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Science and Technology – Drivers for a Common Future

Proceedings of the 3rd Indo-German Conference on Research for Sustainability: Water and Waste Management

RESEARCH

Igniting ideas!

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Results and Recommendations

PD Dr. Lothar Mennicken
Federal Ministry of Education and Research, Bonn, Germany

Secretary Dr. Ramasami, from the Indian Department of Science and Technology and Prof. Surendra Prasad, Director of the Indian Institute of Technology (IIT) Delhi, welcomed the German Delegation headed by Dr. Wolf Junker of the German Federal Ministry of Education and Research (BMBF) to the IIT Delhi campus for the 3rd Indo-German Conference on Research for Sustainability: Water and Waste Management. The main topics of the meeting were research and development (R&D) in the field of "Water" and "Waste Management". The conference also provided a platform for discussing the principle of Sustainability Science, presented by both Dr. Wolf Junker and Prof. Dr. Kazuhiko Takeuchi, from the United Nations University.

India's ability to close the ever-increasing gap between water supply and water demand relies upon the future of sustainable technological solutions, a point that was stressed by Secretary Ramasami. Dr. T. Chakrabarti, from the National Environmental Engineering Research Institute (NEERI), focused on the waste management aspect of the conference. He laid forth a vision where in the future large amounts of waste in India will not be dumped without proper controls, as is the current situation. This goal will be achieved through the support of research and being able to apply appropriate technology and services e. g. into new products or energy. Prof. Dr. Karl-Ulrich Rudolph, University of Witten/Herdecke, and Prof. Dr. A.K. Gosain, IIT Delhi, introduced the topic of R&D in the field of

German Federal President, Horst Köhler, and his wife, Mrs. Eva Luise Köhler, meet the participants of the 3rd Indo-German Conference on Research for Sustainability

water research and technologies in India and Germany. Prof. Dr. Martin Kranert, University of Stuttgart, spoke about Waste Management - from End of Pipe to Sustainable Solutions and Dr. T. Chakrabarti, NEERI gave an overview on Research on Waste Management and Technologies in India. A European Union (EU) perspective was also presented by Philippe De Taxis du Poet, Delegation of the EU to India, looking at Water Research in the EU 7th Framework Programme and Opportunities for International S&T Cooperation with India. Moreover, in parallel sessions more specific R&D topics such as water efficiency, water reuse, appropriate solutions and general aspects, organic waste management, and treatment of residual waste and Clean Development Mechanism (CDM) measures were presented and discussed.
The following subtopics on future joint Indian-German R&D activities were recommended by the scientists:

Water:
- **Integrated water resources management (IWRM);**
- **Decentralised systems;**

- **Reuse technologies;**
- **Finance and refinance (tariffs);**
- **Public Private Partnership (PPP) and governance;**
- **Capacity development;**
- **Holistic approach;**
- **From theory to practice.**

Waste Management:
The participants suggested identifying three areas and selecting a demonstration platform.

1. **Biological waste management (e. g. anaerobic digestion, composting);**
2. **Land filling incl. leakage management (bioreactor landfill vs. low organic residues sanitary reactor landfill);**
3. **CDM measures – methodology, inclusion of recycling activities**
   - Intersectoral cooperation;
   - Integration of the informal sector;
   - Technology evaluation toolkit (comparison of appropriate waste management systems);
   - Refuse derived fuel (RDF) production and co-incineration;
   - CO_2 emission reduction.

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Foreword

Dr. Jakob Rhyner
Vice-Rector in Europe of the United Nations University (UNU-ViE)
Director of the Institute for Environment and Human Security (UNU-EHS)

One of the most important pillars for sustainable planning and decision-making is a certain minimal degree of long term or at least medium term predictability. If the boundary conditions relevant to an envisaged solution develop into an unexpected or even new and unknown direction during its life cycle, its sustainability may be at stake. Therefore, in our age of rapid and profound changes – global warming and shortage of fossil energy resources representing just two examples – long term sustainable planning is facing stronger challenges than ever.

The research into future development scenarios and their effects on the pressing global problems of sustainable human security, development, and welfare, belongs to the mission of the United Nations University (UNU). As the academic arm of the United Nations, the UNU achieves its goals through collaborative research, teaching, capacity development, and advisory services. Headquartered in Tokyo, the UNU also has offices in Bonn, Kuala Lumpur, New York, and Paris, and more than a dozen institutes and programmes worldwide.

In pursuit of its objectives, the UNU implements a system-oriented, interdisciplinary, problem-solving strategy that combines theoretical and practical approaches. Indian State Secretary of Science and Technology Dr. T. Ramasami captured the importance of solution-oriented research in his address to the 3rd Indo-German Conference on Research for Sustainability: "Society wants solutions to existing problems and they are not satisfied with an academic community that is solely focused on the discovery processes of science."

The aim of the Dialogue on Science for Sustainability is to identify the drivers of our common future and harness the potential of science and technology through the creation of research, development, and innovation alliances. This is in line with the motto of the UNU-ViE: "Capacity building and knowledge transfer to strengthen science and technology for human security", as well as the work of the UNU in promoting sustainability science. The UNU is proud to be a partner in this endeavour – a partner in bridging the gap between science and policy, academic discovery, and practical solutions.

I am, therefore, very pleased to present the proceedings of the 3rd Indo-German Conference on Research for Sustainability. This publication addresses a broad range of issues related to water and waste management in India and Germany. While investigating solutions to specific problems on the one hand, the publication on the other hand extends the general understanding of how research contributes to social, environmental, economic, and institutional sustainability. I am convinced that it represents a very valuable contribution to the discussion of the problem of sustainable planning in view of uncertain future development.

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Introducing Germany and India – Drivers for a Sustainable Future

Dr. Volkmar Dietz,
Federal Ministry of Education and Research, Bonn, Germany

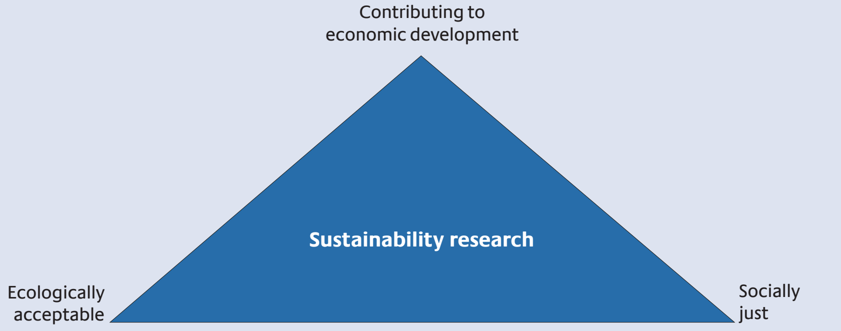
Sustainable development is one of the guiding principles of the policies in both India and Germany. The UN climate conferences in Copenhagen and Cancún revealed how difficult it is to come to multilateral specific and binding agreements to protect the future of our planet. Preparations for a renewed political commitment envisaging the Rio+20 United Nations Conference on Sustainable Development (UNCSD) have already started. In this context, questions also concerning the limits of current economic models and related dynamics in achieving sustainable development and poverty eradication arose. The concept of a "Green Economy" as response to the apparent need for more innovative models on a global level is already included in the recent UNEP report on Green Economy and will be directly addressed at UNCSD.

Nevertheless the Federal Government of Germany is strongly committed to taking on global responsibility and to continue working for the realisation of the principle of sustainable development. In 2007 at the G8+5 Summit in Heiligendamm, a decision was made to establish a dialogue with emerging economies (O5) and develop an internationally coordinated research agenda focussing on central issues such as innovation, energy and resource efficiency and climate protection.

What is the Meaning of Science for Sustainability?

In general you can say:

Triad of sustainability research: Sustainability research addresses three aspects



For the German Federal Ministry of Education and Research (BMBF), sustainability means ensuring equity between generations, quality of life, social cohesion and international responsibility. Present and future challenges are so ambitious that they can only be mastered with new technologies and findings and with new concepts for decision-making.

It seems well accepted that science and technology in general play a crucial role in meeting the pressing challenges of sustainable development. But research into sustainability has not yet captured the attention of all politicians and public. And it is also true that sustainability research is not yet fully accepted by mainstream science. Prof. Takeuchi, a Vice-Rector of the United Nations University, shares his view on "Sustainability Science as a New Academic Discipline" in his remarks on page 21.

In Germany, we have tried to work on this for a number of years. Initially the environmental research supported by the BMBF developed methods and techniques for recording and reducing pollution. The objective of the technologically oriented strategy was to provide further state-of-the-art development of environmental protection technology. The Ministry´s research funding was focused on end-of-pipe technology.

In 2004, BMBF reorganised its structure and launched the framework programme “Research for Sustainability” (FONA I). It was a paradigm shift from knowledge-orientated to interdisciplinary, solution-orientated research. Up to € 800 m were invested from 2004 to 2009, implementing more than 25 calls for proposals on R&D projects.

In February 2010, Federal Minister Prof. Annette Schavan launched the second major framework programme entitled “Research for Sustainable Development” (FONA II). This framework programme lays out the strategic goals and ways how to achieve sustainability for us and our children. Until 2015 the German government will allocate more than € 2 billion of funding for R&D under this framework programme. International cooperation is an important component. The first call for proposals for joint R&D projects entitled “International Partnerships for Sustainable Technologies and Services for Climate Protection and the Environment (CLIENT)” under this framework programme, addressing collaboration with partners in Brazil, Russia, India, China, South Africa and Vietnam, was launched in June 2010.

Dialogue on Science for Sustainability (D4S)

Internationally coordinated research agendas are a must when it comes to finding sustainable solutions to the global challenges of our time. For this reason, the BMBF has launched a series of policy dialogues on Science for Sustainability with India and other key emerging economies, namely South Africa, Brazil, China, Russia. Bilateral events are being held under the slogan “Sustainable Solutions – Science for Sustainability”. The objective is

- **to establish the foundations for long-term, strategic partnerships in sustainability research,**
- **to increase bilateral cooperation in sustainability related research,**

- **to develop projects for the dissemination of already existing results.**

A significant milestone of the Indo-German Dialogue on Science for Sustainability has been the signature of a Joint Declaration by the former Indian Minister for Science and Technology, Shri Kapil Sibal, and the German Minister of Education and Research, Annette Schavan in New Delhi in September 2008.

At that time, the bilateral dialogue started with the 1st Indo-German Conference on Research for Sustainability.

"Land use" and "energy" were the topics of the 2nd German-Indian Conference which took place in Bonn, in April 2009. More than 70 Indian and German stakeholders from government, public and private institutions discussed central questions of these fields. The proceedings of that conference have been published in the meantime, contributing both to a wide dissemination of the results of the conference and to building an Indo-German Sustainability Science network.

The 3rd Indo-German Conference was held at IIT Delhi in February 2010, back-to-back with the 10th Delhi Sustainable Development Summit, which some of the German Delegates also attended.

The focus of this third conference was on water and waste management – two areas which are very important for sustainable development.

Water scarcity and pollution are becoming global problems and thus need to be addressed globally, as is already being done by the United Nations e. g. in the "Water for Life Decade 2005 – 2015". The European Union is also willing to make water research a priority subject in the future R&D cooperation with India. The EU's engagement in this area is presented by Mr. Philippe De Taxis du Poet, Delegation member of the European Union to India.

How to get rid of waste is a question of the past in Germany. Nowadays the question is: how to minimise or avoid waste, how to recycle or even use waste as a valuable source of energy. Some ideas in this regard are shared in these proceedings. A common interest in the topic as well as the consequent prioritisation of research and development in both countries, offers common ground for joint sustainable solutions.

India and Germany – by joining expertise in Science and Technology – can make a substantial contribution towards sustainable solutions and by that will jointly become drivers for a sustainable future.

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Chief Guest's Address

Dr. Thirumalachari Ramasami
Secretary to the Government of India, India

Introduction

Science & Sustainability has emerged as an important theme under bilateral Science and Technology Cooperation between Germany and India, the joint declaration signed in September 2008 between the two countries enunciated clearly the interest of both countries to work together on Science & Sustainability.

The 3rd Indo-German Conference on Research for Sustainability covering the theme of "Water" and "Waste Management" is one of the direct follow-

Dr. Thirumalachari Ramasami, Secretary to the Government of India at his address

up actions under the joint declaration signed in September 2010.
The intents of the workshop on Water and Waste Management are to

- **define common objectives,**
- **build networks and**
- **co-generate values to both countries on issues like water and waste management.**

The aim of the workshop is to share experiences and mount joint initiatives under public private partnerships for delivering technology-led solutions to socially relevant problems through mega projects.

India enjoys strength in basic research and Germany is the global leader in development and deployment of cutting edge technologies in the area of environment. Partnership between India and Germany in the area of Science for Sustainability offers opportunity to develop quality innovations at cost affordable to large section of the global society.

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Chairman's Note

Prof. Surendra Prasad
Director, Indian Institute of Technology Delhi, India

First of all, let me welcome you all to the third dialogue on research for sustainability in Delhi. As a host of this conference, it is my privilege to share some thoughts with our distinguished guests about IIT Delhi itself. The Indian Institute of Technology in Delhi was established in 1961 as a center for higher training, research and development in science, engineering and technology. Later the Institute was declared an Institution of National Importance and was renamed "Indian Institute of Technology Delhi" and was furthermore awarded the status of a university with powers to decide its own academic policy, to conduct its own examinations and to award its own degrees.

The three pillars on which IIT stands, represent at the same time, at least in some sense, the core strengths of the Institute itself. First and foremost, IIT Delhi stands for free thinking. We aspire to be known as a place where exploration of truth and knowledge is pursued honestly; where young people can be free from the legacies of their past or the prejudices, in which they might have been born or raised; a place where young people can be free to explore and express their thoughts and shape their minds even as they influence the minds of others.

We sincerely strive to be a place where our students feel inspired and develop a healthy approach towards life and profession that seeks dignity and honor for human life. We genuinely share the universal dream of

Prof. Surendra Prasad, Director of IIT Delhi, gives the Chairman's note

all great research universities in the world, to be known as a place where science, technology, humanities and management are pursued with an objective to bring a long-lasting benefit to the society and mankind. In the words of the poet Rabindranath Tagore, we want to strive to be a place where the mind becomes free, in the true sense of freedom.

Second, IIT Delhi stands for scholarship and learning. Needless to say that our faculty is selected and rewarded for these virtues, and our students, who are amongst the best that any institution can wish for, make it easy for us to pursue these goals.

Third, IIT Delhi stands for a value system, which recognises the important challenges which our planet and society face today: the challenges of energy security, environment, and climate change and in our part of the world, the challenges of inequity, poverty, lack of access to basic amenities and quality education.

These challenges that have surfaced deserve to be solved fairly through equal access to new technological advances and treated with human compassion. We also feel convinced that the answer to many of these problems lies not in less, but more technology, and more scientific and value-based management of human affairs. This should make it possible for mankind to create a world with sustainable development rather than a world, which has to face the consequences of an unsustainable and chaotic growth which we have seen for the last few decades.

Embedded in this context, we especially welcome this conference. The issues of water and waste management are burning issues, not only for our country, but for the entire world today. Therefore both of these subjects should meet the attention of engineers and scientists in this century and beyond, to find sustainable engineering solutions.

It is our desire to contribute, in our own small way, to the issues of sustainability in a holistic manner. So we hope that the conference will lead to a genuine exchange of ideas, for joint research and action plans in research.

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Sustainability Science: Building a New Academic Discipline

Prof. Kazuhiko Takeuchi
Vice-Rector, United Nations University (UNU)
Director, UNU Institute for Sustainability and Peace (UNU-ISP)
Deputy Executive Director, Integrated Research System for Sustainability Science (IR3S), University of Tokyo, Japan

The world is full of complexities that cannot be looked at through a single lens, but rather must be observed from various angles to fully understand their meaning. Take the simple raindrop. It is comprised of hydrogen and oxygen molecules bonded together to form a single piece of rain. When enough evaporated water has been collected within the atmosphere, the raindrop will be forged and fall from the sky. This humble drop of rain has been a part of the earth's water cycle since its inception. Used and reused by humans, animals, and plants, whereby it continuously becomes polluted and uncontaminated over and over again.

Scientists from several disciplines; chemists, physicists, meteorologists, biologists, botanists, and engineers, just to name a few, are all affected by the actions that this single raindrop experiences throughout its cycle. Let us also not forget that business, politicians, and of course every person on earth who needs this essential resource for survival; are also affected. In this light, does it not make sense that we need to create a system of openly shared ideas to deal with the complexities that surround us on earth?

Just like our raindrop, we have to look at the problem of human and environmental sustainability holistically. However, often in the scientific

Prof. Takeuchi (UNU-ISP) presents on “Sustainability Science as an Emerging Academic Discipline”

community there is a tendency for different disciplines to not freely share their research with other fields of study in the academic community. This problem is not done out of malice, but rather a sentiment that only one’s peers can fully utilise such information. These notions of research exclusivity are not only restricted to academia, but are also often demonstrated by business and governments.

That is why there is such a great need to bring together all of these different sectors and disciplines in an effort to work as a whole so that we can combat the problems facing not only our future, but the future of humankind. We must bridge the gaps between the various academic disciplines to deal with problems such as climate change, maintaining biodiversity, building a green economy, dealing with water scarcity, and so many more. Furthermore, we must combine the great minds of the world who are working on solutions today to help us deal with these difficult challenges.

All of us here today at the 3rd Indo-German Conference on Research for Sustainability have been brought together by this little raindrop metaphorically and literally speaking. Many great minds working in the fields of waste and wastewater management, and water efficiency from different disciplines in India and Germany are here today in order to share their knowledge that will help facilitate creating new sustainable solutions for us all. These particular fields of research are not only connected to each other via water, but also can be connected to other fields of study such as biodiversity and CO_2 reduction. We must keep this in mind when we forge networks here at this conference. Always remembering that fostering these relationships in the future means not only enhancing our personal research, but also the betterment of all individuals working at different universities and in different fields under the common umbrella of Sustainability Science.

That is precisely the reason why we are engaged in creating a university alliance on sustainability science, the pilot project currently underway in Japan. Personally, I have been honoured with being placed in charge of developing the sustainability science initiative at the University of Tokyo. The university alliance on sustainability science is working to foster research partnerships between universities and research institutions that will lead to joint projects as well as education programs. Currently, given that the main thrust of the initiative is coming from the University of Tokyo, our programs are focused on Asian sustainability matters. However, universities in the United States and Europe have expressed great interest in becoming involved with the university alliance.

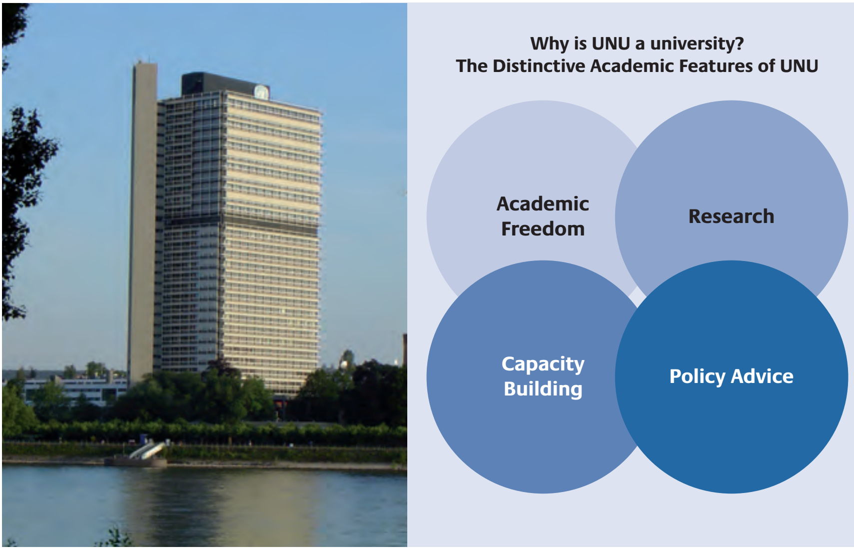
There are also projects underway through different United Nations University (UNU) institutions that are also working hard to facilitate the exchange of ideas in the field of Sustainability Science. For example at the Institute for Sustainability and Peace (UNU-ISP), a new UNU institute established in January 2009 at the UNU headquarters in Tokyo, the section which focuses on Global Change and Sustainability, has designed a program known as University Network for Climate and Ecosystems Change Research (UN-CECAR) to bring together universities, particularly in Asia to develop joint education and research materials for postgraduate programmes. This university network is focused on building local capacity, customising global knowledge to local conditions, creating a platform for communication and improving multidisciplinary approaches for problem solving facilitating greater resource sharing, and building upon institutional strengths for the collective benefit to meet the urgent needs for adaptation. A wonderful example of the UN-CECAR's work has been the organisation's efforts to have several universities, such as Vietnam National University in Hanoi, Gadjah Mada University in Indonesia, Chulalongkorn University in Thailand, National University of Malaysia, TERI University in India, etc., give input on the creation of a joint curriculum and textbook for students.

Additionally, having very recently taken a position with the United Nations University as a Vice Rector, working at the headquarters, I am now trying to combine the work I have been doing in the field of sustainability science at the University of Tokyo with the UNU in order to create a more effective institutional arrangement for the development of this science.

Thirty-five years ago, when the UNU was established, at the General Assembly, there was a big discussion as whether or not the General Assembly would allow the UNU to establish a graduate program. At the time it was felt that the United Nations should not provide academic degrees. However, as of last year the Secretary-General has granted us an amendment to our charter, which has allowed us to establish graduate programs.

We at the UNU are very excited about this new development and are looking forward to establishing collaborative programs with local universities in our regions. For example, the UNU Institute for Environment and Human Security (UNU-EHS) in Bonn is currently working on developing a graduate program with the University of Bonn.

Moreover wanting to personally make an impact on the process of facilitating the defragmentation of information between the different disciplines, I established a new journal, Sustainability Science. This journal is published by Springer, an organisation that is making efforts to connect scientific and professional communities through fostering communication.



Established in 2007 as the first UNU Vice Rectorate outside Tokyo, the United Nations University Vice Rectorate in Europe (UNU-ViE) is dedicated to developing knowledge-based sustainable solutions to global problems

The Sustainability Science journal can be easily accessed through the Springer website under the Environmental Management section. Many of the articles are downloadable. We are strongly encouraging those individuals and groups that are working on sustainability issues to submit papers to this journal in the future so that we can all share the knowledge.

All of this information and all of these efforts to bring people together can be best described as a new way of thinking: called Knowledge Innovation. An example of this integration of Knowledge Innovation can be demonstrated through how research being done in Japan on how to reduce CO_2 emissions can have an impact on Germany and India. There are essentially two solutions that the Japanese researchers have come up with for becoming a more low carbon society; either becoming more reliant on nuclear energy (technology priority) or utilising more biomass in energy production (nature harmonious). The later being the main approach that Germany and India are striving for.

Global sustainability is our ultimate goal. This is the idea of sustainable society. In order to achieve this, we need to consider technological innovation and also the social reform. Knowledge management and innovation helps us to create inter-linkages between these fragmented sciences.

Additionally, I have proposed this concept of a sustainable society to the Japanese government, and the government approved my idea. This is now the basic framework of understanding a sustainable society. The sustainable society is subdivided into overarching categories: one is low-carbon society- this is related to climate change; resource-circulating society- this is related to material circulation, waste issues, and the third component is nature-harmonious society- related to biodiversity and ecosystem services. Under this framework all matters dealing with sustainability could be addressed. So, if we are to look at the issues that concern us here today at the 3rd Indo-German Conference on Research for Sustainability, we would be dealing directly with the second subdivide; resource-circulating society, as it applies to waste management and water sustainability. However, as all things are interconnected, we too can apply our research to the societal images of the low-carbon society and the nature-harmonious society. For example, as we strive to develop new innovative solutions that allow us to fully reuse wastewater, we should not create new technology that emits high CO_2 levels. It is my greatest hope that when we return to our home institutions, may it be Germany, India, or elsewhere, that we continue to strive to maintain the networks we have formed here. I feel that we are up to dealing with these challenges as long as we all keep in mind that everything in the world is more than just the sum of its parts.

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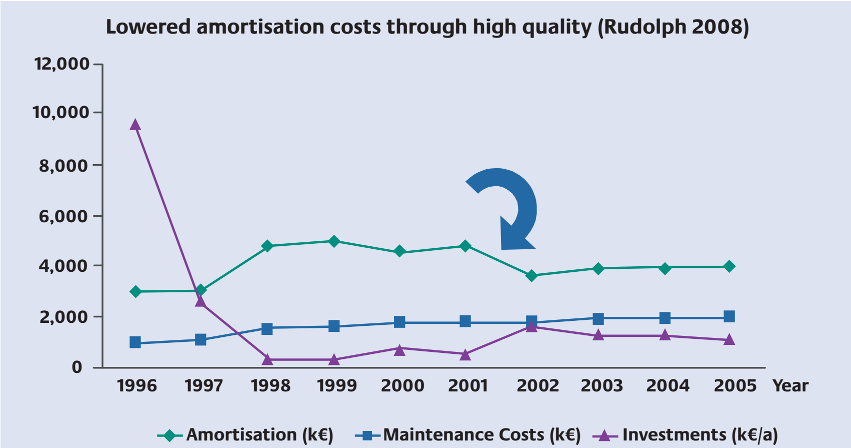
Research on Water Management Technologies in Germany

Prof. Dr.-Ing. Dr.rer.pol. Karl-Ulrich Rudolph
Institute of Environmental Engineering and Management at the University of Witten/Herdecke, Germany

Until the German reunification in 1989, the former German Democratic Republic was in a poor state regarding wastewater and solid waste management. A modern and sustainable environmental infrastructure had to be developed in a short time period, in compliance with German and European standards. Unique experiences and know-how had been generated during that time period. Important lessons had been learnt in technologies and management. These lessons could be well utilised by other emerging countries trying to achieve rapid progress in water and sanitation.

