strategic Intelligence

In nearly all of the key areas investigated in ICT-ENSURE a paradox was encountered: on the one hand, there is an increasing amount of information that is difficult to manage; on the other, it is increasingly difficult to get access to relevant information. It appears that it is not clear if there is too much or too little information.

One trend in ICT that certainly affects this issue is the growth of “strategic intelligence” (once referred to as data mining). This technique shifts the emphasis from information to raw data, and is driven by the emergence of systems that can elicit meaningful patterns from massive quantities of raw data based on statistical recurrences more than an analysis of content. As compared to more traditional models of knowledge management, strategic intelligence approaches thrive on exponential increases of the quantity of data available.

This trend could have important effects on both SEIS and SISE in the near future. A first impact will probably be increased pressure on public authorities to open up their systems to allow access not only to “validated” information but also to raw data (the so-called “InfoLab” model). At a second stage, it would be useful to explore the possibility of replacing certain reporting requirements with direct monitoring.

## 4.6 Impact

The process outcome of the ICT-ENSURE project has mainly been the definition of a common research agenda for the community of disciplines related to ICT for environmental sustainability. To some degree, this corresponds to the starting point of the process map of future directions for ICT-ENSURE with a far broader ambition of reaching sufficient societal impact to make a real change in the prospects for environmental sustainability.

This reflects, and ultimately aims to capitalise on a basic shift of ICTs themselves from a tool for process efficiency and technical innovation to one of social innovation based on process effectiveness. Indeed, societal impact is not a final step in the process but a final result that is built into every step of the process:

- *Communities of practice* broaden their inter-disciplinary scope to link environmental sustainability to socio-economic, cultural and other perspectives.
- *Open toolkits* allow for broadened participation in environmental research activities and for the integration of tools into ICT environments of daily life.
- *Social networking* engages ever broader communities of stakeholders in knowledge-building and decision-making processes related to environmental sustainability.
- *Systemic complexity* is captured in open, dynamic models capable of representing the semantic richness of all dimensions of environmental sustainability.
- *Strategic intelligence* builds on a constantly growing mass of data related to environmental sustainability to provide real-time strategic insights into on-going processes and options for action.

ICT-ENSURE provides the baseline upon which to build this effort. Carrying these results forward into the future opens new possibilities for steering the use of ICT in environmental sustainability research to achieve real societal impact

## 5 Conclusions

The ICT-ENSURE project has carried out a thorough investigation of the current research landscape for ICT for environmental sustainability research in Europe. This exercise has involved extensive networks of researchers in different fields, in iterative validations of the needs and requirements identified for future research. In parallel, more structured activities have sketched the requirements for a general system model and information architecture framing the common research agenda.

In order to define the future steps, we need however to take into account the rapidly changing context that shapes the ICT-ENSURE problem space. On the one hand, the trends of environmental decay and climate change continue unfettered. Policy responses are emerging (i.e. the 20-20-20 strategy and the new Europe 2020 policy on innovation) but it is unclear that they will be sufficient, particularly in the face of a global inability to take action in contexts such as the recent Copenhagen summit. On the other hand, ICT is evolving rapidly through new paradigms that at first sight appear to move exactly in the directions required: de-specialisation of sophisticated tools, ability to deal with massive quantities of data, and social engagement and innovation leading to behavioural changes.

This brief synthesis aims to provide a first glimpse of where to go next, which basically entails linking the emerging opportunities in ICT developments with the urgent needs of environmental sustainability. The process map used to illustrate the different activities of ICT-ENSURE provides a useful framework for future directions, highlighting the role of communities of practice, open toolkits, social networking, complex system models, and strategic intelligence systems. Such a broad roadmap aims to identify the key opportunities for future work that can capitalise fully on the solid baseline of ICT-ENSURE results to achieve effective societal impact in response to the challenge of environmental sustainability.