One important lesson has been that cheap quality in water and sanitation causes surplus capital and operational costs, as well as poor levels of facilities performance. In contrast, appropriate quality in process technologies as well as in machinery and constructions, may lower amortisation costs, in the long run - as experienced and verified in the case of the joint research and development demonstration project “Industrial Wastewater Plant, Bitterfeld” with 580,000 population equivalents in capacity on demand (see Figure, p.28).



BMBF-Funded Water Technology and Management Research, Status 2009

The German Federal Ministry of Education and Research (BMBF) is currently funding and active in the following fields of water and sanitation, technologies and management:

- **Decentralised (alternative) water systems;**
- **Adaptation of technologies (climate, education, culture) for drinking water supply and sewage treatment;**
- **Integrated water resources management (IWRM);**
- **Retention and degradation processes to reduce contamination in groundwater and soil;**
- **Permeable reactive barriers for groundwater remediation;**
- **Prognosis regarding the entry of noxious substances in groundwater.**

Opportunities for Indo-German cooperation might be best focused on the areas of water reuse, e. g. sewer harvesting (www.uni-wh-utm.de/html/de/

forschung/vae.html), as well as in lean cost and near-to-nature technologies such as advanced pond systems (www.uni-wh-utm.de/html/de/forschung/abwasserteiche.html), also in integrated water resources management (http://www.uni-wh-utm.de/html/de/forschung/iwrm.html), which is a topic requiring a holistic, multidisciplinary approach in research and application.

Other "Hot Topics" in Future Water Research

Other "hot topics", which will likely dominate future water research sponsored by BMBF, industries and other actors include the following:

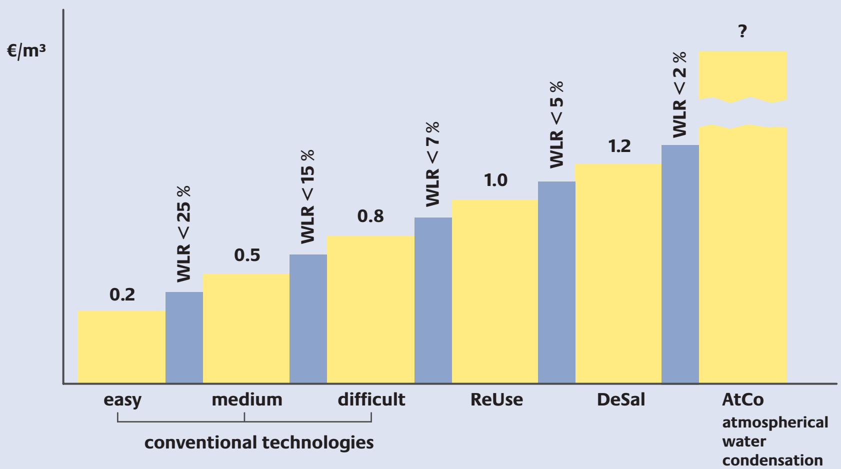
- **Water Efficiency (focusing on specific issues such as: Reuse, Non-Revenue Water, Demand Management in urban and rural areas, for industries, settlements, agriculture);**
- **Utility Management, Economics and Finance;**
- **New Disinfection Strategies and Technologies;**
- **Planning Uncertainties, Stage-by-Stage Concepts and Modular Process Technologies;**
- **Climate Change, Adaption of Water Systems, Mitigation, Resilience;**
- **Energy Efficiency (Clean Development Mechanism, Biogas, etc.), Valuables Recovery, Sludge Management;**
- **Infrastructural Vulnerabilities;**
- **ICT, Remote Control Satellite based GIS Automation.**

The figure (p. 30) visualises the cost hierarchy of water production and explains in which situations advanced solutions regarding water efficiency as well as water treatment technologies are appropriate- especially in water distribution and addressing water loss reduction:

- **As long as water production is easy and cheap (i. e. clean water abstraction from mountain springs), there is no need to reduce water losses below approximately 25 % and no need for efficient management or technological efforts;**

- Once water production becomes more difficult, such as purification of contaminated surface waters, the economic conditions might make it feasible to reduce water loss reductions down to approximately 7 %;
- In cases when water production is even more costly or water is scarce, it might become necessary to enforce water reuse with so-called recycling technologies;
- In regions where the desalination of sea water (DeSal) is the only option left, after attempting less costly options as previously mentioned, the water losses should be below 2 % (as in many regions in Germany);
- Perhaps in the future, when the atmospheric water condensation (AtCo), i. e. "air water milking" will be applied, even more has to be done to maintain water efficiency with water re-use and water loss reduction.

The cost hierarchy of water production (Rudolph 2009: 11)



Preferred Structure of International Cooperation

German funding in water research and other fields with international partners, often follows the so-called "2+2-Scheme" – which means that two twinning partners from academic institutions (universities, research institutes) should collaborate jointly with two twinning partners from the water industry, two per sector per country. This scheme is visualised in the figure.

The author is convinced that the Indo-German cooperation will find many fields of interest for both sides as well as third parties, all together promoting water services for the advantage of human health and environmental quality worldwide.

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Research on Water Management Technologies in India

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Integrated water resource management planning is a comprehensive planning process, involving all stakeholders within the drainage system, who together as a group, cooperatively work towards identifying the water resource issues and concerns, as well as developing and implementing plans with solutions that are environmentally, socially and economically sustainable at various levels of connectivity of the drainage system.

It is important to understand that integrated water resource management should not merely imply the maintenance of an inventory of different activities to be undertaken within a hydrological unit. It also requires the collation of relevant information needed to evaluate the cause and effect of all the proposed actions within the drainage basin. The watershed is the smallest unit where the evaluation of man–induced impacts upon natural resources becomes possible. Therefore, although the Panchayat (cluster of villages) remains the preferred implementation unit, the watershed should be the evaluation unit used in assessing impacts.

Since a watershed is considered the smallest unit of a drainage basin, a hydrological framework that can keep track of the inter-connection of these units is essential. The impact resulting from action taken at the watershed level will be experienced at a higher level within the drainage basin, and the assessment of these impacts will require the availability of the framework.

Such a framework will require regular maintenance and updating to reflect fully the most accurate ground truth data and the infrastructure requirements for planning and management of the relevant planning departments. Such a framework, once available, could be used by all the line departments and updated by the relevant departments which have designated jurisdiction over the data entry.

The development of a Hydrologic Information System component is a logical response to meet the specific information technological needs of the various line departments. A hydrologic information system consists of a hydrologic information database coupled with tools for acquiring data to fill the database and tools for analysing, visualising and modelling the data contained within it.

This Geographic Information System (GIS) portal (http://gisserver.civil.iitd.ac.in/his), for the general user, provides Web Mapping Application for accessing Hydrological Information and web-based Interface applications based on the Soil and Water Assessment Tool (SWAT) hydrological modelling.

Requirements of Hydrologic Data Model

A hydrologic information database must be carefully designed. All tools developed for data acquisition, analysis and visualisation depend on the way the data is structured in the database. Special interfaces to the database are needed for each information source and analysis task that defines how data is inputted or acquired from the database.

A hydrologic data model is required to be able to meet the following generic needs:

- **Represent hydrologic information in each phase of the hydrologic cycle (atmospheric water, soil water, surface water, ground water).**
- **Be capable of tracking the movement of water and the transport of constituents across interfaces between phases of the**

hydrologic cycle, and accounting for the storage of water and transported constituents in each phase (McKay, 1991: 257).

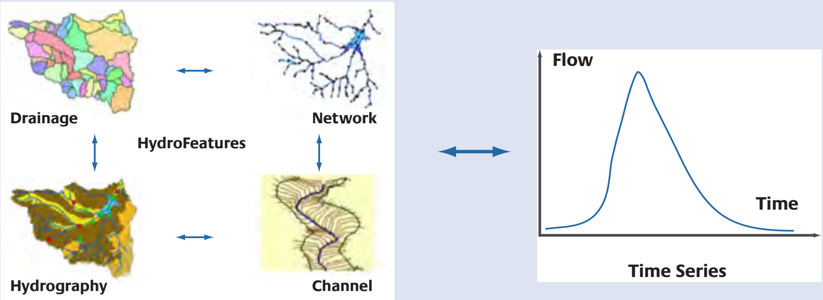
- **Allow for describing the horizontal flow of water through elements of the landscape, such as watershed to stream, to river or lake, to estuary, to bay, and finally to the ocean; (Abbott and Minns, 1998: 557) (Naiman and Bilby, 1998: 705).**
- **Be capable of integrating geospatial and temporal information.**
- **Be able to deal with both continuous and discrete spatial representations of data and of the transformations of data from one spatial framework to another.**
- **Be able to link data from different spatial scales, such as detailed descriptions of channel morphology on small stream reaches referenced to their correct location within the stream network of the basin (Gupta et al., 1986: 246) (Quattrochi and Goodchild,1997).**
- **Be able to deal with data of any desired time scale and manipulations to transform data from one time interval to another (e. g. accumulation of daily data to monthly data, monthly data to annual data, etc.).**
- **Have a metadata component so that the lineage of how the data was produced can be traced.**

In particular, it is necessary that the data model design is not only concerned with file formats data conversion and the like, but also with the provision as to how this data is going to fit within analysis framework. In other words, a conceptual framework is needed that connects the data describing the hydrologic environment to the physical laws that govern how water moves (Gray et al., 1993: 232). This is a challenging task, but a critical one since it forms the foundation for advancements in hydrologic knowledge built using hydrologic information infrastructure.

Arc Hydro: A Specific Hydrologic Data Model

The Arc Hydro data model developed at the University of Texas, USA, enables a watershed to be described in a single Geodatabase which can be used by

Arc hydro data model components (adapted from Maidment et. al., 2002)



GIS based hydrologic and hydraulic model to simulate watersheds. A data model is different from a simulation model since it provides a standardised framework for storing data which simulation models can both pull from and write to. Arc Hydro, provides a means for linking simulation models through a common data storage system. Thus, a schema that reflects temporal and geospatial hydrologic data is created to support surface water hydrology and hydrography modelling at any scale. Its benefits can be better seen on complex projects where an overwhelming amount of data may lower the efficiency and possibly jeopardise the results of a model simulation. Arc Hydro is a good hydrologic information system for retrieving and analysing hydrologic data (Maidment et. al., 2002: 203).

The Arc Hydro data model divides water resources data into five components:

- **Network – connected sets of points and lines showing pathways of water flow;**
- **Drainage – drainage areas and stream lines defined from surface topography;**
- **Channel – A 3-D line representation of the shape of river and stream channels;**

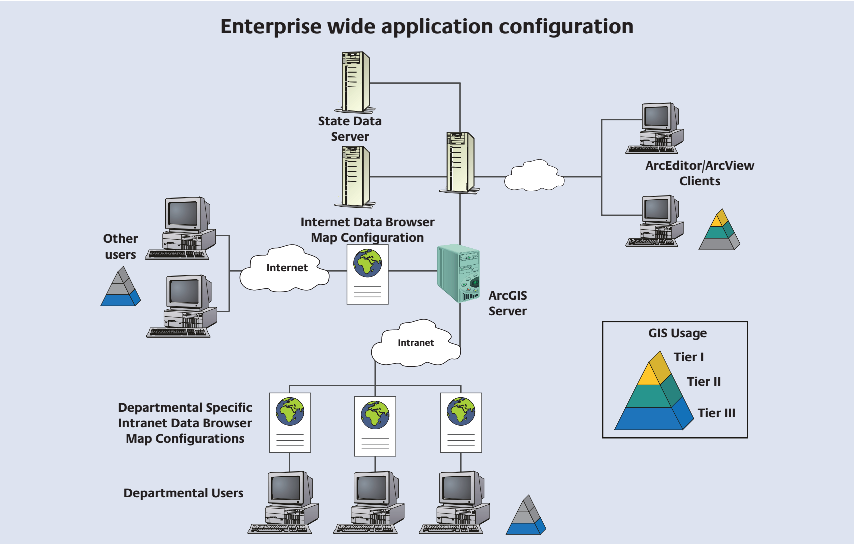
- **Hydrography – the base data from topographic maps and tabular data inventories;**
- **Time series – Tabular attributes data describing time varying water properties for any hydro feature.**

GIS Server

It is a real challenge to minimise redundancy while ensuring that the right data is accessible in a timely and efficient manner. With hundreds of remote offices and thousands of internal and external GIS users at different levels of expertise and needs, it is important to overcome multiple barriers while designing enterprise GIS. The following are some of the essential attributes desired of such databases:

- **Facilitate interdepartmental coordination through data sharing;**
- **Ensure that data is collected and maintained in a standardised format that allows interdepartmental overlays;**
- **Ensure that only the most recent GIS data is accessible to the users. Users should not be misled by multiple versions of the same data that is maintained by different branch offices;**
- **Ensure an acceptable level of computing performance in terms of speed, accessibility, and reliability;**
- **Provide sensitive data to authorised users with appropriate protection to the sensitive elements while serving the portions of the same dataset that have no restrictions to general users.**

One solution is to implement a server-based GIS that could cope with all the above desired attributes. The aggregation of information should be done at a central place by placing a GIS server and database server for the purpose. Server-based GIS can be defined as centrally hosted GIS computing. Internal GIS capabilities are shared with users in the department network while a Web-based platform is also maintained for external users. GIS users are connected to the central GIS servers using desktop GIS software, Web browsers, and custom applications as depicted in the next figure (p. 37).



Data Storage, Sharing and Protection

In the present study it is proposed to store the GIS data in a geodatabase using ArcSDE and Microsoft SQL server. ArcSDE can be phased in as a spatial data access server that allows administering spatial data stored in a relational database management system (DBMS) and shall provide access to data required for client applications. Because spatial data is stored as tables in a DBMS, the strengths of a DBMS (data storage, data integrity, and data security) can also be applied to the spatial data. By transferring almost all GIS data into the ArcSDE geodatabase, a centralised resource for geospatial data is created that can be accessed through the intranet and internet by various GIS applications and functionalities designed to serve its many GIS users.

Different line departments are responsible for managing different elements of data. Data Transformation Services (DTS) and the built-in import functionality of SQL Server could be used with ArcSDE geodatabase.

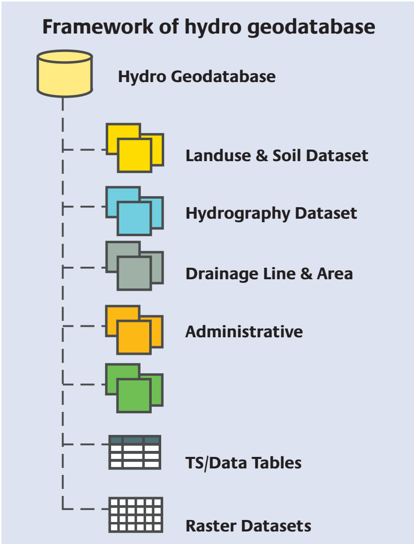
This ability to create spatial views in ArcSDE geodatabase and control user rights through SQL Server has made it easier to deal with data protection. Several spatial views are created with information that is appropriate for general users while the original layers that contain sensitive information are password protected and accessible only to higher-level users with appropriate rights.

Distributing Data and GIS Functionality

Historically, most typical data requests for geospatial and tabular data are provided through manual processes such as phone calls or on-site visits. Traditionally, these requests would be handled by office personnel. This would require intermediate steps, discussions, and often multiple revisions before the final product was created. The advent and subsequent rise in Internet use opened new avenues for data requests as well as a whole new group of data requestors. Now, with the help of built-in functionalities and customised ArcGIS Server applications that use .NET technology and Active Server Pages (ASP), it is easier to build enterprising GIS applications that can be centrally managed and accessed via Web-based interfaces, custom applications, or traditional desktop GIS. Built on ArcObjects, an ArcGIS server can provide all the strength of advanced GIS functionalities in a distributed multiuser setting. A user can generate customised maps and tables in real time. The data delivery mechanism is streamlined, user friendly, and cost-effective (Mehdi et. al., 2009).

Major Elements of the Framework

The common framework for water resources planning and management requires the creation of base layers at different scales so as to cater to the relevant problems at the respective scales. However, it is imperative that all these scales should merge through the GIS environment for aggregation and integration to be possible. It is intended to provide this framework at the State level and with implementation at various departments connected with water resources. Major elements of the framework are shown in the next figure.



Arc Hydro data model could only meet some of the basic information needs. Therefore the Geodatabase was extended to capture information related to administrative area, land use, soil feature class and non spatial data related to socio-economic aspects.

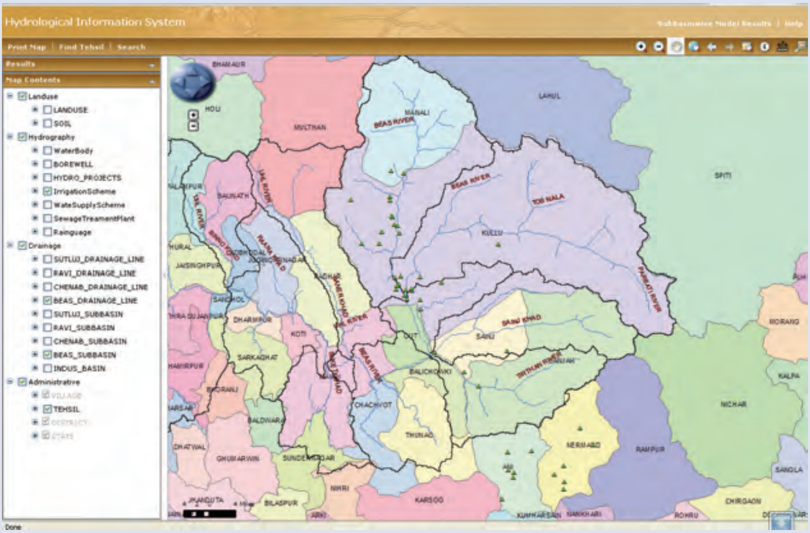
Web Interface for Water Resources Applications

In the present review, the Hydro model has been implemented on Himachal Pradesh state as a case study. The principal departments that are responsible for water resources development in Himachal Pradesh for various purposes are the Irrigation and Public Health Department (IPH), Agriculture Department, Rural Development Department (RD), Forest Department (FD).

A wide range of applications relevant for the planning and management of water resources is demonstrated using this framework built at the macro level as well as some patches developed at the larger scales. This web portal can be accessed by the request of the URL http://gisserver.civil.iitd.ac.in/his.

As part of the demonstration, information from the Irrigation and Public Health (IPH) Department pertaining to their activities was incorporated in the Web-based GIS portal. The next figure (p. 40) shows Web-based Mapping Application on the irrigation schemes being operated by IPH department in a respective village. It shows the watershed boundary, drainage line,

Information of the irrigation schemes operated in the State by IPH



irrigation scheme location feature class which are overlaid over the village boundary. By using the identify button on the irrigation scheme location, along with the attributed data of this feature class, it is possible to obtain the attribute data of all the feature class below it. This helps the user to get detailed information about the irrigation scheme, on which watershed this scheme is operating, and the beneficiary village population.

Model Base to Hydro Data Model

Arc Hydro data model structure could not support the SWAT model output which is crucial for many studies. The Arc Hydro data model was further extended to support SWAT model output. The details of this development are out of scope of this paper.

Conclusion

The development of a Geospatial Web Portal is a desirable solution to organising hydrological information and data management. The Web Portal is built around a hydrological data model which synthesises data from diverse sources describing the water resource, providing visualisation and linking to externally modelled results. This Geospatial Web Portal would provide a robust platform for the planning, execution and monitoring of the status of water resources in different basins.

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Solid Waste Management: from End of Pipe to Sustainable Solutions

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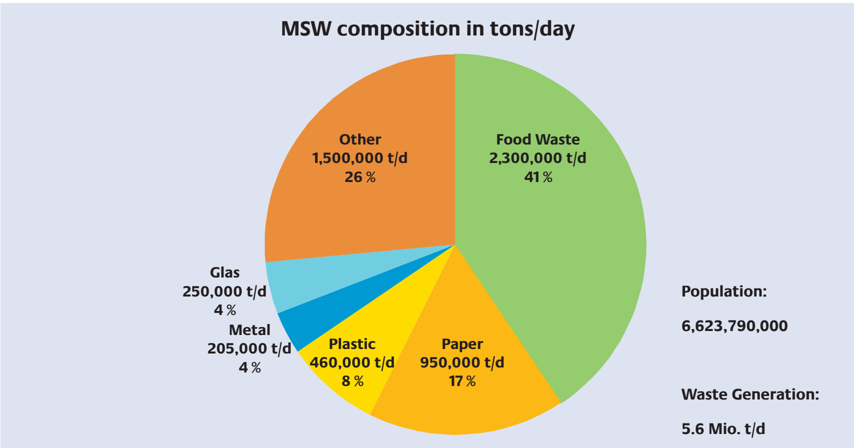
Currently, about 5.6 million tons of municipal solid waste is produced each day primarily due to two factors, a large population in Asia and a 700 kg per inhabitant per year rate of solid waste disposal in North America. Of this amount worldwide organic waste is nearly 40 %.

Waste management has been becoming increasingly more important as it relates to resource and climate protection, in addition to hygienic



Waste management in Germany 1930 – 2005, (Source: Berliner Gold and Deponie Burghof and Ludwigsburg County Waste Recovery Facility, mbH)

concerns. Just factoring the limited availability of resources (e. g. 20 years for lead, 30 years for copper) makes it necessary to recycle materials and to use the energy content found in waste. Landfills account for about 10 % of anthropogenic methane emissions, which has a high impact on the climate. Therefore, it is only logical that these emissions must be decreased in order to prevent climatic changes. Waste management must redevelop whereby it incorporates end-of-pipe solutions that support sustainable development. For this it is necessary to collect recyclable materials separately. This was already being practiced in Berlin, Germany (3-Bin System) in 1903; today, waste is recycled by separation at source from 50 to 60 %.

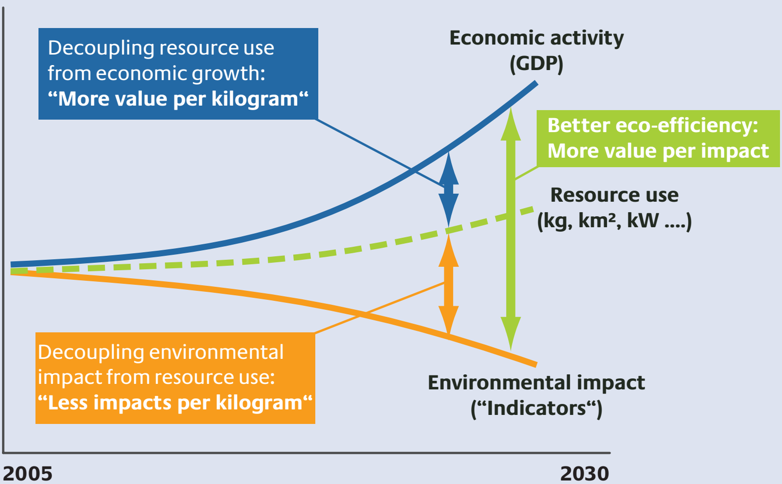
It is necessary that the informal sector, which plays a vital role in recycling, is involved with the waste management process in developing countries.

Through this, it will be possible to increase income generation for the population. Here attention should be paid to the fundamental social and organisational aspects.

According to the Landfill Ordinance, 65 % of all organic waste must be kept out of landfills in the European Union by 2020. In Germany the dumping of untreated waste has not been allowed since 2005. A significant step to achieve this goal has been to build and operate sorting, composting and anaerobic digestion plants and waste to energy plants in the context of short-term waste management concepts.

The main challenge is achieving an eco-efficient use of resources. This means that increasing economic activity can cause less environmental impact and reduces resource consumption. It aims also to decouple resource use from economic growth.

Target: Decoupling economic growth and environmental impact



Source: Timo Mäkela: Recycling Consultative Forum Dublin, January 2007

In addition, it has especially been important to develop new technologies in industrialised countries. Examples include sensor-based sorting of recyclable materials, to improve the bio-treatment processes and improve control systems (composting, anaerobic digestion) and to integrate innovative technologies (e.g. fuel cells).

New methods for energy recovery from biogas with high efficiency have to be implemented. The energy efficiency of waste to energy plants should be increased further.

Non-recyclable waste must be treated at least by mechanical and biological processes. On landfill sites with high potential emissions and leachate, they have to be treated or recycled. Particularly in developing countries the costs for this can be financed, at least partially, by Clean Development Mechanism (CDM) activities.

To assess waste management systems in terms of their sustainability and to improve them, evaluation methods are required. They include economic, environmental and social criteria. An essential tool that can be used to assess the aforementioned criteria is the life cycle assessment (LCA). On the other hand, resource conservation potentials of limited resources have to be considered as well. As a result Life Cycle Thinking needs to be brought to the forefront. Joint research activities between Germany and India in the field of waste management are seen in the following areas:

- **Further development of evaluation systems in terms of sustainability;**
- **Investigation in the field of biotechnological processes (composting and anaerobic digestion) in order to optimise the ecological and economic efficiency and the generation of new products;**
- **Reduction of emissions on landfills by pre-treatment measures and sustainable landfill operations;**
- **Use of CDM measures for financing waste management measures;**
- **Implementation of projects involving the cooperation**

with the universities, Indian Institutes of Technology and industry and local authorities to enable an integration of academic knowledge and practical requirements and to achieve research and technology transfers, is of the upmost importance. There is high development potential for this kind of collaboration that can currently be observed in India.

In addition to the global situation of resource prevention and climate protection, the challenges for the future are different in developed industrial countries and developing countries.

In the developed countries demographic changes and improved resource efficiency play an important role. Adapted and improved technologies are required. On the other hand, in developing countries a lack of infrastructure and capital, lack of information and growing population, urbanisation with megacities and fast changing conditions are important.

Training and education combined with decentralised and modular technical systems are potential solutions. This includes recycling and recovery in place and the integration of the population in waste management systems, through which income generation by waste management can be increased. Scientific cooperation between Germany and India is essential for reaching these goals.

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Assessment of Climate Change Impacts on the Water Resources of India

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The general impacts of climate change on water resources have been addressed by the Third Assessment report of the Intergovernmental Panel on Climate Change (IPCC, 2001). It indicates an intensification of the global hydrological cycle and affects both ground and surface water supply for domestic and industrial uses, irrigation, hydropower generation, navigation, in-stream ecosystems and water-based recreation. Changes in the total amount of precipitation as well as in its frequency and intensity have also been predicted which will in turn affect the magnitude and timing of runoff and soil moisture status. The impacts of climate change are also predicted to be dependent on the baseline condition of the water supply system and the ability of water resource managers to respond not only to climate change but also to population growth and changes in demands, technology, and economic, social and legislative conditions.

The coping capacity of societies will vary with respect to their preparedness. The countries with integrated water-management systems may protect water users from climate change at minimal cost, whereas the others may have to bear substantial economic, social and environmental costs to do the same.

Thus, the climate change impacts are going to be most severe in the developing world, because of their poor capacity to cope with climate change and adapt to it in variable ways. India also falls under this category. The NATCOM study (Gosain et. al., 2003) was the first attempt to quantify the impact of the climate change on the water resources of the country. This paper presents detailed results of the study on two extreme river basins of the country affected with respect to the drought and flood severities on account of the climate change.

Methodology

The Soil and Water Assessment Tool (SWAT) water balance model has been used to carry out the hydrologic modelling of the river basins of the country. The SWAT model (Arnold et al., 1990: 225), developed by the Agricultural Research Service, Blackland, Texas, USA simulates the hydrologic cycle in daily time steps. The SWAT Model has the capability to route water from individual watersheds, through the major river basin systems. SWAT is a distributed, continuous, daily time interval hydrological model with an ArcView GIS interface (AVSWAT) for pre- and post-processing of the data and outputs.

The study determines the present water availability in space and time without incorporating any man-made changes like dams, diversions, etc. The same framework is then used to predict the impact of climate change on the availability of water resources in the future with the assumption that the land use shall not change over time.

Data Used for the Study

The SWAT model requires the data on terrain, land use, soil and weather for assessment of water resources availability at desired locations of the drainage basin. It is this data (1:250,000 scale) for all the river basins of the country which has been used. The following sections provide the description of data elements used and preprocessing performed on them, wherever required.

Digital Elevation Model

The Digital Elevation Model (DEM) represents a topographic surface in terms of a set of elevation values measured at a finite number of points. DEM for the study areas have been generated using contours taken from 1:250,000 scale ADC world topographic map.

Stream Network Layer

There is an option to use the actual stream network in the absence of large scale contour/DEM data, which was used in the present study. This option helps in conforming to the shapes of the sub basins in the absence of large scale data availability by guiding the generated stream networks. Appropriate threshold values have been used for generating the stream networks for various river basins which primarily decides the density of the stream network and consequently the number of sub basins in each of the river basins.

Delineation of the River Basins

Automatic delineation of each of the river basins is done by using the DEM as input and the final outflow point on the river basin as the final pour/drainage point. The figure (p. 50) depicts the modelled river basins (automatically delineated using GIS). The river basins have been divided into sub-basins depending on the selection of the threshold value.

Weather Data

The data generated in transient experiments by the Hadley Centre for Climate Prediction, U.K., at a resolution of 0.44° X 0.44° latitude by longitude RCM (Regional Climate Model) grid points (see Figure, p. 50) has been obtained from IITM (Indian Institute of Tropical Meteorology), Pune,

The modelled river basins along with the Regional Climate Model (RCM) grid locations

India. The daily weather data on temperature (maximum and minimum), rainfall, solar radiation, wind speed and relative humidity at all the grid locations were processed. The RCM grid has been superimposed on the sub-basins for deriving the weighted means of the inputs for each of the sub basins. The centroid of each sub basin is then taken as the location for the weather station to be used in the SWAT model. The procedure has been used for processing the present/control (representing series 1981-2000) and the future/GHG (representing series 2041-2060) climate data.

Land Cover/Land Use Layer

Classified land cover data produced using remote sensing by the University of Maryland Global Landcover Facility (13 categories, Source: Global Landcover, University of Maryland Global Landcover Facility) with resolution of 1 km grid cell size has been used (Hansen et al., 1999).

Soil Layer

Soil map adopted from the Food and Agriculture Organisation of the United Nations (FAO) Digital Soil Map of the World and Derived Soil Properties with a resolution of 1:5,000,000 have been used (FAO, 1995)

Hydrologic Modelling of the River Basins

The AVSWAT distributed hydrologic model has been used on each of the river basins given in Table 1. The basins have been sub-divided using the threshold values given in Table 1. These values were adapted to divide the basin into a reasonable number of sub-basins so as to account for the spatial variability. After mapping the basins for terrain, land use and soil each of the basins has been simulated imposing the weather conditions predicted for control and GHG climate.

Control Climate Scenario

Each of the river basins has been simulated using the SWAT model first by using generated daily weather by the Hadley Centre Regional Climate Model 2(HadRM2) (1981- 2000). Although the SWAT model does not require elaborate calibration, yet in the present case, any calibration was not meaningful since the simulated weather data is being used for the control period which is not the historical data corresponding to the recorded runoff. The SWAT model has been used on various Indian catchments of varied sizes and it has been observed that the model performs very well without much calibration (Gosain et al., 2004).

Presently, the model has been used with the assumption that every river basin is a virgin area without any major man-made changes, which was reasonable for making the initial national communication to the United Nations Framework Convention on Climate Change (UNFCCC), the basic objective of this study.

The model generates detailed outputs on flow at sub-basin outflow points, actual evapotranspiration and soil moisture status at daily interval. Further sub-divisions of the total flow into components such as surface and subsurface runoff are also available. It also provides the recharge to the ground water on daily basis.

GHG Climate Scenario

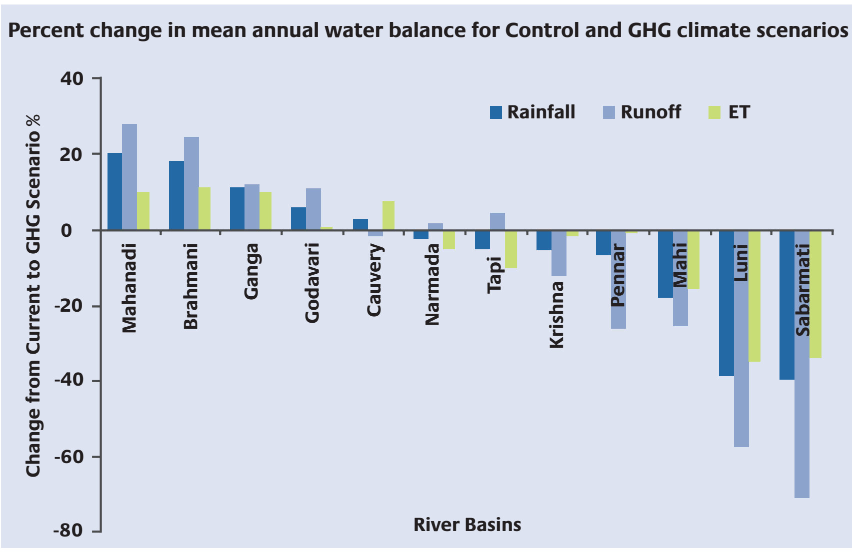
The model was then run on each of the basins using GHG climate scenarios (2041-2060) data but without changing the land use. The outputs of these two scenarios were analysed first at the basin level with respect to the possible impacts on the precipitation, runoff, soil moisture and actual evapotranspiration. Subsequently, detailed analyses were performed on two of the river systems, namely Tapi and Brahmini to demonstrate the impacts at the sub-basin level. Incidentally, these are the river basins which have been identified as having an effect upon droughts and floods respectively.

Summary Results of River Basins Modelled

The next figure (p 53) shows the plot of the percent change in water balance components from the Control to GHG climate scenarios for the 12 river basins. Table 2 depicts comparisons of change in water balance components between rainfall, runoff and actual evapotranspiration for GHG scenarios. It can be observed that the impacts are different in different catchments. A close examination of the table also reveals that the increase in rainfall due to climate change is not resulting always in an increase in the surface runoff as may be generally predicted. For example, in the case of the Cauvery River basin an increase of 2.7 % rainfall has been observed but the runoff has in fact been reduced by about 2 % and the actual evapotranspiration has increased by about 7.5 %. On the contrary, a reduction in rainfall in Narmada has resulted in an increase of runoff water, which is again contrary to the usual expectation. It is important to note that these inferences have become possible because of the fact that daily computational time step has been used in the distributed hydrological modelling framework that has been able to simulate the natural processes in a realistic manner so as to represent the complex spatial and temporal variability inherent in the natural systems. Due to paucity of space, the figure (below) presents only three major components of the water balance which are aggregated over time and space.

Conclusions

It has been a challenging study for quantifying the climate change impact wherein the water balance simulation modelling approach has been used



Fishing in the Ganges (Varanasi)

to maintain the dynamics of hydrology and thereby make assessments of vulnerability which are more authentic and reliable. Usefulness of such handling has been proved by the fact that the results of the GHG scenarios have been dictated by temporal variability at daily level as well as the spatial state of the land mass in terms of its moisture conditions and land use.

The initial analysis has revealed that the GHG scenario may deteriorate the conditions in terms of severity of droughts and intensity of floods in various parts of the country. However, there is a general reduction in the quantity of the available runoff in the GHG scenario.

It may be appropriate to reiterate that the study has been carried out with some assumptions. Two of the major assumptions were firstly, that the land use has not changed over time and that secondly the river systems have been assumed to be in virgin conditions (i. e. no man-made changes such as reservoirs etc.). These changes have not been incorporated at this stage due to lack of data on their capacities and the operation rules.

There are definite impacts that may induce additional stresses and shall need various adaptation strategies to be taken up. The strategies may range from change in land use, cropping pattern, to water conservation and flood warning systems etc.

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Irrigation Water Efficiency

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The charting of our Water Future requires a well-informed scientific decision making community which can meet the emerging challenges in the water sector. Given the important linkages between surface and ground water, as well as land and water, a holistic hydrologic "basin approach" to accommodate the future water needs for different sectors and for different possible scenarios is of great interest.

Irrigation diversion for crops presently accounts for a large part of the water needs in countries, like India, with a sizeable rural poor population, who are engaged in agricultural activities. With the increasing scarcity of the resource base and a growing population, efficient use of water has assumed greater importance. The National Water Mission Document is one of several documents launched by the government of India to address Climate Change. Laid out in the document's objectives, there is a specific targeted goal which calls for the increase of water efficiency in India by 20 % over present levels, which is indeed a challenge (Government of India Ministry of Water Resources: 2009).

"Efficiency" as often widely discussed in water and agricultural sectors represents different connotations for differing interests; it is also scale-dependent. My presentation on Irrigation Water Efficiencies, aims to shed light on a few aspects with respect to losses as noted within irrigation systems and the scope to achieve water savings (Gopalakrishnan: 2010).

Irrigation of fields

The presentation flags issues such as the 'scale impact' and what it could mean at a farm level, a system level and a basin level. Not all inefficient uses actually require equal prioritisation when scarce funding support is present. For example, at basin level, the water might be recovered and reused. The multiple uses of water add another element of difficulty when trying to calculate the specific costs of recovery faced by farmers when trying to achieve maximum water efficiency and water savings.

ICID recently undertook "basin level studies" involving plausible future scenarios, which involved consulting with multiple stakeholders and their influence upon their individual dynamic environments. The ground water and surface water interactions, changing patterns of land use, industrialisation, water reuse and urban needs have all been taken into account. A quick analysis based on a model that can be easily used to study the impacts of different decisions and scenario options is feasible with such analyses. Moreover, using the model one can fairly judge the allocation of water for three broad competing sectors; food, people (domestic and industrial use) and nature (aquatic and terrestrial ecosystem needs).

Properly siphoned investment based on scientific research and technological tools such as the one described above can help solve future water challenges. More and more basins in the country are required to research adopting a similar approach in order to better understand and help define the water rich and water deficit scenarios and long distance water transfer.

I look forward to seeing the Indo-German initiative on "Research for Sustainability" in the water sector extending its scope to include both water quality and water quantity augmentation regarding the study of, as well as efficiency enhancement in, how agricultural water use can reduce water diversions. More basin studies are required to bring in hydrological aspects in order to avoid consequences. Furthermore, instances following uncontrolled, stimulation of conflicting actions within a watershed can be detrimental to the overall interest if not well coordinated.

ICID can support and partner any future research and help research programs by commissioning similar studies like the ones done in India which co-opted all interest groups from different sectors. Recent technological advances and studies which have been undertaken by the Indian Institute of Technology Delhi (IITD) involving the practice of gleaning and its impacts on Climate Change could also be incorporated. Specific new proposals for four Indian Basins could also be developed in consultation with the Indian National Committee on Irrigation and Drainage.

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A Practical Approach to Water Leakage Reduction

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Increasing human demand in correlation to the available water resources will cause regional water crises due to shortages and complicate people's access to safe water. Thus efficient usage of the existing water resources is mandatory. The present paper will provide an overview of pressure management systems as an immediate saving approach for leaking urban water distribution systems.

Introduction

Looking at drinking water leakage rates in western European countries, the bandwidth ranges from 5 % (Netherlands), 8 % (Germany), 22 % (England and Wales) and up to 33 % in France. The average leakage rates in developing or transition countries tend to be significantly higher and may even be above a 50 % loss which stresses the scarce locally available water resources to their limits.

The very first step in the process of water loss reduction is to perform a mass balance of water entering and leaving the water supply system. For this purpose the broadly accepted International Water Association Standard Water Balance in Table 1 is used. From its analysis it is evident that leakages create real losses, meaning a loss of available water to people. This is contrary to apparent losses, which just add to the non-revenue water but still do not factor into delivered water calculations.

Table 1: IWA Standard Water Balance

Water supply capacity (System input volume)	Authorised consumption	Billed authorised consumption	Billed metered consumption	**Revenue water**
			Billed unmetered consumption	
		Unbilled authorised consumption	Unbilled metered consumption	**Non revenue water**
			Unbilled unmetered consumption	
	Water losses	Apparent losses	Unauthorised consumption	
			Metering inaccuracy	
		Real losses (Leakage)	Leakage at the distribution system	
			Leakage and overflow at tanks	
			Leakage between service connection and water meter	

Leakages at the distribution system and leakages at service connections are a major part of the real losses and depend on various factors. The key factors from the structural view on the network are age, condition of the network as well as density of valves, fittings, and service connections. The important factors from the operational point of view are supply pressure and supply strategy as well as the maintenance and rehabilitation measures taken.

Following the approach of the IWA, there are four complementary strategies for reducing the water losses from the Current Annual Real Losses (CARL) to a level close to that of the Unavoidable Annual Real Losses (UARL). These strategies are: pressure management, active leak detection, asset management and quality and speed of repairs.

From the strategies above only pressure management has an immediate impact on leakage rates reduction. The other strategies, although important and complementary to each other, have an impact on water losses reduction but primarily only have an impact on the long-term.

Pressure Management

Pressure management systems reduce the pressure to the minimum needed to fulfil existing supply standards. As a consequence it reduces both leakage on existing defects and the stress on the distribution system, and thus, positively impacts the break rate of the system. The main idea behind a pressure management initiative is to reduce unnecessary excess pressure during hours of low consumption, especially during night hours, to more acceptable levels. Whereas in Germany this problem is mostly solved from the supply point by using variable speed pumps; in most developing and transition countries the problem of excess pressure is dramatic due to very high elevation differences and relatively small net diameters. Thus, depending on consumption, there are extreme pressure variations.

The best way to tackle this problem is through the use of valves that regulate the pressure of the system known as pressure reducing valves. The saving potential of such pressure management solutions depends on the type of solution chosen.

The first and simplest one consists of using fixed pressure reducing valves that ensure a constant low outlet pressure to the distribution system or system part needed to fulfil the demand at all times. The effect is the lowering the level of the entire pressure figure but keeping the absolute difference between the maximum and the minimum pressure thus reducing leakage but not the stress on the network.

More sophisticated active pressure management solutions use variable pressure reducing valves that can vary the outlet pressure upon request. The simplest of these active solutions open or partially close the inflow of water at fixed times. In this case valves are set up to reduce pressure levels at a time where consumption is expected to be low, usually during night time. This time adaptive control relies on demand figures determined during measurement campaigns and therefore is the most inflexible solution of the active solutions as it can not react by itself to demand changes differing from the predefined scheme.

A more advanced solution uses variable valves that react to demand by monitoring pressure at a point considered critical. In this case pressure is reduced at the pressure reducing valves just to levels that always ensure that enough pressure is available at this particular critical point. Here the stress on the system is reduced even further to the level to maintain the minimum supply pressure at the most critical point. Yet there is still an amount of unneeded pressure as in times of a demand close to zero the supply pressure can actually be reduced to the minimum level preventing the infiltrating/ pollution of the distribution system.

The last solution tackles this problem by reducing pressure using active pressure reducing valves according to measured flows in the system and thus reacting to the true demand within the system. Although all active solutions do actively reshape the pressure gradient figure rather than just lowering the unchanged figure like the fixed pressure solution does, the latter active solution is promising the highest saving potential as it does not control the pressure by fixed schemes or demand describing substitutes, but the real demand figure.

Independent of the type of solution to be adopted, an extensive hydraulic analysis of the supply net must be performed, modelling possible alternatives. The first step is to verify that the model reliably represents current supply conditions. Thereafter, a calibration process of the hydraulic model against pressure and/or discharge measurements is performed. The model is then used to compare different alternative solutions. At the end of this process an optimised solution is envisaged.

The choice of the proper technology to be installed depends on consideration of local conditions and development level. Every system has advantages and disadvantages that need to be evaluated. The better a system can reshape the pressure to the meet present demand, the higher the complexity of the system will be and thus the need for continuous care throughout the lifetime of the operation will rise. Therefore, the choice should not only be made according to the saving potentials but also must consider the long-term implications of the system's future operational needs.

Conclusion

Pressure management represents a very cost effective way of immediately reducing water losses and lowering brake rates by reducing the stress on the water distribution system. This method allows for additional support for the network operator in implementing the other three of the complementary International Water Association strategies for reducing the water losses and supports the change towards more sustainable resource usage. Successful implementation and the long-term successful operation of pressure management systems require sound engineering judgement to ensure adequacy and sustainability which could potentially be seen as a drawback to utilising this approach. Nevertheless, it is manageable when adequate training programs for the utility engineers are accompanied with the installation of pressure management projects.

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Water Franchise: Sustainable Financing and Operation of Water Efficiency

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India is among the countries with the most urgent need to invest in new constructions, modernisations, operations and maintenance of water and sanitation facilities. However, as has been experienced worldwide in the last decades, financing and sustainable maintenance of facilities are pre-conditions to each other. Without finance, no investment or budget for operations and maintenance can be realised. Vice versa, without sustainable operations and maintenance, financing of facilities would lead to malfunction and end in sunken investments or in a loss of money.

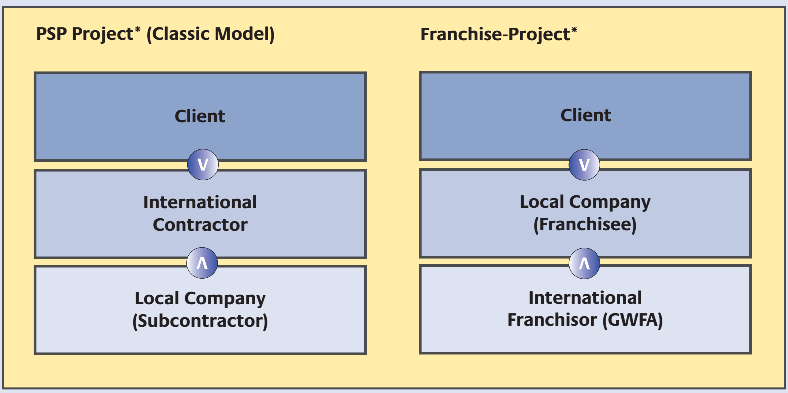
Idea: Sustainable operations and maintenance on site need local ownership and local business. For large and complex technical deliveries and services, the local businesses have mostly been excluded, or limited to the role of sub-contracting under expatriate companies.

The reason is that donors and banks prefer big players from the international arena. One essential pre-condition for them, as for any investor, sponsor or lender, is that he can expect successful performance of the water and sanitation facilities to be built with his financial contribution. Most sponsors would request a performance guarantee-covering development, technologies and operations. Small and medium-sized companies, as well as public utilities undergoing transformation (i.e. local players) cannot deliver this. This is why donors, such as the European Union, are delivering Technical Assistance mainly through international consultants, or why the European Bank for Reconstruction and Development (EBRD) and other international organisations are financing privatisation schemes with large international water service providers.

The word "Franchise" is derived from the word "frank", related to the word "free" (still used with the phrase "frankly speaking…"). "To franchise" means in our context "to set free" the local business from the limitations that have prevented them from developing their local water business as contractor of engineering, technologies or operational services. The Franchisor (usually a strong, professional company that is internationally established) will "set free" the Franchisee (usually a local, small or medium sized regional enterprise) by eliminating restrictions, which can then allow the local company to deliver high quality water technologies and services. In other words, the Franchisor will enable its Franchisee to promote, build, finance and/or to operate ambitious water facilities.

Well-known examples are McDonald's (fast food), Mister Minit (shoe repairs) or Hilton Hotels. In all cases, the local operator (Franchisee) is acting as

Relations between Client, Local and International Enterprise in the Classic Model and in a Franchise Model



an autonomous enterprise, contracted by its customers and responsible for delivering the goods and services to the customers' satisfaction. The Franchisor will provide all necessary organisational background, logistics, tools, software etc. He will secure continuous quality management, starting from project development and promotion (reputation, branding) until project completion. The Franchisor will train his Franchisee to reach the required level of know-how and capacities, enabling the Franchisee to deliver all goods and services at high reliability, quality and performance.

Franchise can be understood as a capacity-buy-in concept, as a specific form of a twinning approach, even as a local ownership scheme, or a micro-PSP, but always within a professional, sustainable structure and with a performance guarantee ensured through a strong partner.

The Global Water Franchise Agency (GWFA) has been founded by HUBER (www.huber.de), REMONDIS Aqua (www.remondis.de), and RUDOLPH (www.professor-rudolph.de), with the goal of sharing know-how, capacities and technologies for project development and project opportunities, while improving water and sanitation world-wide for the sake of the people and the environment. The GWFA is open to others who are capable of strengthening the Agency's platform, or who would like to utilise it for local business development.

Applicability

The Franchise concept is applicable and a good option for further consideration in cases where:

- **Ambitious technologies have to be applied, which need more experiences and capacities for operations as can be guaranteed on the local level [High Tech (i.e. for recuperation of valuables from solid waste) may be one of these, similar as High Brain/Lean Tech (i. e. green technologies with intelligent process control, such as solar sludge drying)];**

- **There is a shortage of financing resources for water projects and necessary investments, perhaps because banks are reluctant facing investment and functional risks, even though such projects are of outstanding importance regarding humanitarian, ecological or economic needs, and although such projects would be profitable if executed with appropriate technologies and good management;**

- **Technologies (respectively investments) could be applied in large number, and realised much cheaper and quicker through Franchise models based on standardised organisation and financing schemes with significant savings through economies of scale (e.g. for compact plants for water reuse, for seawater desalination, for biogas production and, in general, for decentralised plants);**

- **The Client/Employer is interested in developing the local water and recycling business as an important part of the local economy and society.**

Franchise concepts may not be the best option in certain cases, where alternative options can be realised without difficulties, for instance in cases where:

- **Simple process technologies and simple operational schemes are sufficient, as can be handled easily on the local level, without specific know-how and capacities regarding financing and operations;**

- **The customer demands the delivery of machines, which can be financed and operated without problems by existing local water and sanitation utilities respectively by the industrial customer itself;**

- **There are no political restrictions or similar difficulties to directly involve international companies (i.e. in the frame of management contracts, Build, Operate, and Transfer (BOT) contracts, concessions) or**

- **All stakeholders are satisfied to include local small and medium enterprises limited to their role as subcontractors (this is often the case with the so-called "Technical Assistance" sponsored by international donors)**

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Water Reuse Technologies

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Water reuse offers a climate-independent water source that is dependable, locally-controlled, and generally beneficial to the environment. Water reuse allows communities to become less dependent on groundwater and surface water sources and can decrease the diversion of water from sensitive ecosystems. Additionally, water reuse may reduce the nutrient loads from wastewater discharges into waterways, thereby reducing and preventing pollution. This "new" water source may also be used to replenish overdrawn water sources and rejuvenate or re-establish those previously destroyed.

In a global view, the reuse of wastewater has a long tradition and is currently being successfully applied in different nations. For example, in New Delhi about 12,000 farmers use treated wastewater in areas around Keshopur Sewage Treatment Plant (STP) and Okhla sewage treatment plant to irrigate 1,700 ha of land to grow vegetables such as cucurbits, eggplant, okra, and coriander in the summer; spinach, mustard, cauliflower, and cabbage in the winter (Mekala: 2008). Reclaimed water can be used in far more applications to satisfy most water demands, depending on the level of treatment. The water is treated differently to meet specific regulatory guidelines for the intended end use. Typical uses for reclaimed water include:

- **Agricultural irrigation which represents the largest current use of reclaimed water throughout the world. This reuse**

Irrigation in Darewadi, India

category offers significant future opportunities for water reuse in both industrialised countries and developing countries;

- **Landscape irrigation is the second largest user of reclaimed water in industrialised countries and it includes the irrigation of parks, playgrounds, golf courses, freeway medians, and landscaped areas around commercial properties, as well as around private residences. Many landscape irrigation projects involve dual distribution systems, which consist of one distribution network for potable water and a separate pipeline to transport reclaimed water;**

- **Industrial activities represent the third major use of reclaimed water, primarily for cooling and processing needs. Cooling water creates the single largest industrial demand for water. The reuse water taken in by industries for cooling purposes is predominantly used for either the cooling of towers or the cooling of ponds. However, industrial uses vary greatly between industries and**

water quality requirements tend to be industry-specific. To provide adequate water quality, supplemental treatment may be required beyond conventional secondary wastewater treatment;

- **Groundwater recharge is the fourth largest application for water reuse, either via spreading basins or direct injection into groundwater aquifers. Groundwater recharge includes groundwater replenishment by assimilation and storage of reclaimed water in groundwater aquifers, or establishing hydraulic barriers against saltwater intrusion in coastal areas;**

- **Recreational and environmental uses constitute the fifth largest use of reclaimed water in industrialised countries and involve non-potable uses related to land-based water features such as the development of recreational lakes, marsh enhancement, and stream flow augmentation. Reclaimed water impoundments can be incorporated into urban landscape developments. Man-**

A well in Pehesar

made lakes, golf course storage ponds and water traps can be supplied with reclaimed water. Reclaimed water has also been applied to wetlands for a variety of reasons including: habitat creation, restoration and/or enhancement, provision for additional treatment prior to discharge of receiving water and provision for a wet weather disposal alternative for reclaimed water;

- **Non-potable urban uses include fire protection, air conditioning, toilet flushing, construction water, and flushing of sanitary sewers. Typically for economic reasons these uses are incidental and depend on the proximity of the wastewater reclamation plant to the point of use. In addition, the economic advantages of urban uses can be enhanced by coupling with other ongoing reuse applications such as landscape irrigation;**

- **Potable reuse is another water reuse opportunity, which could occur either by blending in water supply storage reservoirs or, in extreme cases, by direct input of highly treated wastewater into the water distribution system.**

Despite all the benefits that arise from the reuse of treated wastewater, it should not be forgotten that the health of the end users is the main priority and technical options available for wastewater treatment must pay careful attention to the potential health risks of the general population. But also other aspects need to be considered, such as the effect of water quality on scaling, corrosion, biological growth and fouling, as well as potential cross-connections with potable water systems, as these may lead to a variety of problems if ignored. Further aspects to be considered are:

- **Economic efficiency**
  - Investment costs
  - Operating costs.
- **Effects on environment**
  - Methane emissions
  - Odor nuisance.

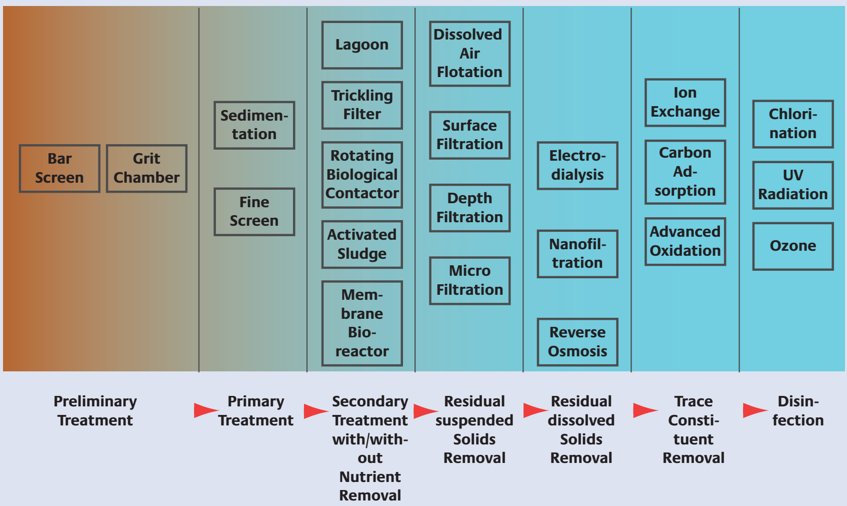
  - Noise
  - Aerosols
  - Flies, worms.
- **Requirements on operators**
  - Required training
  - Maintenance.
- **Plant technology**
  - Process stability
  - Influencing discharge quality
  - Treatment performance
  - Accumulation of residues.
- **Irrigation**
  - Sub-irrigation, e.g. drip irrigation
  - Trickling irrigation
  - Sprinkler and spray irrigation
  - Flood irrigation
  - Furrow irrigation.

From the technical view special interest has to be given to treatment performance, which is characterised by:

- **Suspended solids**
- **Organic matter**
- **Inorganic matter**
- **Pathogens**
- **Nutrients**
- **Trace constituents, such as**
  - Pesticides
  - Pharmaceuticals
  - Hormonally active agents.
- **Physical properties**
- **Salting up by process**

Water utilities use a variety of well-tested and reliable treatment processes to reclaim water. Utilities generally describe the various stages of treatment rather than the

Core stages of treatment for waste water reclamation (adapted from Asano, 2006)



technologies utilised when referring to water quality, as there are multiple treatment techniques for achieving essentially the same result. Generally speaking, the core stages of treatment are preliminary treatment, primary treatment, secondary treatment, removal of solids, trace constituent removal and disinfection as shown in the figure above. Each stage itself represents a variety of numerous techniques whereas the biological processes show the most variations. An excerpt of some of these different types is given in the figure above.

The number of treatment steps will vary based on the intended end use of the water. Most reclaimed water, however, will undergo some form of disinfection.

Table 1: Economic considerations for different wastewater treatment systems (WHO 2006)

System	Land requirements (m^2/inhabitant)	Power for aeration		Sludge Volume		Costs	
		Installed Power (W/inhabitant)	Consumed Power (kWh/inhabitant/year	Liquid sludge to be treated (litres/inhabitant/year)	Dewatered sludge to be disposed of (litres/inhabitant/year)	Construction (US$ per inhabitant)	Operation and maintenance (US$/inhabitant/year)
Primary treatment (Septic tank)	0.03–0.05	0	0	110–360	15–35	12–20	0.5–1.0
Conventional primary treatment	0.02–0.04	0	0	330–730	15–40	12–20	0.5–1.0
Advanced primary treatment (chemically enhanced)	0.04–0.06	0	0	730–2500	40–110	15–25	3.0–6.0
Facultative pond	2.0–4.0	0	0	35–90	15–30	15–30	0.8–1.5
Anaerobic pond + facultative pond	1.2–3.0	0	0	55–160	20–60	12–30	0.8–1.5
Facultative aerated lagoon	0.25–0.50	1.2–2.0	11–18	20–220	7–30	20–35	2.0–3.5
Complete-mix aerated lagoon + sedimentation pond	0.2–0.4	1.8–2.5	16–22	55–360	10–35	20–35	2.0–3.5
Anaerobic pond + facultative pond + maturation pond	3.0–5.0	0	0	55–160	20–60	20–40	1.0–2.0
Anaerobic pond + facultative pond + high-rate pond	2.0–3.5	< 0.3	< 2.0	55–160	20–60	20–35	1.5–2.5
Anaerobic pond + facultative pond + algae removal	1.7–3.2	0	0	60–190	25–70	20–35	1.5–2.5
Slow rate treatment	10–50	0	0	–	–	8–25	0.4–1.2
Rapid infiltration	1.0–6.0	0	0	–	–	12–30	0.5–1.5
Overland flow	2.0–3.5	0	0	–	–	15–30	0.8–1.5
Constructed wetlands	3.0–5.0	0	0	–	–	20–30	1.0–1.5
Septic tank + anaerobic filter	0.2–0.35	0	0	180–1000	25–50	30–50	2.5–4.0
Septic tank + infiltration	1.0–1.5	0	0	110–360	15–35	25–40	1.2–2.0

Criteria for Best Available Technologies

There are many aspects that influence the usage of reclaimed wastewater. That said, evaluation criteria must be chosen based upon the best available technology which can account for all the aforementioned aspects. Some general criteria can be found in the literature; see Table. 1 (WHO: 2006). Concerning new technologies, it would be advantageous to create and test new criteria in order to discover sustainable technologies for wastewater reclamations and reuse. This could be achieved through a collaborative project between German and Indian researchers.

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Sewage Treatment – Indian Experiences and Suggestions for Sustainable Approaches for Wastewater Management

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Comprehensive analysis of capital cost, operation and maintenance cost, reinvestment cost, energy and land requirement based on data obtained from various sewage treatment plants in India has been performed based on primary and secondary data gathered from the operation of sewage treatment plants over the last two decades. The analysis has been summarised in the figure (see Figure, p. 81) as a linkage between the total annualised cost (Rs/kL as in 2008) and the land area requirement (m^2/MLD) for various available technological options (Tare and Bose, 2009). For a particularly desired effluent quality, the technological option with a more annualised cost will generally require less land area and vice-versa.

For example, among the treatment options that produce effluent of quality better than the Indian standard for discharge into water bodies (i.e., BOD_5 < 30 mg/L, SS < 30 mg/L), unlined waste stabilisation ponds (WSP) have the lowest treatment cost (≈ Rs 1/kL) but the highest land requirements (≈ 20,000 m^2/MLD), while an advanced aerobic process like sequential batch reactor (SBR) will have high treatment costs (≈ Rs 5/kL) but low land requirements (≈ 600 m^2/MLD). The conventional activated sludge process (ASP) is somewhere in the middle, with moderate treatment costs (≈ Rs 3.5/kL) and moderate land requirements (≈ 2000 m^2/MLD). Similarly, among treatment options that produce effluent of recyclable quality (i.e. BOD5 < 5 mg/L, SS < 5 mg/L), the ASP + coagulation-flocculation (C-F) + rapid sand filter (RSF)/ dual media filter (DMF) process has the lowest treatment cost (≈ Rs 6.50/kL) but the highest land requirements (≈ 3,000 m^2/MLD), while the membrane bioreactor (MBR) process has the highest treatment costs (≈ Rs 9/kL) and the lowest land requirements (≈ 600 m^2/MLD). The SBR + C-F + RSF/DMF process has an intermediate treatment cost (≈ 7.50/kL) and also an intermediate treatment area requirement (≈ 1,200 m^2/MLD).

Improvement of River Water Quality

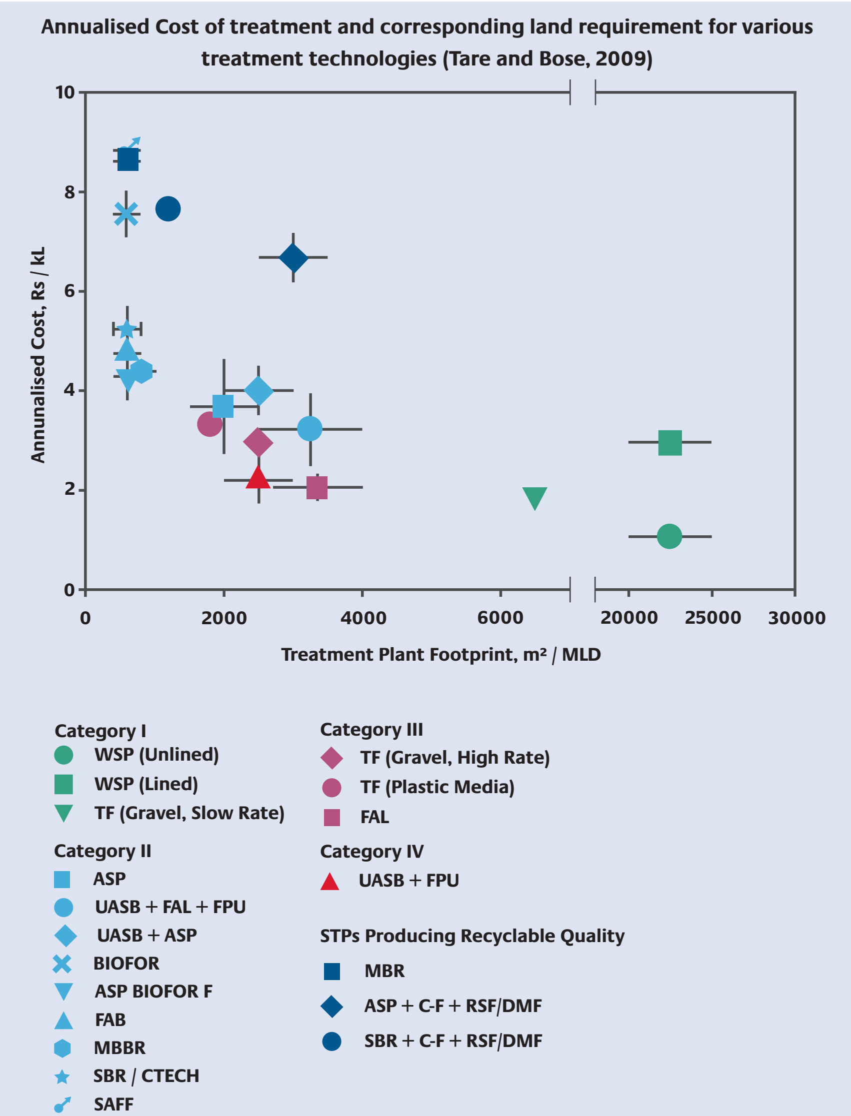
It should be noted that none of the treatment technologies discussed above can completely remove nutrients (especially nitrate) from the sewage. In addition, there is a severe lack of dilution water in the dry season in most rivers. Considering the above factors, substantial growth of algae or other aquatic plants such as water hyacinth in receiving water bodies cannot be ruled out even if all influent sewage is intercepted and treated using the most efficient technologies before being discharged into rivers. Thus, the original objectives of the River Action Plans (RAPs), i.e. restoration of bathing quality water in the rivers, may not be fulfilled unless the supply of dilution water in these rivers is increased substantially. It is advisable that sewage is treated to recyclable water quality and used for various purposes including recharging local water bodies such as lakes, ponds etc.

A Paradigm Shift in Human Excreta Management Practices: Blend of Advanced Technologies with Traditional Wisdom

Sewage systems constitute an ecologically mindless technology. Consider first the large amount of water that is used just to carry away a small quantity of human excreta. Big dams and tube-wells are needed to bring this water home leading to enormous environmental problems. Then large quantities of water that get flushed down the toilet pollute rivers and large water bodies. This is neither rational, nor sustainable. A paradigm shift in human excreta management practices is suggested. The new approach should combine advanced technologies with traditional wisdom. This approach should consider

1. **A move to decentralised systems from the currently adopted centralised systems;**
2. **The use of dry (EcoSan) sanitation systems as alternative to water based sanitation systems;**
3. **The rethinking of standards, inter alia monitoring practices and**
4. **A shift in use of the technologies which are used for transferring/transporting and processing. The choice of options depends on specific circumstances.**

Just below the Dapka Ghat, Kanpur: A „nhala“ or drainage ditch pours raw sewage into the River Ganges



Annualised Cost of treatment and corresponding land requirement for various treatment technologies (Tare and Bose, 2009)
Annualised Cost, Rs / kL
0
2
4
6
8
10
0
2000
4000
6000
20000
25000
30000
Treatment Plant Footprint, m² / MLD
Category I
WSP (Unlined)
WSP (Lined)
TF (Gravel, Slow Rate)
Category II
ASP
UASB + FAL + FPU
UASB + ASP
BIOFOR
ASP BIOFOR F
FAB
MBBR
SBR / CTECH
SAFF
Category III
TF (Gravel, High Rate)
TF (Plastic Media)
FAL
Category IV
UASB + FPU
STPs Producing Recyclable Quality
MBR
ASP + C-F + RSF/DMF
SBR + C-F + RSF/DMF

Conclusion

Conventional techniques for the disposal of human waste are built on the premise that the nutrients contained in human excreta have little value. Conventional solutions are based on the assumption that waste is suitable only for disposal and that the environment is capable of assimilating the waste. The burden is often shifted to downstream communities. Solutions to some of the problems that society faces today, such as water pollution, scarcity of fresh water and loss of soil fertility, will depend on how society learns to deal with its wastes, specifically how it will deal with human excrement.

The technology developed by the Indian Institute of Technology Kanpur (IITK) is aimed at the principle of zero discharge. The toilets are identical to those in conventional water borne systems. The solid and liquid matters are separated underneath the toilet seat itself by using a solid liquid separator. The separator allows the formation of a thin water film that adheres to the surface of the separator while most of the solids gravitate into the retention compartment of the retention cum polishing (RCP) tank. The solids gradually solubilise to form slurry, which is then evacuated from the tank through a closed pipe system. The liquid is passed through a micro filter and recycled for flushing the toilet; thus avoiding the excessive use of fresh water for flushing while no compromise is made on using the liquid for completely flushing the toilet pan. Vermicomposting of feces can then be done to create rapid and effective utilisation of valuable organics and nutrients. Furthermore, the excess recycled flush water is evaporated using solar energy to obtain valuable nutrients present in human urine. The pilot Zero Discharge Toilet systems operating for several months for various applications include Indian Railway's passenger coach toilets, house boats in Dal Lake, Srinagar, Jammu and Kashmir, India, and community toilets in Aligarh, Uttar Pradesh, India.

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Valuables from Wastewater

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What is Wastewater? Wastewater is a mixture of water, nutrients, organic and inorganic matters, pollutants and pathogens. In the 19th century – when mineral fertiliser was scarce throughout the world – wastewater was regarded as an important source of nutrients to keep agriculture sustainable. In the European context, wastewater is considered to be unusable for the refinement process when it comes from households and industries. In India, China and other countries, wastewater from animal husbandry is regarded as wastewater, too. This is an important difference when scientists and companies discuss wastewater treatment options.

Valuables in Wastewater: Nutrients from human excrements could theoretically substitute 20 – 30 % of the mineral fertiliser demand in Germany with an economic potential of more than 350 million Euros per year. Nutrients from animal husbandry satisfy around 50 % of the fertiliser demand in Germany. Most of them are field applied as liquid manure with dry matter contents between 4-10 %. In the past, Germany struggled with over fertilisation problems from the use of liquid manure. After the introduction of a legislative framework, liquid manure became dosed similarly to mineral fertilisers.

Organic matter in wastewater is a small fraction that can be used as a soil conditioner. However, its economic value in Germany is rather limited, as the soils in Germany, on average, have a rather high concentration of organic matter. In regions with low organic carbon concentrations and degraded soils, this fraction may be of a certain economic value.

In theory, wastewater can be decontaminated to the point where it is safe for human consumption. A low-cost alternative is to use treated wastewater for fertigation: the combination of irrigation and fertilisation. The exclusive use of wastewater for plant production usually goes along with an excessive input of nutrients and other salts. To avoid this problem, either both nutrients and salts have to be removed to a certain extent from the mixture or the wastewater needs to be diluted with additional water that has a lower salt content.

Prerequisites for the Use of Wastewater Valuables

Before wastewater can be used as a source for valuables, the hazards that go along with wastewater need to be minimised, namely hygiene and chemical pollution (Yen-Phi, Clemens: 2010). Additionally, technologies which concentrate the nutrients are desirable, such as source separation of excrements into urine and solid excrement (Winker, Vinnerås, Muskolus, Arnold, Clemens: 2009).

Wastewater from Animal Husbandry and Municipal Wastewater – A Comparison

In Germany, the collection of wastewater from animal husbandry and households is similar; all excrements are mixed and flushed away. Human wastewater is transported to a wastewater treatment plant to remove pathogens, Biochemical Oxygen Demand (BOD) and nutrients. The treated wastewater is then discharged to rivers. Wastewater from animals is stored close to the farm and is field applied.

In India and other Asian countries, the sanitation systems for handling human excrement are diverse. In bigger systems, flushing systems are

One step of the sewage treatment process

used with central treatment plants. In smaller cities septic tanks may be the dominant treatment technology. Other types of sanitation exist in peri-urban and rural sites. For animal husbandry, common technologies require a manual removal of solid material. The solid material is collected and treated. For example, in Delhi, areas with a very high density of animal husbandry exist. Here, cow dung is dried and used as renewable fuel. The liquid fraction is flushed into the sewers of Delhi. In China, the situation is similar. In big animal husbandries, excrements are collected separately and treated; one common means is through composting. The liquid fraction, either treated or untreated, is then discharged into the rivers.

As a consequence, animal husbandry is a big environmental threat to rivers or to wastewater treatment plants – even in cities. On the other hand, the source separation is a very good beginning for the recycling of nutrients, organic matter and water.

Research Strategies

In a joint Sino-German research project on the recycling of organic residues (see: http://www.organicresidues.org) an interdisciplinary team of Chinese and German scientists are focusing on improving the recycling of nutrients from agriculture (BMBF grant no. 0330847, MOST grant no. 2009DFA32710). An animal husbandry case study with a capacity of 80,000 pigs per year was selected as the focal point.

Objectives of the project are:

- **Recycling nutrients from agricultural organic waste;**
- **Reducing environmental pollution;**
- **Producing safe fertilisers;**
- **Optimising nutrient management.**

The activities include:

- **Farm gate balances in animal husbandry;**
- **Site-specific and regional nutrient management;**
- **Biogas process optimisation;**
- **Fertiliser production;**
- **Compose optimisation;**

- **Fertiliser biosafety optimisation;**
- **Phosphorus, antibiotics and heavy metal input into soils;**
- **Environmental economy analysis of the site specific animal husbandry;**
- **Quality management implementation.**

So far, the results have clearly shown that there is no single "model solution", but that the overall geo-ecological situation has to be considered. This means that to recycle nutrients from wastewater economically, the site specific situation also has to be taken into account.

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Energy from Wastewater

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According to prognoses made by the International Energy Agency (IEA), the world's energy demands will rise substantially by 45% during the next 20 years as population growth is expected to reach 8.2 billion by 2030; accompanied with an increasing standard of living, especially in the developing world. Therefore, environmental concerns related to global warming and sustainability are resulting in politically driven considerations to move the world's energy consumption away from fossil fuels. Alternatives to fossil energy resources are becoming more and more significant and their share to energy production is increasing constantly. This rise in alternative fuel sources is in part due to public subsidies. Nevertheless, energy from regenerative sources such as solar radiation, wind and waterpower cannot be created efficiently everywhere, especially in densely populated regions.

Particularly in urban areas, domestic and industrial wastewater provides an alternative high-level, yet often neglected energy source. Wastewater not only contains thermal and hydrostatic energy, which is available year-round, but also nutrients and organic matter with a high energy potential. Moreover, further organic matters and sewage sludge that could be used as additional energy sources is produced during the treatment process of conventional wastewater.

Energy from Urban and Industrial Wastewater

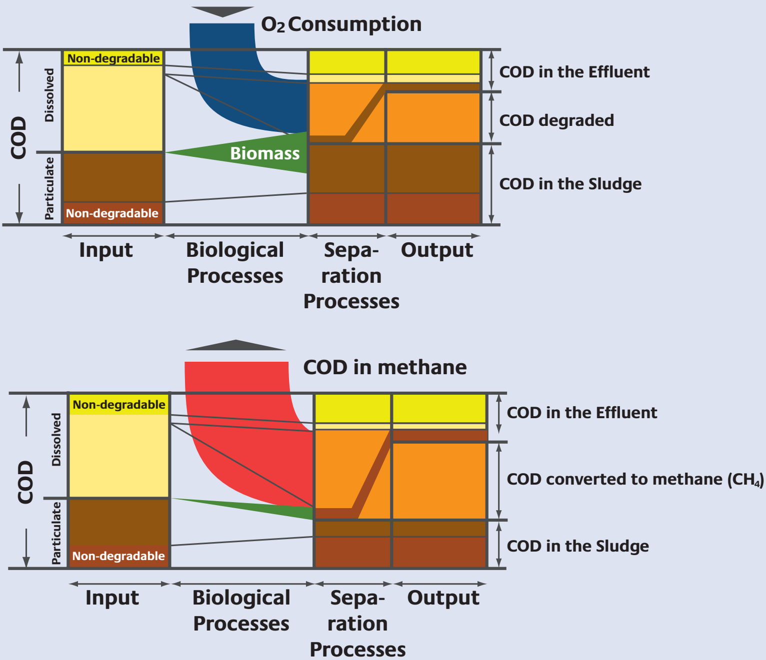
Domestic wastewater temperatures in Germany vary from 6 °C during wintertime up to 20 °C during the summer with an average annual temperature of 12 to 14 °C. Heat recovery from wastewater is becoming increasingly more vital as the benefits help to save energy costs for wastewater treatment. In theory, the energy for heating in at least 10 % of all buildings in Germany can be supplied with thermal energy recovered from wastewater.

There are several options for recovering thermal energy with heat pump and heat exchanger technology inside buildings, sewers or at the wastewater treatment plants before or after treatment. Nevertheless, the recovery of thermal energy may have significant consequences for wastewater treatment itself when the temperature of raw sewage is reduced. Biological degradation processes depend on temperature and the lower the treatment temperature the lower the microbiological activity and the slower the nutrient removal. Consequently, higher treatment volumes can become necessary for sufficient removal of organic compounds and nutrients.

Most conventional wastewater treatment processes are aerobic, especially when carbon concentrations are comparably low and an enhanced wastewater treatment with nitrogen and phosphorus removal is required. The Chemical Oxygen Demand (COD) sample removed from most conventional wastewater treatment processes corresponds equally to the oxygen consumption. Therefore, aerobic treatment results in high energy requirements for oxygen supply and high amounts of sewage sludge as a significant fraction of biodegradable COD is converted into biomass.

A more effective way regarding energy balancing is to treat wastewater in an anaerobic way. During anaerobic processes, organic matter is converted to carbon dioxide and methane, which can be utilised as an energy source. The amounts of sludge produced are very low (see Figure, p. 90). For this process little or no additional energy is required, especially in warm climates. Nevertheless, if enhanced nutrient removal is required, additional post-treatment, i. e. a combination of anaerobic digestion and post-aeration,

COD balances for aerobic (above) and anaerobic (below) wastewater degradation processes (Kayser, 1995)



is necessary. Influent to anaerobic digesters has to be kept constant as the microorganisms involved are not good at coping with variations in flow or composition.

Anaerobic wastewater treatment plays an important role in industrial wastewater treatment where organic loading is high and anaerobic (pre-) treatment, i. e. in UASB reactors, leads to high benefits from gas production and combined heat and power generation.

Energy from Sewage Sludge

Sewage sludge as “organic waste” produced during biological wastewater treatment has to be treated in order to prevent hazardous effects on the environment. Treatment options for raw sewage sludge differ and always have to be chosen in regard to the local conditions and possible reuse or disposal options of the material. The concentrated biomass in sewage sludge offers a high energy potential when stabilised anaerobically. The quality and quantity of gas produced during sewage sludge digestion primarily depends on the sludge characteristics and the sludge digestion time. The organic compounds in sewage sludge, carbohydrates, proteins and grease define gas production and methane content. Due to its characteristic composition, primary sludge generally produces more biogas than waste activated sludge (see Table 1).

Table 1: Gas production and CH_4-content (Kapp, 1993, ATV, 1994)

Substrate	Gas production		CH_4-Content
	[L/kg VSS_0]	[L/PE•d]	[%]
primary sludge	500 - 600	15 - 18	60 - 65
waste activated sludge	200 - 300	5 - 7.5	60 - 65
primary + waste activated sludge	400 - 500	20 - 25	60 - 65
carbohydrates	890	-	50
proteins	590	–	84
grease[1]	1540	-	70

[1] 1 kg grease = 10 kWh primary energy

The technologies chosen for biological wastewater treatment as well as the treatment objective have a strong influence on raw sludge quality and therefore on gas production as well. In general, the stricter the wastewater treatment objective, the more advanced the nutrient elimination, the higher the solids retention time and the lower the gas production (Table 2).

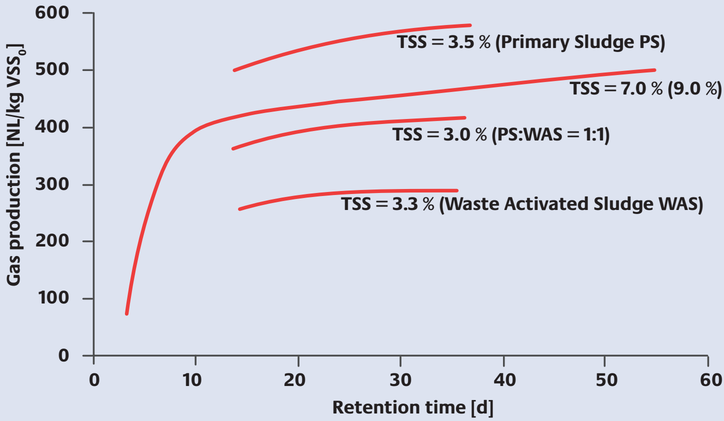
Table 2: Gas production during sewage sludge digestion in dependency on the biological wastewater treatment process (ATV-M-363, 2002)

Biological ww treatment process	Organic loading [g BOD5/PE•d]	Specific gas production range	[L/PE•d] average
nitrification (summertime), partial denitrification $t_{TSS} = 8$ d	inflow AST = 35	16.5 - 25	20.75
nitrification + denitrification, year-round $t_{TSS} = 15$ d	inflow AST = 35	14.5 - 22	18.3
nitrification + denitrification, year-round $t_{TSS} = 15$ d	inflow AST = 48 (no primary sed.)	10.5 - 15.9	13.2
nitrification + denitrification, year-round $t_{TSS} = 15$ d	inflow AST = 60 (no primary sed.)	6.2 - 9.4	7.8
nitrification + denitrification, aerobic stabilisation $t_{TSS} = 25$ d	inflow AST = 60 (no primary sed.)	3.5 - 5.35	4.45
AST = Activated Sludge Tank			

The figure (p. 93) shows the dependency of gas production on solids retention time and sludge type for anaerobic sludge treatment with mesophilic temperature conditions (35 - 37 °C).

In warm climates, where the average temperature is already near the optimum temperature for mesophilic anaerobic digestion, anaerobic stabilisation is possible without further heating. This aspect makes anaerobic sludge stabilisation very interesting even for developing and threshold countries as treatment costs are reduced. Nevertheless, stabilisation time increases significantly the lower the temperature. Recent research results show that at digestion temperatures of 25 °C, sludge retention time has to be doubled for full stabilisation of municipal sewage sludge (Bauerfeld et al, 2010). Nevertheless, even a reduction of pathogens can be achieved so that the material can be reused in agriculture according to the U.S. Environmental Protection Agency recommendations.

Gas production in dependency on sludge retention time (Kapp, 1993)



Prospects

Sustainable wastewater treatment has become one of the driving challenges to environmental technology. Municipal sewage and sewage sludge is no longer regarded as solely waste to be treated and disposed of, but as a resource that can be processed for the recovery of energy, nutrients and other constituents. However, the highest potential for energy recovery can be seen in the anaerobic treatment of highly polluted wastewaters and of sewage sludge. Anaerobic digestion already plays an important role in many industrialised countries and much experience is available. Future examinations have to concentrate on the adaption of know how and on process optimisation, especially when exporting these treatment options to other countries and conditions. New scenarios for adequate and sustainable sanitation and organic waste management should consider a combined treatment of sewage sludge and bio-waste for maximum energy recovery.

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Decentralised Wastewater Treatment

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Development and Assessment Institute in Wastewater Technology (PIA): In early 1999, the Development and Assessment Institute in Wastewater Technology at RWTH Aachen University (PIA) was founded as a non-profit organisation. The same year, PIA was accredited as an affiliated institute of the Faculty of Civil Engineering at RWTH Aachen University. The goal of the organisation is to promote research and training in the fields of wastewater technology and environmental protection.

The Ministry of Environment and Conservation, Agriculture and Consumer Protection of the State of North Rhine-Westphalia was a significant sponsor in assisting with the set-up of the infrastructure at PIA. Through employment of the premises of former municipal wastewater treatment plant "Bildchen", the city of Aachen was able to lay the foundations for research and development, assessment and experiments concerning wastewater.

PIA works closely with all other university faculties in the areas of training and research. This cooperation enables joint execution of national and international research projects. Activities in the fields of decentralised wastewater disposal and wastewater treatment on ships include:

- **Research and development concerning the treatment of wastewater onboard ships;**

- **Research and development concerning decentralised treatment of wastewater;**
- **European and international research cooperation;**
- **Consulting, education and information.**

Since 2002, tests of wastewater technology plants have been carried out by PIA GmbH, a subsidiary company of PIA e.V. Meanwhile, with nearly 200 test operations, PIA is able to make use of an immense wealth of experience in the sector of testing wastewater treatment plants. The PIA GmbH has been approved as a testing institute according to the Construction Products Directive (CPD) and is indicated in the lists of the European Union as Notified Body 1739 (see: CPD: 2010).

Decentralised Wastewater Systems in Europe

In Europe, one of the most important directives for small wastewater treatment plants is the construction products directive (CPD). Furthermore, the requirements of other European standards must be respected, such as machinery guidelines, low voltage guidelines, etc.

A construction product is any product that is produced with the purpose of being incorporated in a permanent manner into construction works, including both buildings and civil engineering works.

European member states are responsible for ensuring that building and civil engineering works on their territory are designed and executed in a way that fulfills the following criteria:

- **Mechanical resistance and stability;**
- **Safety in case of fire;**
- **Hygiene, health and environment;**
- **Safety in use;**
- **Protection against noise;**
- **Energy, economy and heat retention.**

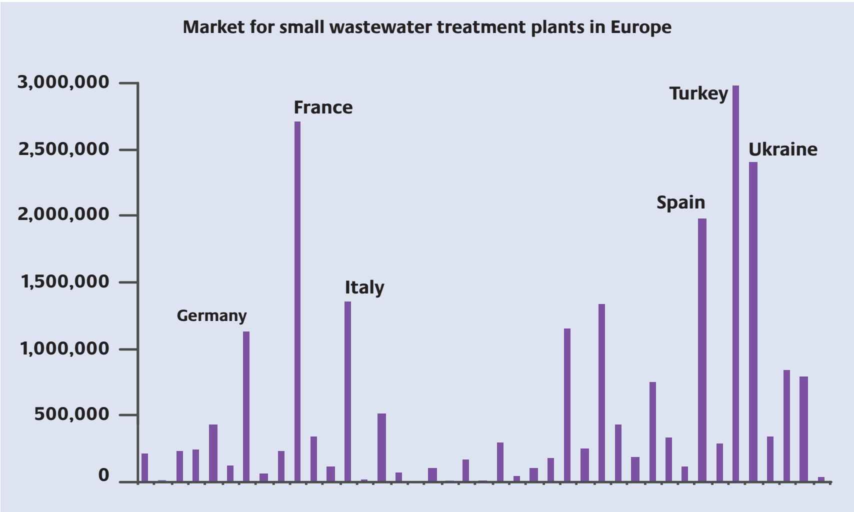
This canal running through the heart of Kancheepuram town overflows with garbage and pollution.

The quality of rivers and ground waters in Germany has improved greatly in recent years. A reason for this improvement has been the increased connectivity of the population to the sewer system and to wastewater treatment plants. When looking at Germany as a whole, the connection of the population to the sewer system and to wastewater treatment plants was 96 % in 2004, whereas it was 90 % in 1991 and only 80 % in 1983 (Statistisches Bundesamt: 1991, 2004).

Due to centralised and decentralised solutions for wastewater treatment being equal in cleaning efficiency, both are viable options. For example, in remote areas, a cost-intensive sewer network connection to a remote municipal sewage treatment plant is not practical. In this case, decentralised wastewater concepts can be good solutions also for the retention of water and nutrients. However, decentralised systems are more susceptible to greater fluctuations of wastewater amount and composition. Therefore, the decision between either a centralised or decentralised wastewater treatment solution cannot be made on principle alone and the specific conditions should be respected, especially taking into account a sustainable water economy.

Decentralised wastewater treatment is a substantial component of the sewage disposal in Europe and its importance will increase in the future. Small wastewater treatment plants in Europe correspond to a capacity of up to 50 percent of the population. On the market, small wastewater treatment plants exist in different models and designs. In principle, the same treatment methods are applied to small sewage treatment plants as to large plants. First, the wastewater is mechanically pre-treated. Solids are held back in single or multi-component sedimentation tanks or in multi-component digestion tanks. The mechanical preliminary treatment is followed by the biological treatment step with final clarification.

Small wastewater treatment plants play a key role for wastewater treatment in rural areas in Europe. In the next decade around 10 – 15 million of new small wastewater treatment plants will be needed.



CE-Marking in Europe

With reference to the European Legislation, small wastewater treatment plants are construction products and have to be CE marked. CE stands for 'Communauté Européenne', the French for European community.

The free movement of goods is central to the single European market, and the New Approach to product legislation and the Global Approach to conformity assessment are the key to helping to achieve this. They are intended to remove technical barriers to trade - without compromising health, safety and environmental aspects of a member state (MS).

The health and safety aspects are covered by the essential requirements which are laid down in the Directives, whilst the technical barriers to trade refer to:

- **Legislative barriers arising from the regulations of a MS – including de-facto regulations;**
- **The technical specifications and codes of practice which support those regulations;**
- **The requirement to involve third parties - often specified and approved by a MS and associated with a national mark.**

The CE mark shall display the compliance of a product with the significant guidelines of the European Union (EU). The CE mark is a lawful labeling and serves as a 'merchandise pass' for the market surveillance authority.

For small wastewater treatment systems the annexes A, B and C of the EN 12566-3 describe the methods for testing. The following initial type tests are mandatory and have to be executed by a Notified Body (EN: 2009).

- **Treatment Efficiency Testing:**
  The test is normally applied to the smallest model of a range assuming this size represents the worst treatment efficiency. The test follows a strict testing schedule that is

specified in the standard. The schedule (Annex A1) shows the daily inflow of wastewater and the quantity of samples.

- **Water Tightness Test:**
  The water tightness of every single tank of a range of treatment systems has to be tested. There are different ways to test the water tightness. One is the "water test", the second is the "vacuum test" and the third is the "pneumatic pressure test". Which test is applicable depends on the material of the tank. A detailed tabular list of materials and the corresponding tests can be found in Annex A2.

- **Crushing Resistance/ Maximum Load Deformation:**
  There are also different ways to test the structural behaviour of a tank depending on the material of the tank. There are practical tests and calculations. In contrast to the watertightness test, not every tank of a range has to be tested, only the one with the worst structural behaviour. Again a detailed tabular list of materials and the corresponding tests can be found in Annex A3.

- **Durability:**
  The durability test is not necessary when the manufacturer uses materials of which the properties are already known, i.e. from the supplier, which is mostly the case.

Every small wastewater treatment plant of a model range which complies with the European small wastewater treatment plant standard and has passed the tests of an accredited institute such as the PIA may be CE marked by the producer within the scope of the certificate of conformity. Part of the CE marking is the declaration of the product and its production (factory production control and preliminary testing by the producer). The manufacturer is obligated to deliver to each plant specific installation manuals, including details concerning the choice of the installation site and comprehensive operation and maintenance instructions.

The CE marking guarantees the free movement of goods within Europe. For the application of CE marked goods, further admission criteria of the individual country needs to be respected.

Decentralised Wastewater Treatment in India

In rural areas local wastewater systems are important for both economic and environmental reasons. Investment and operating costs for distribution systems are very high due to the need for long pipes used for transportation. The systems are susceptible to failure and not consumer oriented. Strong rainfall, such as monsoons, can cause serious dysfunctional setbacks to the sewer systems and potentially cause the contamination of drinking and groundwater. Furthermore, these kinds of sewage systems enable people to use drinking water without requiring permits (public costs arise).

Local solutions with no long pipes for water and wastewater are often the better solution. The modular construction of decentralised systems allows for easy expansion. The operator or the user community could lease or buy such systems; this leads to a higher identification. Furthermore, these systems can be combined with solar or wind energy plants (regenerative energy).

The great technological advancements that wastewater disposal has seen in recent years enable a very good quality of water when full functional efficiency is given. Maintenance and inspections are important for every kind of system in order to guarantee functional efficiency every time.

Decentralised technologies have a great future in India. Appropriately designed, sited, operated and maintained, decentralised wastewater systems are able to meet the public health and water quality goals equally as well as a centralised system can.

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Integrated Water Resources Management: Quality Aspects for Surface Waters

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Economically and demographically rapidly growing countries often face the problem that water demand and wastewater discharges increase faster than the technical facilities that exist to provide or process them. Consequently untreated or insufficiently treated wastewater is discharged into surface waters. High concentrations of nutrients, pesticides, hazardous substances and/or bacteria are often a consequence and may cause eutrophication and/or harm the use of water bodies for drinking water production.

In India only eight cities treat 50 % of their total sewage discharges (Sinha, 2010). Even more disturbing is that many rural areas within the country possess no or very limited wastewater treatment facilities. At the same time with about 260 l/per day per inhabitant, the water usage amounts are two-fold that the daily water demand per inhabitant in Germany. The improvement of sewage treatment has been identified as a major undertaking which needs to be tackled and ambitious plans have been set up to reduce emissions from these sources.

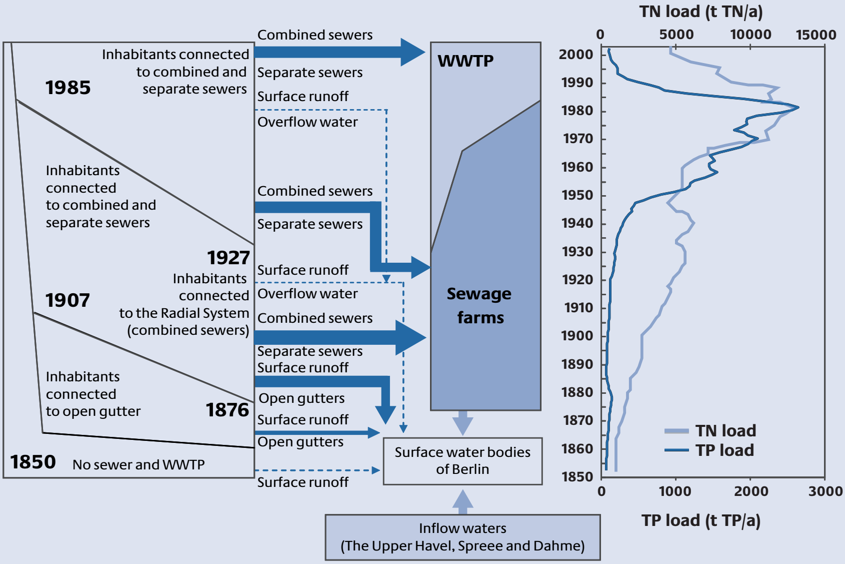
As a consequence, future emissions from diffuse sources – especially from agriculture – will gain importance. Furthermore, the growing population will place further demands on water and food supplies. These demands will only be met with increasing agricultural production thereby intensifying the negative effects on local water systems if no system for wastewater treatment is established. Up until now fertiliser application has maintained a rate of 58 kg/(ha•a); this is much lower than in Europe where the standard is 150 kg/(ha•a) (Prasad et al., 2004), but a significant increase of N-surplus is expected for India (OECD, 2008). Experiences made in European river systems during industrialisation and in current times could help to identify problems and solutions for sustainable water resources management.

Increasing Sewage Treatment

Up until 1850 Berlin had no sewer system and no wastewater treatment plant. Beginning in 1875 open gutter and sewage farms were installed. Due to the soil and groundwater passage, sewage farms and decentralised treatment plants often have a high retention capacity of up to 70 – 90 % of the total loads. Because of an increase in the interconnectedness of population from between 1875 to 1945, and as a consequence of the long usage, the sewage plants became overloaded and the emissions to the surface water were increased dramatically (see Figure, p. 105). The first wastewater treatment plants were built in 1927. These plants had a limited retention capacity. In the following years emissions to the rivers increased again. Phosphorus elimination stages in treatment plants, the banning of phosphates in detergents and the implementation of denitrification stages; finally helped to reduce current phosphorus loads back to their 1850 levels and nitrogen loads back to their 1910 levels. This was when sewage farms were used for wastewater treatment. While in cities large and efficient working treatment plants can be installed, in rural areas the connection of scattered villages to sewer systems, and with this to wastewater treatment plants, is often not feasible. Here solutions like decentralised treatment plants or local treatment, including the reuse of particulated matter, have to be considered.

Intensified Nutrient Application in Agriculture

Although current emissions from agriculture are low in India, the growing food demand will lead to an intensification of agricultural production,



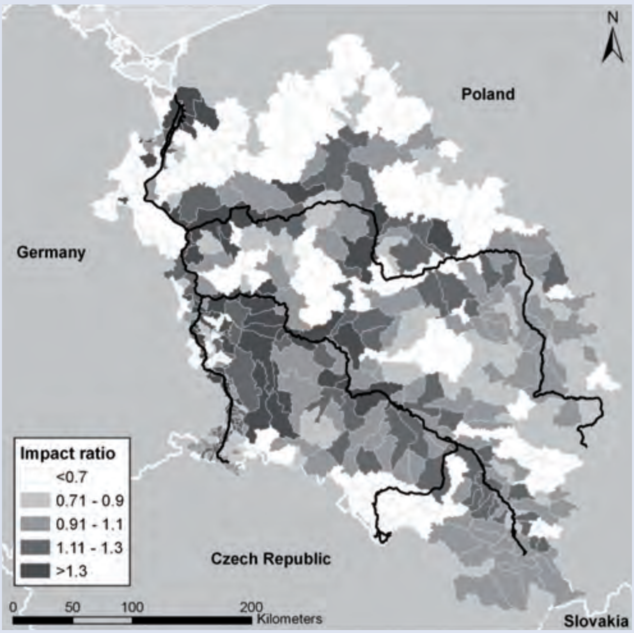
Development of nitrogen and phosphorus emission to the surface water bodies of Berlin (Dinh, 2008).

thereby increasing emissions. Whereas in Europe, the nitrogen surpluses on agricultural land are expected to remain stable or decrease, in India they are assumed to increase significantly (OECD, 2008). This situation has been experienced in many European countries from 1940 after the industrial production of fertiliser until 1990 when the political shift in Eastern European countries caused a breakdown of agricultural production. In these years, nitrogen and phosphorus fertiliser were applied in high amounts and therefore can be expected to remain in soils and groundwater for several decades. Consequently, a rapid reduction of emissions to surface waters from diffuse sources can be reduced only in a limited range. Additionally, high phosphorus loads in the surface waters have led to an accumulation in the sediments, which have, in some cases, been shown to release phosphorus back to the surface waters for the past 20 years.

Identification of Emissions Hotspots

The European Water Framework Directive (EC, 2000) demands quantification of nutrient emissions to surface waters and the implementation of management plans to reduce emissions in order to reach a good ecological status of surface waters. In this context the model MONERIS (Behrendt et al., 2000; Venohr et al., 2009) has been used in many European river systems to quantify the amount and spatial distribution of emissions. MONERIS models emission from various diffuse pathways and from point sources such as wastewater treatment plants and industrial

Impact ratio in sub-catchments indicating an above (values > 1) average share of the emission on the resulting load at the river outlet (Venohr et. al., 2010)



direct dischargers. Furthermore, it can be used as a tool to model the effect of measures to reduce nutrient emissions. The tool allows the identification of emission hot spots and areas contributing to an above average share on the resulting loads at the river outlet, expressed by an impact factor (Venohr et al., 2009). To solve recent and upcoming problems a detailed analysis of the emissions and their sources is essential, which is the basis for setting up management plans to reduce emissions and for improving water quality.

Studies in the river system Oder (Venohr et al., 2010) showed that a consequent implementation of measures in sub-catchments with a high impact factor can have the same effect as the overall application of less extensive measures in all catchments. The results suggest that not necessarily those catchments located closely to the catchment outlet also have the highest share on the resulting total load of a river. This concept would allow designating intensively used sub-catchments and areas with very restricted agricultural use, to combine the need for water protection and the intensification of agriculture in developing countries.

Considering Stakeholders and Farmers for the Implementation of Measures

Cooperation with farmers or their regional representative is often a win-win situation. Farmers have detailed information about their land and the activities on it. On the other hand, farmers often do not have an overall perspective of the consequences of agricultural practices on ground and surface waters. Presenting model results on water consumption or emission from agricultural land is frequently first met with mistrust by farmers, but in the end they are able to identify model errors or unrealistic assumptions and can help to improve modelling results.

Farmers often act according to traditional agricultural practices. The implementation of new techniques is being slowly accepted. In China, for example, traditionally flood irrigation has been applied for many years now. This form of irrigation implicates high water losses to the ground and to the atmosphere on the field but also in the irrigation channels. It was tried in an attempt to introduce water saving drop irrigation. The farmers did not get financial support from the government nor the sufficient training needed to maintain the irrigation system. Consequently the irrigation systems have been removed and the farmers returned to the traditional irrigation system.

Setting up feasible management plans and their subsequent implementation will be more successful with an early consideration of stakeholders and farmer representatives.

Conclusions

At first the rate of inhabitants connected to wastewater treatment plants and the retention capacity of these have to be increased to improve the surface water quality. Similar to rapidly developing countries, European urban systems have long been the major contributor of emissions to surface waters. The potential to decrease sewage discharges in rural areas by substituting small decentralised solutions with large wastewater treatment plants is very limited as the retention capacity in soils and groundwater might be higher than such in wastewater treatment plants. However on a long term perspective, the retention capacity of soils and groundwater will certainly decrease when intensively used.

By reducing emissions from point sources, however, diffuse emissions from agriculture gain importance in the total nutrient budget of surface waters. Accordingly, in European catchments emissions from agriculture often contribute 40 – 70 % of the total emissions. The spatial distribution, the sources of diffuse emissions and measures to reduce them efficiently can only be identified by tools like MONERIS. This model has been applied in German and other European river systems to quantify nutrient emissions and as a basis to set up management plans. In India several measures would have to be applied to prevent the significant increase of currently low emissions from agriculture and enable an early and sustainable quality improvement of Indian surface waters. The potential for farmers to contribute to a resource saving method for water usage and fertiliser needs should be taken into account in the near future, as modifications in agricultural practices often need a long time before being accepted by the majority of farmers.

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WISDOM: Water Related Information System for the Sustainable Development of the Mekong Delta – Thoughts on Sustainability and Long-Term Implementation

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The transdisciplinary project WISDOM focuses on the Mekong Delta region in the South of Vietnam, and in future will in some aspects also include the whole Mekong Basin, comprising of six countries. The innovative goal of the project is to establish a transferable information system for the Mekong Delta. The information system contributes to planning aids and decision support in the field of sustainable land management, integrated water resources management (IWRM), as well as in the field of climate change adaptation. Such a system is a novelty for the Mekong Delta.

The population of the Mekong Delta is confronted with serious challenges, induced by environmental but also socioeconomic conditions and changes. The main problems related to topography and the prevailing geophysical conditions are annual floods emanating from the North, changing runoff and sediment responses triggered by land use changes in the Upper Mekong. Compounding the problem, climate change has contributed to an increase in extreme events such as extreme floods and droughts. Furthermore, the current and predicted sea levels are rising, which is

Mekong Delta, Vietnam

resulting in saltwater intrusion from the South and West, an increase in tropical cyclones, an aggravated effect on coastal erosion, as well as a loss of mangrove ecosystems and biodiversity. From a more anthropogenic point of view, the people who are living in the Delta have to cope with increased resource pressure due to a steady increase in population and economic development. Additionally, as a result of nutrient input, pesticides and hormones polluting the water system combined with an insufficient drinking water supply, the inhabitants of the Delta, are becoming vulnerable to not only unsustainable land use practices, but also challenges to their livelihoods and health.

At the administrative and planning level, environmental information is limited, and is furthermore rarely exchanged. Currently, planning in the water sector does not fulfill the criteria of IWRM; since numerous ambiguous jurisdictions, loopholes in competences as well as in communication and information flow exist. It requires nationwide and intensive training, not only in fields such as environmental monitoring, standardised data storage and data distribution, and the utilisation of the information system, but also in the area of knowledge management, information exchange, transdisciplinary planning, adaption and prevention.

In the course of the first phase of the WISDOM project, eight German and eight Vietnamese partner institutions are cooperating with each other, involving over 60 scientists on both sides. Fifteen PhD students, half from Vietnam and half from Germany and Europe, have each spent a whole year in the Mekong Delta and will finalise their dissertation in 2010. Another three dissertations and two Master's theses, which are associated with the WISDOM project, are in progress. In the first phase of the project numerous post doctorates and established scientists, as well as staff from three small and medium-sized companies carried out research in the Delta. They

Mangroves in Vietnam

focused on the following thematic areas: characterisation of the landscape, water quality, water quantity, water supply, land management, land use change, vulnerability, knowledge management, environmental and water related legal and institutional framework analysis, method development for remote sensing analyses, the installation of monitoring networks, in-situ field mapping, sampling, laboratory analyses, literature studies, household surveys, interviewing decision makers at local, regional and national scale, and other studies.

Parts of the research demand could be covered and many questions could be answered. However, further research still remains to be conducted. Seven German and eight Vietnamese institutions as well as six German small and medium sized enterprises (SMEs) and eleven associated partners from the natural-, social- and engineering sciences have set up a research and implementation strategy to form the second phase of the project and to achieve sustainable results.

The innovative WISDOM Information System is under construction featuring a complex, state-of-the-art data infrastructure based on a variety of open source software modules. This system will be accessible through the internet for the respective institutions and authorities in Vietnam, as well as to all scientists working on the project. Moreover, the system will contain all results of the Wisdom project (data products derived from remote sensing, GIS-maps, point data from monitoring networks, statistical data, graphics, pictures, legal texts, literature and institutional data bases) in the style of a "Mini Google Earth" for the Mekong Delta. The system will also be adaptive to the needs of the Vietnamese consumers through giving active support monitoring tasks for sustainable land and water resource management and by regularly providing current information and data. The prototype, given its current rate of development, should reach maturity within the course of the second phase and is to be implemented in Vietnam by the end of the project in 2013.

The WISDOM project therefore directly addresses the demand of the country's needs which were formulated in the "National Water Resource Strategy until 2020" and in the "National Target Plans" for water resource management and climatic change adaptation. In the context of German programs related to research funding, the WISDOM project closely follows the High-Tech Strategy for Germany and Research for Sustainability Framework Programme (FONA) of the German Federal Ministry of Education and Research. The project is positioned within the research focus of integrated water research management, but also serves the FONA subprograms for river catchment management, coastal zone management as well as water supply and sewage disposal. WISDOM is closely integrated into the structures of international cooperation in Vietnam and is also linked beyond the BMBF programs to initiatives in the fields of technical cooperation, development cooperation and financial cooperation – including actors from the German Agency for Technical Cooperation (GTZ), German Water Partnership (GWP), German Development Bank (KfW) and at an international level with programs of the Asian Development Bank (ADB) and the World Bank. In particular, based on the last three contacts mentioned, the project pursues a clear-cut strategy regarding a long-term and sustainable implementation and ownership in the country.

Thoughts on Sustainability and Long-Term Implementation

Several lessons have been learned during the first phase of WISDOM, which will help to guarantee a successful future for the in-country project section in terms of sustainability, implementation and ownership. Thus, it will be easier to take these findings into consideration during the second phase. When starting future projects, it would be useful to consider the following topics to grant optimal success of the project's sustainability.

1. **Sustainability Science:**
   Sustainability Science means moving from a pure "discovery science" to "solutions science". From the very start, the scientists in the project should address the question: "How will your research results help to improve the situation in the country or solve the problem you are addressing?" Scientists should

be encouraged to get a feeling of gratification not only from creating research results published in papers, but to think a step further and tackle topics such as: "Which recommendations for action can be derived from my scientific results? Who might be the right person/institution/organisation to address? Who might be the right person/institution/organisation to communicate these recommendations to? Who should know about my results?" Scientists of large consortia need to recognise the "sustainability approach" early on. They need to understand its benefits, such as the impact of their research, which can be a resolution to a problem or any other benefit to the partner country, such as delivery of new methods, tools or solutions. Upon the WISDOM project's completion, long-term benefits will be gleaned by the academic community and local population in the areas of data collection and capacity building. The project's information system – maps, reports, legal documents, contact databases – will be available online after the project's end. Capacity Building (Training of Trainers and creating kernels in the partner country will ensure the implementation and long term success), and the development of a long term strategy involving international donors (seeking for ODA funding after the end of the BMBF funded project) play a crucial role.

2. **Research Theme:**
Furthermore, it is important that the project idea and cooperation proposal are demand-driven and not purely put into practice due to the topic being popularised or because some experts have a one-sided interest in a topic. The topic must be relevant to the country in focus. Real users and stakeholders interested in project results should be identified as early as possible within each new project. Here, extensive user requirement campaigns and analyses might be necessary. Intercultural differences in articulating such requirements must be considered. The WISDOM project offered intercultural trainings to all partners, scientists and PhD students. The

trainings helped tremendously to understand the other countries perspective and develop joint understanding of certain issues.

3. **Partnerships:**
   To guarantee project sustainability, beginning with the preparatory project phase, requires the availability of funds to analyse the following
   - Cultural characteristics in the partner country, typical ways of communication
   - Research landscape, institutional mapping
   - Legal framework in the project's foreseen field of activity
   - Careful pre-selection of partners for an initial consortium

Partners should span the range from highly motivated scientists, with an intrinsic curiosity in the project's fields of research, to persons, high enough on the scientific/political hierarchy to support the project's progress and visibility in the country. Furthermore, SMEs should be involved as direct counterparts for example, German companies involved in the projects. Joint ventures or partnerships of bilateral SME consortia are one key aspect of keeping project results and implementations (e.g. sewage treatment plants, information systems or knowledge platforms) running and operational after a science and technology project has ended. Although WISDOM did have a preparatory project phase funded by the International Bureau of the German Federal Ministry of Education and Research, the partner selection process has been somewhat random. However, the long-term set up of the IWRM projects (i.e. the second project phase) provides an opportunity to integrate new partners, agencies and ministerial offices.

4. **Start-up Capital:**
   Funding mechanisms / average amounts in the partner country might differ strongly from the ones in Germany. Thus, the partner countries framework of funding should be considered when setting up a project. If, for example, a partner country's ministry of science and technology has funding limits, the relationship of consortia must be kept in mind. Asymmetry in the availability

of funding means that the project partners need to adjust their expectations regarding the partner country's level of involvement and delivery of results. Funding schemes differ. However, less funding is needed in developing and emerging countries; salaries, overhead, and other expenditures tend to be lower. However, the disparity is probably more at a rate of 1:3 than 1:10. In addition, without going into detail, this aspect is furthermore influenced by country-specific patterns of funding money distribution, redistribution and utilisation; which in most cases aggravates the disparity even further. Within the WISDOM project we partially could overcome this by initiating smaller side-lined and WISDOM-associated projects on the Vietnamese side. For example, the project RICEMAN, funded by the International Bureau, which on the German side only supplies small funding for a few travels and one or two workshops in the field of coastal ecosystem assessment, on the Vietnamese side has also been submitted to the Ministry of Science and Technology – and here received a budget comparable to the overall WISDOM budget on the Vietnamese side. Thus, the problem of underfunding can be solved through such schemes.

5. **Pooling Financial Resources:**
Most developing and emerging countries are actually "flooded" with donor money from official development assistance (ODA). This includes funds for research and its implementation from the World Bank, Asian Development Bank, United States Agency for International Development (USAID), the Australian Government's Overseas Aid Program (AusAID), etc., as well as national involvement of other developed countries. The German position here can be strengthened by coordination among German projects, funded by the German Federal Ministry of Education and Research (BMBF) the German Federal Ministry for Economic Cooperation and Development (BMZ) and its implementing agencies, the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), and so forth. A solid unified national strategy is desirable. "Umbrella" initiatives,

such as the existing IRWM projects funded by BMBF and led by Helmholtz Center for Environmental Research, create country round tables. Moreover, funding pools such as the one initiated by the German Water Partnership, are good seedlings to trigger closer cooperation and a more unified national strategy. WISDOM is starting to get involved with the initiatives under the lead of BMZ, BMU, AusAID and KfW active in the Mekong Delta.

6. **Communication and Visibility:**
   A very important factor for the long-term visibility and availability of projects results is the set up of internet-based knowledge hubs and in the best case, information systems. Projects should make most of their results available to the public. Thus, a project portal should not only include the project description but also project documentation, such as maps, feasibility studies, training materials, and other publications generated within the project. An Information or Decision Support System grants that all data and research results collected and analyzed during the course of the project, are available beyond project duration time. The WISDOM project's information system gives access to all satellite-based raster data for the Mekong delta, numerous vector data sets, statistical information, legal documents, and sensor network measurements. Moreover one can also find literature databases, reports, summaries of PhD-theses outcomes, PowerPoint slides and much more. This information will be available online after the end of the project. Ideally, such an information system will be fed further by the partner country – requiring that during the project phase enough leverage and ownership for doing so (including a sound operations concept and funding) have been created.

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Environmental Flow in Rivers – Some Aspects

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Water is essential to all life. Therefore, the major settlements of populations came to develop near river banks all along the length of river, e. g. Ganges in India. Humans use water directly for domestic needs, growing food, generating power and for industrial processing. People also use water indirectly by benefiting from ecosystems that also require water. However, the environmental pollution is resulting in large-scale degradation in the water quality in almost all major rivers, accentuated by the reducing water availability per capita.

Successive international meetings (United Nations Conference on Environment and Development (UNCED), Rio de Janeiro, 1992; the launch of the Earth Charter Initiative, the Hague, 2000; World Summit on Sustainable Development, Johannesburg, 2002) have highlighted the need to ensure the integrity of ecosystems through sustainable water resources management. Water resources management involves ensuring that sufficient water is available for abstraction whilst protecting the environment. The World Commission on Dams (2000) recommended adequate releases from reservoirs to restore and maintain downstream aquatic ecosystems including floodplains and deltas.

For many centuries we have sought to control rivers by building reservoirs, weirs, embankments and artificial channels trying to ensure a constant supply. Overexploitation results in river incapacities which prevent rivers from performing their basic normal functions. A river is alive if it can perform its normal functions such that the river can - flow and maintain a regime, provide habitat for aquatic life, replenish nutrients in flood plains, recharge the groundwater, transport silt and nutrients to sustain its mouth and prevent incursion of salinity from the sea, support livelihoods and meet the needs for drinking, agriculture and industry of the community, assimilate wastes and purify itself, facilitate navigation, recreation, tourism and pilgrimage, play a role in the economic, cultural and spiritual life of society. A river is killed by having so much water abstracted that it becomes dry or nearly so, by having filth and toxic matter poured into the river which kills all aquatic life in it, by having its banks made so dirty and the water so foul that society ceases to reach the river for bathing, recreation or rituals. We need to think about these matters because we need to draw water from river, especially for agriculture; and we need to generate hydropower to meet our power demands. The diversion of water through tunnels to the power house before it is released back into the river impacts the aquatic

A typical village water scene. In most villages, drinking water is not available to each home, but only to the street, requiring families to fetch water every day.

life, water quality and dams because of the sedimentation upstream. Traditionally, river water quality standards and effluent discharge standards have been formulated in view of the dilution potential available in rivers of at least ten times; and minimum flows have been computed based on a fixed flow; these methods of calculation have been found to be inadequate for protecting all river functions.

In view of the foregoing, it is necessary to include the assessment of environmental flows in any water resource management study and/or plan. This paper presents some aspects of environmental flow considerations employing the flow duration curve (FDC) method to estimate the required environmental flows in river downstream of a large dam.

Environmental Flow Assessment (EFA)

The International Union for Conservation of Nature and Natural Resources (IUCN) guide defines environmental flows as "the water regime provided within a river, wetland or coastal zone to maintain ecosystems and their benefits where there are competing water uses and where flows are regulated (IUCN 2003)".

Earlier, the aims of environmental flows included the protection of fish populations and their habitats, other biota like river invertebrates, water dependent birds and biotic diversity. In recent times, environmental flow requirement (EFR) covers ecosystem structure such as channel form, sediments, river morphology, depth, velocity, substratum, cover, shear stress, near-bed indices, habitat requirement of biota, microhabitats, riparian vegetation and flood plains, wetlands, estuaries, ground water, water quality, water temperature, target species, wildlife and processes like nutrient cycling and primary production, cultural, spiritual, aesthetic values and livelihoods. But EFR and minimum flow needs (MFN) determination requires an environmental impact assessment (EIA) to ensure that all options including water demand management receive equal attention (Thatte 2009).

An environmental flow assessment (EFA) is an assessment of how much of the original flow regime of a river should continue to flow down it in order to maintain specified valued features of the river's ecosystem. The riverine ecosystem is seen as all components of the landscape that are directly linked to that river and all their life forms, including the source area, the channel from source to sea, riparian areas (i.e. the longitudinal riverside strips with vegetation types that are distinct from the general terrestrial landscape), the water in the channel and its physical and chemical nature, associated groundwater in the channel and bank areas, wetlands linked either through surface or sub-surface water, floodplains, the estuary, and the near-shore marine ecosystem if this is clearly dependent on freshwater inputs. An EFA has two main areas of focus: 1) the different flow regimes that would maintain a river ecosystem at various levels of health (condition) and 2) the ways these different levels of river health will affect people. An EFR is the product of an EFA. It describes the flow regime required to achieve a specific river condition. EFAs have increased in importance during the last three decades as it has become apparent that flow manipulations are causing serious degradation of river ecosystems. Costs in terms of soil erosion, land loss, loss of valued species, blooms of pest species, loss of fisheries, and much more have profound economic and social implications. As most of these consequences are removed in a far way in space and time from the point of flow manipulation (often a dam) that caused them, they are usually externalised in water-resource plans and costing. The level of such costs is now sufficiently high, however, for EFAs to be accepted world-wide as an essential tool for water-resource management. EFAs can be done at several levels of detail, from a simple statement of the water depth needed to provide wetted habitat for a particular fish species, to a comprehensive description of a flow regime with intra-annual and inter-annual variability of low flows and floods in order to maintain complex river ecosystems. Confidence in the suitability of an EFA to meet its objective is linked to the level of investment in appropriate specialist inputs.

According to the International Water Management Institute (IWMI) Sri Lanka (Smakhtin et.al 2008), the term 'environmental flows' (EF) is used to refer to a "flow regime designed to maintain a river in some agreed ecological condition". All components of the natural hydrological regime have ecological significance. High flows of different frequency are important for channel maintenance and wetlands flooding, while low flows of different magnitudes are important for algae control and fish spawning. However, maintaining the full spectrum of naturally occurring flows in a river is normally impossible due to water resources development and catchment land-use changes. EF should therefore be seen as a compromise between river basin development on one hand and maintenance of river ecology on the other. Another useful way of thinking about EF is that of environmental demand - similar to crop water requirements, industrial or domestic water demand.

Environmental Flow Requirement (EFR)

A flow assessment produces one or more descriptions of possible future flow regimes for a river, each is linked to an objective that works to achieve the terms of the condition or health of the riverine ecosystem. Each possible future flow regime is called the environmental flow requirement (EFR) for achieving that objective. For instance, the requirement may be stated as simply as "a water depth of at least 50 cm throughout the year, to provide adequate wetted habitat areas for fish species A". Alternatively, it may be described with much greater complexity, detailing a comprehensive flow regime, with specified magnitudes, timing and duration of low flows and floods at both intra-annual and interannual scales of variability, all designed to maintain fundamental functioning of all ecosystem components (e.g., fish, riparian trees, water chemistry) at a specified level of condition. Several allied terms are used to refer to managed river flows. The 'maintenance' EFR (King and Louw 1998) describes a comprehensive flow regime required to maintain all river ecosystem functions, including balanced and continual recruitment of aquatic and riparian species. The 'drought' EFR (King and Louw 1998) describes a drastically reduced flow regime for recognised drought years, to maintain species in a system without necessarily supporting recruitment. "Minimum flow" is a very general term that has been used in several ways to represent an EFR. The concept of minimum flow originated in the western USA as a streamflow standard to constrain the usage of off-stream water during the low-flow season. Environmental flows were typically addressed in this way until about 1973. It was assumed that flows for the remainder of the year were adequate if they exceeded this minimum value, and that all higher flows were potentially available for off-stream use. In other words, the original use of the term was as a simple baseflow recommendation, below which river flow should never fall. Most scientists are moving away from the term now, because of the implication of the EFR being a single figure. The term EFR is gaining in popularity, because it implies a comprehensive flow regime, dynamic over time and with cognisance of the need for natural flow variability.

Environmental Flow Assessment Methodologies

Methodologies for assessing EFRs have been developing since the 1950s, with the emphasis gradually changing from flows required to maintain single valued species (usually fish) to those required to maintain complete ecosystems. Today, many methodologies exist, with two main trends. In many northern-hemisphere countries, particularly North America, complex modelling continues of the physical habitat provided by different flows and how these conditions meet species' needs. In South Africa and Australia, with their semi-arid climes, the trend has been to address the condition of the complete river ecosystem using holistic methodologies. A recent development has strengthened the link between river condition and the social and economic implications, so that all the short-term and long-term, short-distance and long-distance, tangible and intangible costs of flow manipulations can be understood. EFAs can be done at different levels of complexity at different phases of the planning process. A coarse-level EFA can be done as a desk-top exercise to aid national and regional planning of water resources at the catchment level. Holistic methodologies, or those at a similar level of complexity, contribute to a detailed understanding of the merits and drawbacks of a series of competing water resource options, in terms of required river flow, water available for off-channel use, and the social and economic implications. Sophisticated habitat-modelling techniques provide additional detailed information on the flows required for specific valued river species or features, where the targeted rivers are of high conservation importance or are the ones where the conflict over water is likely to be high. The sufficient techniques and expertise that now exist in this new field of science enable it to be able to adopt a suitable approach for EFA-related purpose.

There has been a progressive evolution of methodologies for assessing the EFRs of riverine ecosystems, from ad hoc, case-specific approaches through to well-described, formal methodologies with more broad-scale application (Tharme 1996). Historically, and still today in many instances, the focus of environmental flow assessment has been entirely on the maintenance of economically important freshwater (and hence associated estuarine and/or marine) fisheries. More recently, however, the field has expanded to include assessments of the flow needs for other biota, like riverine invertebrates and water-dependent birds, and for biotic assemblage diversity.

The In-stream Flow Incremental Methodology (IFIM) (Bovee 1986) is one of the dominant worldwide standards for defining ecological in-stream flows. Only ten years after his publication, this methodology was the most utilised in North America (Armour 1991). It is currently one of the most common environmental flow methodologies in use all around the world (Tharme 2003). There are a lot of adaptations of the core habitat software known as Phabsim: Evha in France, Habiosim in Canada, Rhyhabsim in New Zealand (Jowett 1989), etc. Four basic groups of methodology are widely recognised, viz. hydrological index methodologies; hydraulic rating methodologies; habitat simulation methodologies and holistic methodologies. Each of these is discussed briefly below.

Hydrological index methodologies: Hydrological index methodologies rely primarily on historical flow records for making flow recommendations, with attention to ecological criteria in only a few instances.

Hydraulic rating methodologies: Hydraulic-rating methodologies use the relationship between simple hydraulic variables and discharge to develop environmental flow recommendations. The hydraulic variables, such as wetted-perimeter or maximum depth, are usually measured along a single cross-section, across the target river section.

Habitat simulation methodologies: Habitat simulation, also known as habitat modelling or rating methodologies also make use of hydraulic-discharge relationships, but provide more detailed analyses of the quantity and suitability of in-stream physical habitat available to target biota under different flow regimes, on the basis of integrated hydrological, hydraulic and biological response data. In most instances, hydraulic rating and habitat simulation methodologies have been designed for a specific activity, such as assessment of environmental flows for spawning, or for a suite of related activities like fish passage, spawning, flushing of spawning gravels and incubation.

Holistic methodologies: Holistic methodologies (Tharme 1996) form a clearly separate group of methodologies that are geared towards addressing the flow requirements for an entire riverine ecosystem, and which may incorporate subroutines derived from methodologies of the first three types. Holistic methodologies, in particular, are amenable to also identifying the flows linked to issues of human use and interest, such as maintenance of aesthetic quality, social dependence on the riverine ecosystem, economic costs and benefits of changing flow regimes, protection of features of cultural or scientific interest, and river-related recreation.

Realistically, the selection of an appropriate environmental flow methodology or methodologies for application in any individual country is likely to be case-specific and primarily limited by the availability of data on the river system of concern, and existing local constraints in terms of time, finances, expertise and logistical support.

Global Environmental Flow Calculator Software and its Application

River Ganga in India is one of the largest perennial river systems originating in the Himalayas and terminating in Bay of Bengal. The flow regime downstream of a large dam, viz. Tehri Dam, is affected due to the dam. It was proposed to study the flow regime and delineate EF for river Ganga in terms of: historical river flow; requirement to maintain Central Pollution Control Board (CPCB) guidelines for Class-B/C river quality and ecological health parameters used worldwide; determination of wastewater input volume (worst case scenario) and existing dilution by available flow; ecological peculiarity of Ganga, if any (secondary data), and intervention needed to maintain the same. This called for use of available software / models to compute and validate ecological flow (the Global Environmental Flow Calculator of the International Water Management Institute (IWMI-GEFC) and Phabsim). Owing to being desktop analysis tool and due to difficulty in obtaining the data required for Phabsim, it was decided to use IWMI-GEFC software package. Data required for input to the model is comprised of the time series of monthly average flow recorded over a long time period.

GEFC, a package coded in Visual BASIC, useful for initial, low-confidence estimation of EF, offers a highly user-friendly environment, makes grasping the concept of EF easy; has a built-in default global flow database through visual examination of streams and river basins of the world on a geographic map; set of explanations under the "Help" facility; global flow database consists of simulated monthly discharges (in m^3/s) at a resolution of 0.5

Global environmental flow calculator software and its application

degree cells; flow time series in each cell spans a time period of 100 years (1901 - 2000); Graphical User Interface (GUI) in MapWinGIS ActiveX selection of source time series for any part of world; software is simple to use and is available free of cost. User input data is accepted in Excel text form.

The algorithm steps involved in computing the EFR using GEFC method are:

- **FDC is prepared on a graph with 17 probability points to depict percentage of time a flow was exceeded.**
  FDCs in GEFC are represented by a table of flows corresponding to the 17 fixed percentage points: 0.01 %, 0.1 %, 1.5 %, 10 %, 20 %, 30 %, 40 %, 50 %, 60 %, 70 %, 80 %, 90 %, 95 %, 99 %, 99.9 % and 99.99 %. These points ensure that the entire range of flows is adequately covered (Smakhtin et.al).

- **Environmental Management Class (EMC) of river is determined – A to F (min to severe) in view of interventions.**
  EF aim to maintain an ecosystem in, or upgrade it to, some prescribed or negotiated condition also referred to as "desired future state", "environmental management class", "ecological management category" or "level of environmental protection". These classes should be based on empirical relationships between flow and ecological status/conditions associated with clearly identifiable thresholds (Smakhtin et.al).

- **Establishing environmental flow duration curves from reference condition.**
  FDC for a given class is constructed by lateral shift of original FDC to left, along the probability axis, 1 point for A, 2 points for B, so on. A shift of a FDC to the left means that: the general pattern of flow variability is preserved although with every shift, part of the variability is "lost"; this loss is due to the reduced assurance of monthly flows, i.e. the same flow will be occurring less frequently; the total amount of EF, expressed as the mean annual environmental flow is reduced (Smakhtin et.al).

- **Simulating continuous monthly time series of environmental flows. Stream flow is regulated to conform to the FDC so generated.**

An attempt was made to compute the environmental flow requirements for different environmental management class (EMC) options as available in the GEFC. Option C/D for EMC (available options are A – natural to F – critically modified ecosystem) would be desirable from the point of view of CPCB classification "C" for river. The historical river flow data at the location of the dam, i. e. downstream of confluence of the two rivers, pertaining to the period from 1981 to 2005, was supplied by the Tehri Dam authorities. The authorities also supplied the data on water released from the dam for downstream flow during the dam's construction/filling and operation period up to 2007. The 24-year long time series was entered in MS Excel worksheet and then converted to text file suitably formatted for use with GEFC.

Discussion and Conclusion

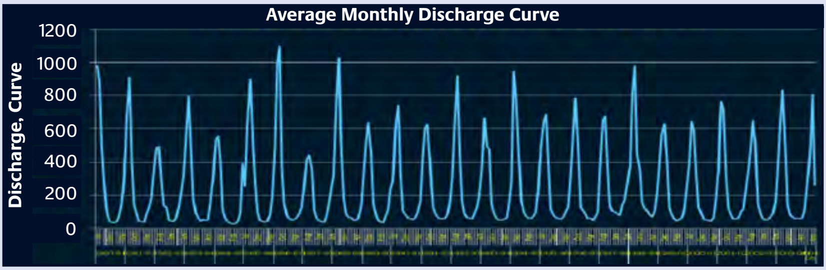
The input flow time series is given in the first figure (p. 130), while the variations in the annual average flow are depicted in second figure (p. 130). It can be observed from the 2nd figure that the average annual flow has almost remained the same during the 24-year period, while the maximum flow has shown a marginal decreasing trend. The results obtained from the GEFC simulation with this set of 24-year flow time series are given in the figure on page 131. The actual discharges from the reservoir during 2005 to 2007 have also been plotted in the figure on page 131 along with the GEFC generated flow time series for comparison.

The river has monsoon non-monsoon perennial flow and the flow regime appears to be stable as indicated by the FDC given in the figure (p. 131). It can therefore be inferred that the low flow requirements dominate the environmental water requirements. The monthly flow data given in the figure (p. 131) indicates that the minimum flow conditions occur towards winter season's end.

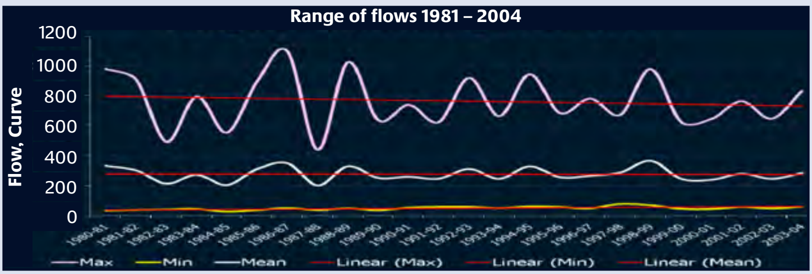
From the analysis of the flow time series and the results obtained from the simulation run of the GEFC it is observed that the discharges made from the reservoir were adequate and can be considered as the required environmental flow in the river for maintaining the riverine ecosystem and water quality in class C category. It would be desirable that the future releases from the dam reservoir be regulated based on the criteria developed by a detailed analysis of the flow and revised EMCs for upgradation of the ecosystem.

It may be appreciated that GEFC only provides an initial insight into the analysis of environmental flows. However, as more data on habitat becomes

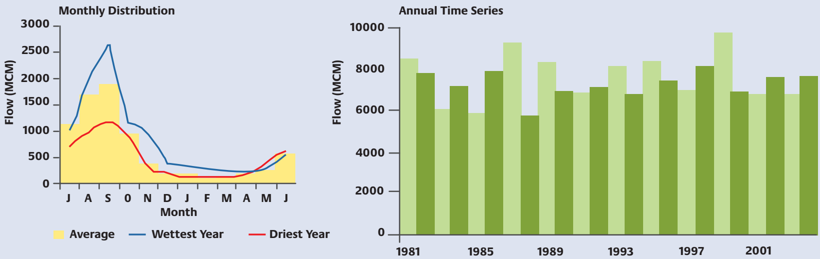
Historical average monthly flows downstream of Tehri Dam location



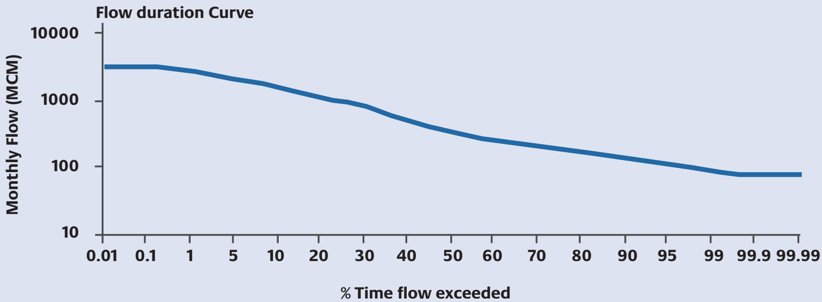
Range of flows (min/max/average) of measured data at the dam location



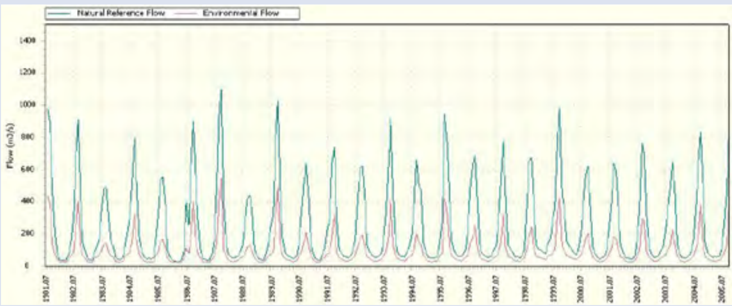
Monthly flow distribution and the annual average flow time series



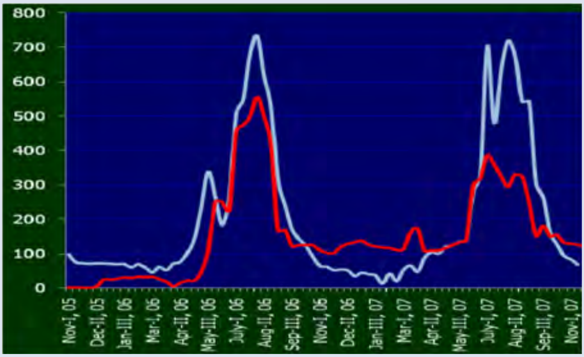
The flow distribution curve (The Base FDC)



GEFC generated flow time series for natural flow and EF



GEFC generated flow pattern along with actual discharges from dam



available it would be desirable to adopt a more robust method such as modeling using physical habitat simulation (Phabsim). Such simulation modeling using Phabsim, however, will need a much longer time frame for the study.

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Sustainable Development through Process Intensification

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The worldwide market of chemicals is estimated to be around 1.6 trillion dollars annually. India's share of the world market in fine and speciality chemicals, including bulk drugs and dyes, is 8.5 % and 6 % respectively, which is 4-6 times higher than the average of 1.75 % share of the overall world chemical market.

Chemical industries are capital intensive and require large amounts of utilities (energy, processed water, and so forth). These industries are facing problems of high capital investment, long gestation periods, high costs of utilities and money. The chemical process industry apart from being capital intensive also has a long gestation period. In stark contrast, the Software Industry requires much less capital, utilities and theoretically has a zero gestation period. It is no wonder therefore, that investment in the chemical process industry has come to a halt whereas the software industry has seen spectacular growth. The solution to these problems lies in order of magnitude, smaller plants consuming less energy and using sustainable technology. This can be achieved by improving existing plants, developing new technology and combining two or more operations. Engineers at many universities and industrial research centres are working on novel equipments and techniques that potentially could transform our concepts of chemical plants and lead to more compact, safer, more energy-efficient and more environmentally-friendly sustainable processes. Chemical engineers all over the world are working towards these goals. An entirely new discipline "Process Intensification" focuses on these issues.

Process Intensification

Professor Colin Ramshaw, a pioneer in process intensification provided the first definition of process intensification as “A strategy for making dramatic reduction in the size of a chemical plant so as to reach a given production objective at lower capital investment” (Ramshaw 1995). These reductions can come from shrinking the size of individual pieces of equipment and also from cutting the number of unit operations or equipments.

Stankiewicz and Moulijn broaden this definition as “Development of novel equipments and techniques that, compared to those commonly used today, which are expected to bring dramatic improvements in manufacturing and processing, substantially decreasing equipment-size/ production-capacity ratio, energy consumption, or waste production, and ultimately resulting in cheaper, sustainable technologies” (Stankiewicz and Moulijn 2000). Or in short, “any chemical engineering development that leads to substantially smaller, cleaner, and more energy efficient technology is process intensification”. Drinkenburg defined process intensification as “It reconsiders the principles of designs and looks for a new technology that can achieve a 1/3 or more improvement in the cost of investment and operation, the use of the construction site, the use of energy and raw materials and/or waste streams” (Drinkenburg 2001).

The concept of process intensification moves around the various themes such as: cost reduction, yield improvement, quality improvement, expansion, trouble-shooting, debottle-necking, and so forth. The whole field of process intensification generally can be divided into two areas:

1. **Process Intensifying Equipment, such as novel reactors and intensive mixing, heat-transfer and mass-transfer devices; Examples: Monolithic catalyst (Stankiewicz and Moulijn 2000), HEX reactors for highly exothermic gas-phase reactions (Ketcham and Jullien 1997), microreactor (Stankiewicz and Moulijn 2000), microchannel heat exchangers (Thonon and Mercier 1997), spinning disk reactor (SDR) (Boodhoo et al. 1997),**

HIGEE mass transfer unit (rotating packed bed) (Ramshaw 1983), Centrifugal Adsorber (Stankiewicz and Moulijn 2000), Oscillatory flow reactor (OFR) (Stonestreet et al. 1999) etc.

2. **Process Intensifying Methods, such as new or hybrid separations, integration of reaction and separation, heat exchange or phase transition (in so-called multifunctional reactors), techniques using alternative energy sources (light, ultrasound etc.) and new process-control methods (like intentional unsteady-state operation). Examples are:**
   - Multifunctional reactors: Reverse-flow reactor (Stankiewicz and Moulijn 2000), Reactive (catalytic) distillation (DeGarmo et al. 1992), Fuel cell (Tagawa et al. 1999) Reactive extractive fermentation (Wasewar et al. 2002, 2003, 2004, 2006) etc.
   - Membrane reactors: Pervaporation reactor (Wasewar et al. 2007, 2008, 2009, 2010)
   - Hybrid separations: Membrane absorption and stripping (Jansen, 1995), Membrane distillation and Adsorptive distillation (Stankiewicz and Moulijn 2000), Ethanol Fermentation-pervaporation (Wasewar and Bathe 2005; Wasewar and Pangarkar 2006).
   - Use of alternative forms and sources of energy: Ultrasonic intensification and microwave heating, electric field intensification (Akay and Wakeman 1996) etc.
   - Other: Supercritical fluids (Goetheer et al. 1999), novel gas liquid reactor (Hills et al., 1996), microemulsion (Bhagwat and Sharma 1988) etc.

Sustainable Development

Sustainable development can be described by three words: social (people), ecological (planet), and economic (profit). 3P is concept of sustainable development (Harmsen et al. 2001). True sustainable development can be learned from the nature. Nature is the biggest intensifier. The best example is human body engineering, which can be elaborated as:

- **Structural Engineering: amazing skeleton, smart load bearing & balancing in static and dynamic positions;**
- **Mechanical Engineering: muscles (springs), teeth (cutters /crushers /grinders), heart (pump), lungs (1250 million alveoli (air sacs)—100 m² area;**
- **Process Engineering: transport processes for blood, nutrients, gases, excretory products, separating toxins, pH & water balance, clot forming etc.;**
- **Chemical Engineering: metabolic activities are like chemical reactions. Liver, a chemical factory. Smelling benzene produces phenol in urine within 1/2 an hour;**
- **Environmental Engineering: waste management consists of well designed disposal system for solid, liquid and gases;**
- **Information Technology: the capacity of DNA to store information vastly exceeds that of any other known system;**
- **Process Control: nervous system takes care of communication, and emergent conditions—fear, anger, fight, pain. Hormones help control/coordinate body activities;**
- **Safety: self-protection is inbuilt, e. g. reflexes. Numerous examples explain how industrial systems are/ can be designed;**
- **Creativity: body is blessed with power of imagination to evaluate situations and generate ideas and solutions, using its system of flashing insights;**

- **Imaging: it is fascinating to note the way the eyes act as camera, coupled with a memory system that makes a lifetime video with an amazing retrieval system;**
- **Reliability: principal organs (brain, heart, etc.) are solitary. Support organs (eyes, ears, lungs, kidneys, hands, legs etc.) with redundancy. Same principle is applied to chemical plant design;**
- **Management: body works with coordination and productivity systems. Manager inside lets it sustain/ grow using history & future functions.**

The motivation for sustainable development comes through nature only.

Examples

Production of Methyl Acetate

The basic reaction in the production of methyl acetate is between methanol and acetic acid which produces water along with methyl acetate. This equilibrium reaction is slightly exothermic in nature. Methyl acetate and water forms an azeotrope and simple separation by distillation or decantation is not possible. Methyl acetate and methanol forms low boiling azeotrope and removal will lower conversion. Basic tasks in this process are to produce methyl acetate, to produce water and recycle excess feed. During the conventional process, there is one reactor, one extractor, one decantor, eight distillation columns, and two introducing columns, in this way there are total 13 columns. Eastman Chemical Company developed and commercialised a sustainable process for production of methyl acetate. In this process many reaction and separation functions are combined in one single large column (a few meters in diameter and 80 meters high, 80 % less expensive, 80 % less energy requirement). The number of pieces of major equipment compared to a conventional design is reduced by a factor of 10 and the primary energy consumption and capital expenditure is reduced by a factor of 5 (Siirola 1995, 1998). The plot area of this process is probably a factor of 10 smaller than the conventional process, because the number of major units has been reduced by a factor of 10. The major contributions to global warming, acidification, thermal pollution, and fossil fuel depletion are probably all directly related to the energy required. Because this is reduced by a factor of 5, it is assumed that these contributions reduce by the same factor, five. It is likely that the number of flanges and valves has been reduced at least by the same number as the pieces of equipment. The VOC reduction in the Eastman case can therefore be a factor of 10 lower than for the conventional design (Harmsen et al. 2001).

Recovery of Carboxylic Acid

Recovery of lactic acid from aqueous solutions is a growing requirement in fermentation-based industries and from waste streams. Lactic acid can be produced by the fermentation of biomass. During fermentation, the accumulation of lactic acid decreases the pH of the fermentation broth and the activity of the lactic acid producing bacteria decreases. Hence, the lactic acid accumulation inhibits the product formation. The traditional recovery process of lactic acid from fermentation broth is quite complicated. Isolation of this acid from dilute solution or fermentation broths is an economic problem because the vaporisation of water consumes too much energy and a direct upgrading of the dilute solution by evaporation is inefficient. Lactic acid is non-volatile, and hence distillation is not useful. In conventional processes, lactic acid has been recovered from the fermentation broth by precipitation of calcium lactate with calcium hydroxide. In this recovery scheme, calcium lactate is precipitated, recovered by filtration, and converted to lactic acid by the addition of sulfuric acid. The diluted lactic acid product is then sequentially purified using activated carbon, evaporation, and crystallisation. These separation and final purification stages account for up to 50 % of the production costs. Thus, this method of recovery is expensive and unfriendly to the environment because it consumes lime and sulfuric acid and also produces a large quantity of calcium sulfate sludge as solid waste. Because of the detrimental effect of low pH, reactor productivities are low and the products are obtained in a diluted form. The effects of end-product inhibition can be

Wastepickers separated recyclable materials from waste at the Gazipur landfill

reduced by in situ removal of lactic acid from fermentation broth by several methods. Reactive extraction with a specified extractant, giving a higher distribution coefficient, has been proposed as a promising technique for the recovery of lactic acid by Wasewar et al. (2002, 2003, 2004). Reactive liquid-liquid extraction has the advantage that lactic acid can be removed easily from the fermentation broth, preventing lowering of the pH. Further, lactic acid can be re-extracted and the extractant recycled to the fermentation process. The suggested process is a sustainable process as it does not consume extra reagent and also does not produce a waste stream and closed loop system.

In-situ Ethanol Recovery by Pervaporation

During the last decade several studies have been proposed on the integration of a product recovery in an alcoholic fermentation, with the purpose of developing a low cost alcohol production process. In situ product recovery is leads to an increase in the productivity of the fermentation and the recovery is more energy efficient than conventional distillation for recovery of alcohol. Pervaporation is one of the alternatives to the in-situ separation of ethanol. Model equations for a continuous 95 % wt, 30,000 lit/day ethanol production by fermentation - pervaporation – distillation were developed. Model equations have been solved iteratively for fixed process conditions and optimised on the basis of economic evaluation. The cost of raw material for pervaporation-coupled process is less than about 5 % because of the better utilisation of substrate. This is possible because the alcohol concentration is maintained low in the pervaporation coupled process and hence the productivity and rates are relatively high. Average saving of 1.45 Rs/lit of the 95 % ethanol in direct production cost for fermentation coupled with pervaporation is observed as compared to the conventional process. In the pervaporation coupled process, a high concentration of ethanol is obtained in the permeate, which is fed to the distillation column. Hence, steam requirement in the pervaporation-coupled process is lower as compared to the conventional process. A 46 % less steam is required for pervaporation-coupled process compared to the conventional process, due to there being a savings of Rs. 1.45 per lit. For a distillery producing 50 lakh liters per year the savings work out to be 72.5 lakh per year. The pervaporation module is expected to cost 1.7 crores. However, because of higher rates of fermentation and higher alcohol concentration, the pervaporation coupled process has an advantage of having a smaller sized fermenter and distillation column and hence the reduction in investments by 70 lakhs. Summarising the forgoing discussion, the pervaporation-coupled process has an investment of Rs. 1 crore higher than the conventional process. However, the operating cost is about 72.5 lakh Rs/year less. Thus, the pervaporation-coupled process appears to be attractive because the payout period is about 1.35 years (Wasewar and Pangarkar 2006) (Wasewar and Bathe 2005).

Hydrogen Peroxide Distillation

Sulzer has developed a new technology for hydrogen peroxide distillation (Meili 1998). In this process, a drastic improvement in safety was achieved by having a lower operating temperature, minimal product holdup in the system, reliable safety devices, and proper selection and treatment of the construction materials. The number of units has been reduced by a factor of

4 as compared to conventional process; therefore it is assumed that the plot area is reduced by the same factor, four (Harmsen et al. 2001). The energy consumption has been reduced by 30 % (a reduction factor is 1.4). This factor is used for global warming, acidification, and fossil fuel depletion. The thermal pollution from cooling water is reduced by a factor of 16 and the operational cost by a factor of five (Meili 1997, 1998) (Harmsen et al. 2001).

Spinning Disk Reactor

Smith-Kline-Beecham investigated the use of SDRs in one of its processes and predicted a thousand-fold reduction in reaction time, a hundred-fold reduction in inventory, and a 93 % reduction in impurity level (Oxley et al. 2000).

Monolithic Reactor

DSM installed an 'in-line monolithic reactor' (a structured catalyst in a pipeline). The result was a reduction in reactor volume of two orders of magnitude compared to the conventional stirred tank mixer followed by a packed bed reactor that is replaced (Stankiewicz and Moulijn 2000).

Natural Gas Dehydration

Shell Global Solutions developed a natural gas dehydration process by membrane separation (Rijkens 2000). In this process, the mass of equipment is reduced by 70 % (factor of 3 reduction) compared to the conventional process. It means the construction volume is reduced by a factor of three.

Power Generation System

Pacific Northwest National Laboratory integrated a catalytic combustor, methanol reformer, vaporisers and a heat exchanger into one micro-system (less than 20 mm^3 in volume) to produce a hydrogen rich stream for fuel cells (Anonymous 2003).

Carbonyl Process

GlaxoSmithKline developed a process for the production of fine chemical from Carbonyl Process (Jimenez-Gonzales 2001). The fine chemical is produced in a high-heat exchange reactor. In this reactor, the residence time is reduced by a factor of 1,800 compared to a conventional batch reactor and the reactive content is thereby considerably reduced; hence the process is safer. The CO_2 emission related to this process is reduced by a factor of 1.4 (from 18 to 13 g CO_2/mol product). The global warming, acidification, and thermal pollution are assumed to be reduced by the same factor. The waste is reduced by a factor of 3.5. (Harmsen et al. 2001)

Conclusion

Process intensification can be defined in three terms for any technology: technically feasible, eco-friendly, and economical. It is the time for process intensification through which we can get a sustainable technology. A strategy of process intensification requires a step change in the philosophy of plant and process design. It is a must to raise industrial awareness for the opportunities offered by process intensification. A technology route map should be prepared for the implementation of process intensification. If it is effectively implemented, it will lead to major improvements in environmental acceptability, energy efficiency, intrinsic safety and capital cost. Chemists, engineers, managers, and officers have to work together for the development and implementation of the sustainable technology. The practical applications of process intensification for sustainable development show that by a schematic approach most of the processes can be further improved. The above-discussed applications are only a few typical examples and many other examples are available in the given literature.

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Megacities of Tomorrow - a Challenge for Solid Waste Management

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What is a Megacity? According to the United Nations, a megacity is a metropolitan area with a total population of more than 10 million people (United Nations 2010). Some definitions also set a minimum level for population density (at least 2,000 persons/square km). While in the past century most major urban centres were located in industrialised countries (e. g. New York, Tokyo, London), at present and in the future most megacities will be located in the regions of the world with economies in transition or in development (e. g. Mexico City, Mumbai, Sao Paolo) (United Nations 2010).

Problems of Megacities

Megacities face many difficulties associated with high population concentration and density, uncontrolled urban sprawl, high levels of traffic, insufficient infrastructure, high concentrations of industrial production, insufficient housing, socioeconomic disparities and erosion of the carrying capacity of the ecosystems they are dependent on (Coy and Kraas 2003). Although future megacities may not have yet reached the same level in population size and ecological pressure, they follow a similar unsustainable path as the megacities of today. The challenge for sustainable development is to take the chance of steering future megacities toward a more viable development path, while avoiding the risk of missing out on the window of opportunity that is presently available for changing this unsustainable trend.

Waste Management in Megacities

Management of waste in existing and future megacities in developing countries is characterised by a disposal-oriented mindset, with little regard to resource recovery and environmental protection. Since there is no source separation, refuse is collected jointly with valuable material and transported to dumpsites or substandard landfills. At the disposal sights landfill gas and leachate management is limited, and consequently, the impact on the local environment and global climate is significant. As result of this "out of sight, out of mind" mental model, strong policies that lead to environmental protection, resource conservation and greenhouse gas emission reduction fail to be implemented.
Stimulated by considerable unemployment rates and lack of opportunities in the formal working sector, large number of waste pickers have emerged in metropolitan areas in developing countries seeking to sustain their livelihood by scavenging valuable materials from refuse. Although waste pickers play an important role in the resource recovery chain, the rates of recovery of recyclables they achieve are relatively low. Furthermore, the conditions they work in, in terms of occupational safety and health, are far from adequate. This is also true for other workers of the waste management sector, which manage wastes without sufficient personal protective equipment and are exposed to different health and safety risks (Cointreau 2006). In most cases, the activities workers from the informal and formal sectors carry out are intensive manual labour, with low productivity and high physical strain associated with the labour.

Addis Ababa: Case Study for Sustainable Waste Management in Emerging Megacities

Although increasing urbanisation in rapidly growing urban centres in developing countries has led to the increased environmental pressure on natural resources, it simultaneously opens a window of opportunity for the exploration of new approaches in order to help these countries direct their efforts towards sustainable development.

The research project, Income Generation and Climate Protection through the Sustainable Valorisation of Municipal Solid Wastes in Emerging Megacities (IGNIS), strives to develop a new concept for the improvement of waste management and the local environment while generating new workplaces, increasing general welfare, considering occupational safety and health and reducing greenhouse gas emissions. Funded by the German Federal Ministry of Education and Research (BMBF) through the Future Megacities programme, the IGNIS project takes on a systemic research approach to resource recovery from wastes in large urban centres in developing countries by implementing the project in the Ethiopian capital, Addis Ababa.

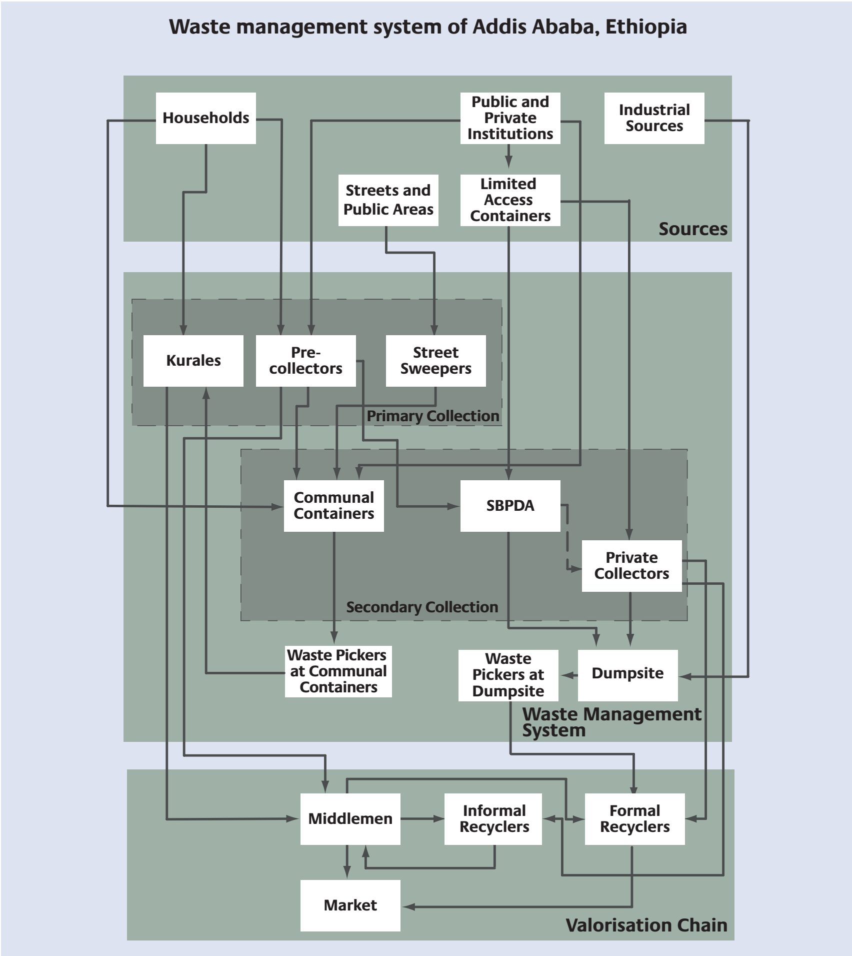
Founded in 1886, the Ethiopian capital is a fast growing urban centre, with a current estimated population of over 3 million inhabitants and an area of 560 km^2. With a demographic growth of 6 % per year, the city will reach the status of a megacity within sixteen years. As in many African cities, Addis Ababa suffers from insufficient infrastructure and deficient services to guarantee adequate sanitation and waste management. The level of coverage of refuse collection is estimated at around 65 %, while the remainder of the waste ends up on streets, public areas, water courses and the surrounding environment.

The project consortium is composed of the AT-Association, the University of Stuttgart, the Institute for Future Energy Systems and the Federal Institute for Occupational Safety and Health, from Germany, and the Environmental Development Agency for the Third World, Faculty of Technology and the Centre for Regional and Local Development Studies of the Addis Ababa University and the Environmental Protection Agency of Addis Ababa, from Ethiopia. The consortium will holistically assess constraints of the existing waste management system, introduce decentralised pilot projects and evaluate their environmental, economic and social impacts. It will also develop a decision support system and carry out extensive training of the local authorities and personnel. Finally, the project will evaluate the extent to which the results and insights gained from research are transferable to other emerging megacities.

Within the scope of the IGNIS project, understanding the material and energy flows that move through the urban metabolism is of great importance for the establishment of the environmental, economic and social relevance of these flows. Materials consumed by households, commercial and public institutions are converted into wastes and enter the municipal waste management system. A large part of these materials are land filled without treatment or recovery, while only parts of the secondary resources with market value are recovered and reintroduced in the economic cycle.

As with most megacities in developing countries, in Addis Ababa the fate of postconsumer materials, organic waste and other residuals are not well known. This is a result of the lack of a system of data collection along the waste management chain. Since there is no systematic recording and assessment of the amount of waste collected and transported by the municipal or private enterprises, and the final disposal site is lacking a weighing bridge to register the amount of residues land filled, there is almost no robust data that helps assess the performance of the waste management, or determine to what extent the streams of valuable materials recovered and recycled is available. The previous situation is compounded by the fact that large amounts of recyclables are recovered by an army of informal waste pickers who buy materials from households or scavenges for recyclables on the streets and at the final disposal sites, thereby making this system practically invisible to the waste management authorities. The figure on page 151 illustrates the system of waste management and resource recovery in Addis Ababa.

Based on the case study of the Ethiopian capital, the IGNIS project strives to structure the complexity of the waste management system by identifying the actors that determine the dynamics of the system and by quantifying the material flows (see figure, p. 151). For this purpose the project consortium is currently developing a methodology to characterise in detail how the different subsectors of the waste management chain function. This involves eliciting which factors influence the performance of the collection, transportation and street sweeping sector, which interactions determine



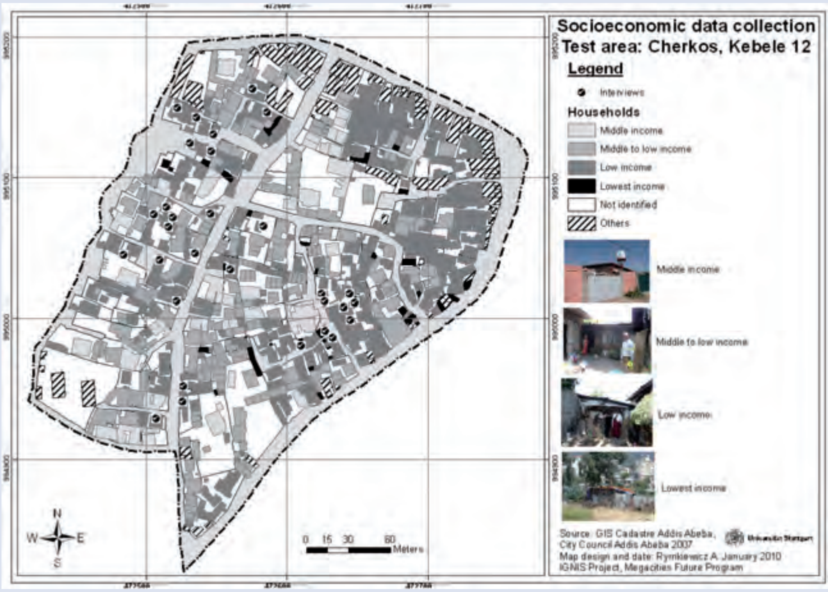
how much material is recovered and recycled by both the formal and informal recovery sectors, and what are the reasons for the amount of waste currently being disposed.

Examples of Waste Management and Resource Recovery Operations in Addis Ababa

In order to guarantee that the project findings are well founded, a reliable data basis must be collected. This data basis includes relevant information of spatial, socioeconomic, and waste management structures, which in many developing countries are missing or incomplete. The quantification and characterisation of the resource potential in the municipal wastes being generated currently, and in the future, is a key step towards completing this data pool. Especially for planning purposes, it is not enough to know the composition of the waste; knowledge about the per capita waste generation is also necessary. For this purpose, standard methodologies used in industrialised countries for the characterisation and quantification of municipal solid wastes have been taken as a basis, and have been adapted and synthesised into a solid waste analysis procedure appropriate for considering the restrictions and local conditions. Furthermore, in order to estimate the total quantity of the waste generated by households in the city, these were classified into different strata according to representative building structures and socioeconomic level.

For each stratum, the amount of waste per inhabitant and its composition will be determined and then based on the number of persons living in each building class; the total amount of waste streams will be extrapolated. The selection of the test areas for the execution of the sorting analysis was refined by analysing the spatial distribution of the different building types within selected mapping areas in the city. The figure on page 153 shows an example of the spatial distribution of four income classes (building structures) and of households within a mapped area, where socioeconomic characterisation interviews were executed.

Spatial distribution of household classes and interviewed households in a mapping area



Occupational safety and health standards for handling and sorting wastes had to be adapted as well by using the locally procurable means, since working conditions during waste collection and sorting were not comparable with the European situation. Efficient and inexpensive solutions on a low technical level were developed and integrated into the solid waste analysis procedure (figure on this page).

As a result of the methodological development and validation, an applicable waste sorting analysis procedure has been achieved, while finding a compromise between data quality, workers' safety and health and available resources. Furthermore, since standard sample survey techniques have been taken into consideration, sampling errors and uncertainty levels have been accounted for, thus guaranteeing the collection of statistically representative data.

As income generation is an important component of the action oriented research project, pilot projects that contribute to the generation of new work places will be implemented and analysed. The pilot projects include composting of market waste and of source-separated biowaste from households; biogas production from a biolatrine; improvement

Quantification and Characterisation of Household Wastes in Addis Ababa of occupational safety and health issues during collection of waste and valuable materials; paper, plastic, metal and e-waste recycling with inclusion of the informal sector; charcoal production from biowaste; biogas plant in multi-household condominium; sustainable waste disposal (MBT, gas extraction); compost and sludge use for jatropha cultivation and erosion prevention. The scientific assessment of the sustainability and viability of pilot projects includes the analysis of processes (workflows, material and energy flows), the evaluation of technical functionality, the assessment of the extent of environmental protection, the analysis of the potential for income generation and sustenance of livelihood, the evaluation of the financial feasibility, ensuring that adapted occupational safety and health standards are met and that the pilot projects are integrated to urban development policy.

In order to design and test waste management policies, a virtual laboratory using System Dynamics models will be developed. With this simulation tool the effects of the multiplication of decentralised waste treatment pilot projects, of the up-scaling from pilot to full-scale plants, and of their integration with the existing WMS can be assessed. Furthermore, it will help to identify improved waste management policies that prevent pollution, conserve resources and protect climate, while being economically self-sustaining and socially acceptable.

Complementing the research and implementation work, efforts to educate local personnel and increase their competences in waste management will be conducted. This may include on the job training for skilled technical personnel, continuing education of managers, capacity building in research and teaching for university staff, and setting up graduate courses regarding sustainable waste management.

Although the research initiative strives to answer relevant questions, still some questions are left unanswered. For example, why have megacities been unable to implement sustainable waste management systems? What do the megacities need to implement sustainable waste management systems for? Would more financial resources, more technology transferred from abroad, more laws and administrative structures, and/or more and better-trained personnel solve the problem? In order to answer these questions, academia, governmental institutions, industry and the general population have to step up to the challenge of striving for sustainable waste management in megacities. To this end, academia can start by providing tools, models and methods to improve the understanding of the problem; educating professional and technical personnel, enabling know-how transfer, and promoting networking activities.

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Resource Efficiency and Management Waste Electrical and Electronic Equipment

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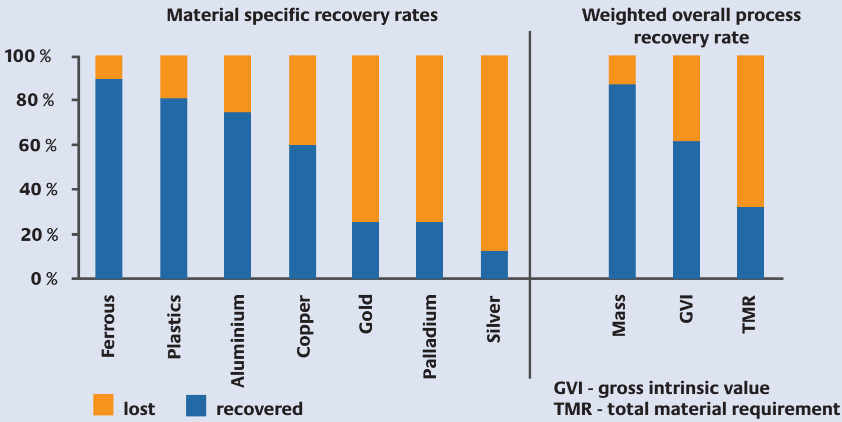
According to the European Waste Framework Directive, the following waste hierarchy shall apply as a priority order in waste prevention and management legislation and policy: (a) prevention; (b) preparing for reuse; (c) recycling; (d) other recovery, e. g. energy recovery; and (e) disposal. This simplified approach is not necessarily meeting objectives of eco-efficiency for the end-of-life management of complex products. These are oftentimes instances where materials cannot sufficiently be separated in the first pre-processing steps and are therefore lost or diluted upon entering particular recovery routes (Hagelücken 2006) (Chancerel & Rotter 2009). This is specifically true for some elements such as the precious and specialty metals which only occur in trace amounts.

On the basis of a case study for Waste Electric and Electronic Equipment (WEEE), a full scale state-of-the-art pre-processing plant (Chancerel et al. 2009), it can be shown as to why assessment tools are necessary to identify and evaluate priorities in the End-of-Life Management for complex products. Material-Flow-Analysis (MFA), the approach of Total Material Requirement (TMR) assessment and economical assessment are compared by considering the data requirements; complexity of evaluation and interpretation of results.

Material specific recovery rate for selected materials and overall process recovery rate are weighed relative to the mass, the gross intrinsic value (price basis September 2008) and the total material requirement in a pre-processing plant for WEEE



As results show, there is a clear trend from high material specific recovery rates for the large mass relevant fractions such as ferrous metal and plastics, over slightly higher losses for aluminium and copper, till significant losses for trace elements such as gold, palladium and silver. Summed up, the investigated process achieves an overall process recovery rate of 83 % and thus complies fully with the recovery target of the WEEE Directive. At the same time, it has to be noticed that, despite an overall mass-based recovery rate of 83 %, this process only recovers approximately 60 % of the Gross Intrinsic Value (GIV) and that, under ecological considerations, materials are being recovered that account only for 38 % of the TMR of the incoming waste.

This research shows that when recycling complex products, there is always the dilemma that liberation and separation are not 100 %. Moreover in recycling there is always a trade-off due to one fraction being partly utilised while the other fraction cannot be recycled. A simple mass-based approach, as stimulated by the European legislation, is not able to assess the environmental performance of recycling as it only looks at the major mass fractions or elements. The minor and trace elements are not accounted for although these are much more relevant from an environmental perspective. Their resources are limited and mining and smelting is accompanied by a high environmental burden compared with base elements such as iron and aluminium. By introducing alternative assessment methods, this can be taken into consideration. Even a simple approach for process evaluation, on the basis of the GIV and the TMR as used in this work, delivers already valuable information to optimise recovery processes under economic and ecological considerations.

In terms of sustainability, material and waste flows have to be steered towards the long-term focus with a more resource efficient way, avoiding dissipative losses of valuable materials over the entire product-life cycle. A systems-view allows identifying leakages for relevant metals in the recycling chain from collection to the end-processing (Hagelücken 2006) (Chancerel et al. 2009). Both technical and organisational instruments have to be applied.

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Estimation of Lifetime Cancer Risk to the Receptors near Landfills: A Case of Okhla, Delhi

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This study focused on estimating the risk of cancer to receptors (adults and children) in and around the Okhla Landfill in New Delhi, a city that generates large amounts of waste and is searching for more effective methods to manage its municipal solid waste. New Delhi at present generates approximately 6,500 tonnes of municipal solid waste every day. More than 90 % of that goes into three landfills at Okhla, Gazipur and Bhalswa and less than 10 % of the waste is biologically processed into compost. The amount of landfill gases was predicted using Landfill Gas Emissions Model (LandGEM) and the ground level concentrations of pollutants were estimated using the Industrial Source Complex Short Term (ISCST3) air dispersion model. The associated cancer risk was determined at different distances from the landfill site.

Risk assessment is helpful to areas of environmental decision-making, such as operation of landfill sites. Risk assessment requires an understanding of the source of a hazard, the characteristics of a receptor that may be at risk from that hazard and the means or pathways by which the receptor may be affected by that hazard.

The site is in an industrial area known as Okhla Phase I and is located in the southern part of the capital state of Delhi in India. The landfill site with an area of 16.2 hectares, receives municipal solid waste at the rate of about 1,200 tonnes/day at present. The landfill started its operations in 1994.

Wastepicker women at Ghazipur Landfill

Estimation of Landfill Gas

Estimation of landfill gas was done using the United States Environmental Protection Agency's Landfill Gas Emissions Model (LandGEM). The Model estimates annual landfill biogas generation using a first-order decomposition rate equation over a specified time period.
Since the depth of the Okhla landfill is not as great as when compared to its surface area, it is considered an area source. To estimate the ground level pollutant concentrations, the air dispersion model ISCST3 was used. In order to do this the area of the landfill was divided in such a way that the ratio of longitudinal and lateral dimensions for each section was less than 10, which is required for use of the model. The 2008 hourly based meteorological data; flow vector, wind speed, temperature, stability category, rural mixing height and urban mixing height was used for the modelling. Receptor locations were used in polar format with radial distances 100, 300, 500, 1,000 and 2,000 m at 36 divisions. Outputs were obtained for first and second highest 1-hour, 24-hour and average ground level concentrations.

Results and Conclusions

The incremental lifetime cancer risks due to six selected carcinogens were calculated in the proximity of 100 m, 500 m, 1,000 m and 2,000 m. Accumulative incremental lifetime cancer risks due to all carcinogens considered were found to be more than of the order of 10^{-6} within 500m from landfills. It was found that the cancer risk due to Vinyl chloride is highest followed by Tetrachloroethylene. This is due to the higher potency factor of these pollutants.

The Okhla landfill poses considerable cancer risk up to a periphery of 500 m from the landfill site. The risk is found to be exceeding the acceptable limit of 10^{-5} as proposed by Central Pollution Control Board, New Delhi, India. At present, the landfill does not have any lining nor any gas collecting systems; remedial action is warranted in order to avert subsequent cancer risk to the receptors.

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Biogas – A Sustainable Technology for Decentralised and Centralised Waste Management Systems

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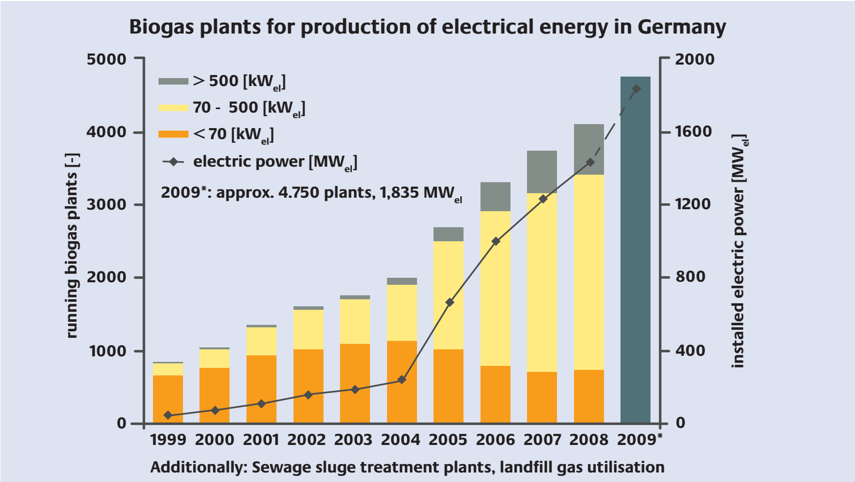
Biogas Utilisation in Germany: Over the past few years, the production and utilisation of biogas has gained much importance in Germany. This was essentially caused by the setting of an appropriate energy-economic framework. The revision of the Renewable Energy Sources Act (Act on Granting Priority to Renewable Energy Sources), in the years 2004 and 2009, encouraged investigators with additional economic incentives to generate electricity out of biomass by using natural state biomass and organic waste, innovative technologies and cogeneration of heat and power (combined heat and power (CHP).

As the figure on page 164 illustrates, due to the increasing number of biogas plants in Germany, the ratio of the total energy converted out of biogas has increased considerably. By the end of 2009, there were about 4,750 running biogas plants with a complete installed electrical capacity of about 1,835 MW_{el} in Germany (see figure, p. 164). Most of these plants can be found in the agricultural sector, primarily using renewable resources. The expansion of the existing facilities into co-fermentation plants allows the utilisation of available organic remnants and waste which are not in competition with food and feed. This is an actual trend that can be seen clearly.



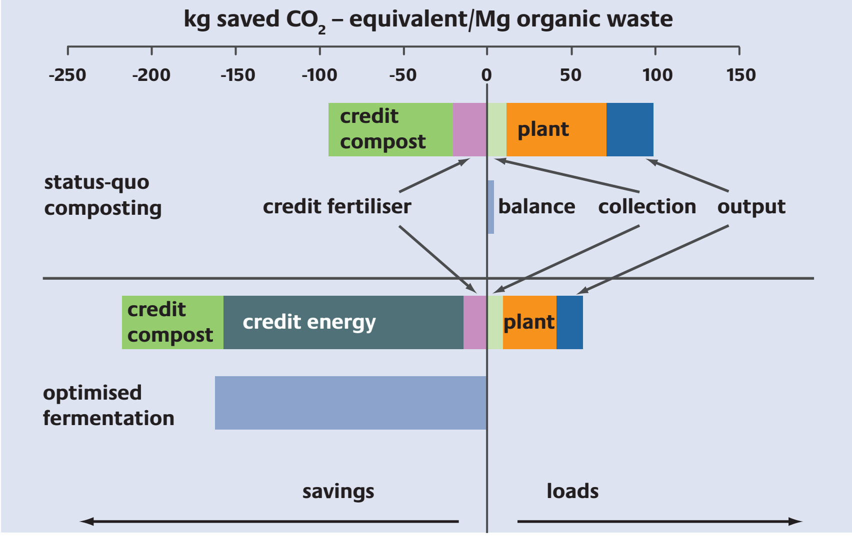
However, in many places it is impossible to extend the running plant concept into larger facilities. Therefore, the existing municipal organic waste fraction, when primarily applied, is approaching full capacity. Based on these premises, most plants in the waste sector evince an installed capacity between 0.3 and 3 MW_{el}. The growing trend of biogas plants, which do not convert the gas directly into electricity on-site, but rather condition the gas to natural-gas quality, which can then be fed into the local gas grid (by the end of 2008 there were 15 plants, mostly in the renewable resource sector), has also an effect on the waste sector. The demand of such components can clearly be observed and some plants with this kind of technology are currently planned or are already in the course of construction.

Biogas: Integration in Waste Treatment Systems

Today, there are about 300 to 500 running fermentation plants in Germany, which utilise, next to municipal separate collected organic waste, partly or mostly industrial organic residues. The separate collection of organic and green waste provides the foundation for the recycling and energetic utilisation of biogenetic waste. Furthermore, combined treatment concepts, consisting of different fermentation and composting stages, can considerably support climate protection. Here, the specific composting of organic waste has a slight negative climate balance, whereas the optimised combined treatment concept can save about 160 kg of the CO_2- equivalent per t organic waste (figure below). Against this backdrop, about 200 of the total 800 biogenetic waste composting plants are to be extended with an additional fermentation stage in the next years (Scholwin et al., 2008).

Even after the separate collection of the organic waste, there is still a considerable share of organic matter in the residual waste in Germany. Out of that residual waste, 75 % is fed to incineration plants. The remaining 25 %

Climate gas emissions from the organic waste utilisation (Scholwin et al., 2008)



Mechanical biological treatment plant in Rostock

of the waste is processed in a material flow specific treatment at about 50 mechanical biological treatment plants. In general, the waste is separated on the basis of its physical substantial characteristics in the mechanical treatment stage. The combustible part, mainly plastics, is then fed to the thermal stage, whereas the organic fraction is processed in an aerobe-composting unit. Today there are about 10 mechanical biological treatment plants equipped with an additional fermentation stage (Engler et al., 2009). The little share of mechanical biological treatment plants with anaerobe technologies can be explained, among others, by higher investment costs and uncertainties in operational safety and control of the fermentation process. Since the integration of such a digestion unit, which is similar to the biogenetic waste treatment, can improve the climate balance of the total waste treatment concept, the fermentation technology will take on greater significance in this sector in the following years. Thus, the mechanical biological treatment plant in Rostock was extended with 3 parallel operated anaerobe digesters in 2008, which you can see in the figure on this page.

Biogas: Research and Development

Over the last years fermentation technology has rapidly advanced and established a firm place for itself within the energetic utilisation of organic waste and the mechanical biological treatment. The integration of fermentation plants in waste management concepts leads to an improvement of the energy efficiency and contributes considerably to climate protection.

Thus, there is still a large amount of research and development potential (Scholwin and Nelles, 2009). Technological optimisation potentials, such as the energetic and utilisation of fermentation residues and biogas, operational safety or process control can further improve the level of efficiency and the relevance of the anaerobe technologies (Nelles et al., 2009). In the following, the main innovation potentials are listed in note form, also see figure on page 168.

Advancements of Plant Technologies and Concepts

- **Development of substrate disintegration methods (mechanical, thermal, chemical or ultrasonic pre-treatment);**
- **Development of concepts for the separate utilisation of the solid and liquid phase;**
- **Concepts for the digestion of solids and special substrates (e. g. green cut or nitrogenous substrates);**
- **Concepts for the separation of the different biological process stages, with the aim of developing a high load process;**
- **Further development of stirring technologies, modulation of the mixing;**
- **Advancements of safety facilities (e. g. pressure relieve valves) to increase operational safety and lower emissions;**
- **Development of measuring systems and strategies (e. g. Micro-GC, NIRS, TS probes, titration or gas measuring systems);**
- **Further development in the fermentation residue treatment to regain nutrients or solid fuels and pre-cleaned wastewater.**

Further development of the process biology

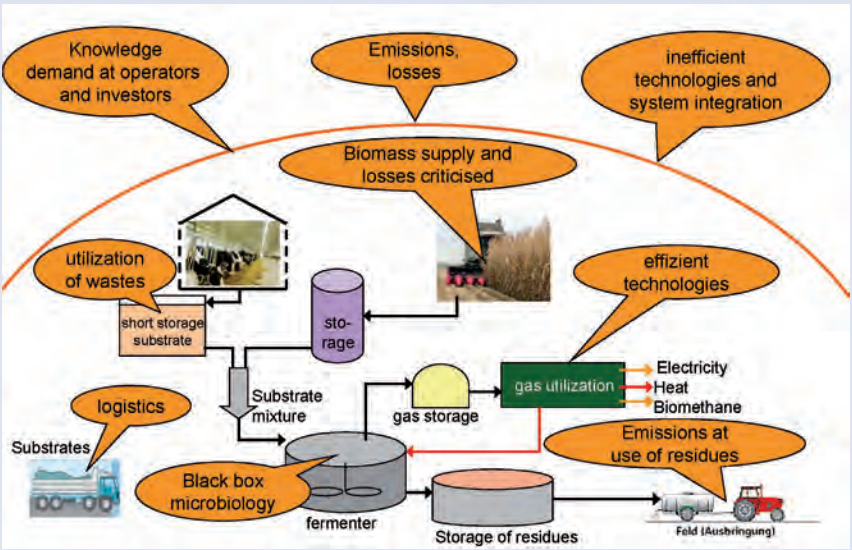
- **Understanding of the process metabolism and involved species and their interaction;**

- **Measuring methods for the microbiological activity / probes for the structure of the microbial society;**
- **Creating dynamic modeling of the organisms behaviour;**
- **Supplying of starter culture media and inoculation substances;**
- **Effect of trace elements / additives or enzymes on the biogas process;**
- **Influence of the hygienisation (of organic waste) on the process biology.**

Further development of the process control

- **Identification of regulating variables;**
- **Process modelling for a comprehensive closed-loop control;**

Biogas: Research and development fields (Scholwin and Nelles, 2009)



- **Plant supervision for intelligent process analysis;**
- **Closed-loop control on the basis of various control and regulating variables.**

Further development of the gas cleaning and treatment

- **Advancement and application of gas dryers to extend the lifetime of different process units;**
- **New technologies for further desulphurisation of the biogas to extend the lifetime of different plant aggregates;**
- **Advancement of existing conditioning methods to lower the energy demand and the methane emission of the plant;**
- **Development of new technologies for the gas treatment (e. g. gas permeation, cryogenic methods or membrane techniques);**
- **Development of treatment and reformation technologies for fuel cells.**

Further development of the gas utilisation

- **Utilisation of biogas in fuel cells;**
- **Application of gas turbines or Stirling engines;**
- **Improvement of the efficiency of combined heat and power coupling;**
- **Methods to lower emissions out of gas utilisation units;**
- **Application to CO_2-fixing of the exhaust gas by algae cultures;**
- **Improvement of system integration of energy out of biomass in existing energy concepts;**
- **Integration of biogas plants in polygeneration concepts.**

Further development of the utilisation of fermentation residues (including transport, storage and utilisation)

- **Understanding of connections between ammonia and climate gas emission while and through application of fermentation residues;**
- **Technologies for the separation and**

treatment of fermentation residues;
- **Specific recovery of nutrients;**
- **Thermal utilisation of fermentation residues.**

By such research and development further improvement of process engineering, energy efficiency and emissions of biogas plants can be attained. Hence, one can expect that the biogas technology will be a very important (probably the most important) sector within the supply of renewable energy out of biomass and organic waste. The utilisation of the biogenetic waste flow is of great importance, especially at the global point of view. For this reason, there are many points of contact for corporate research and development between India and Germany, which should be pursued in the future.

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Energy Balance of Biowaste Compost Used in Agriculture

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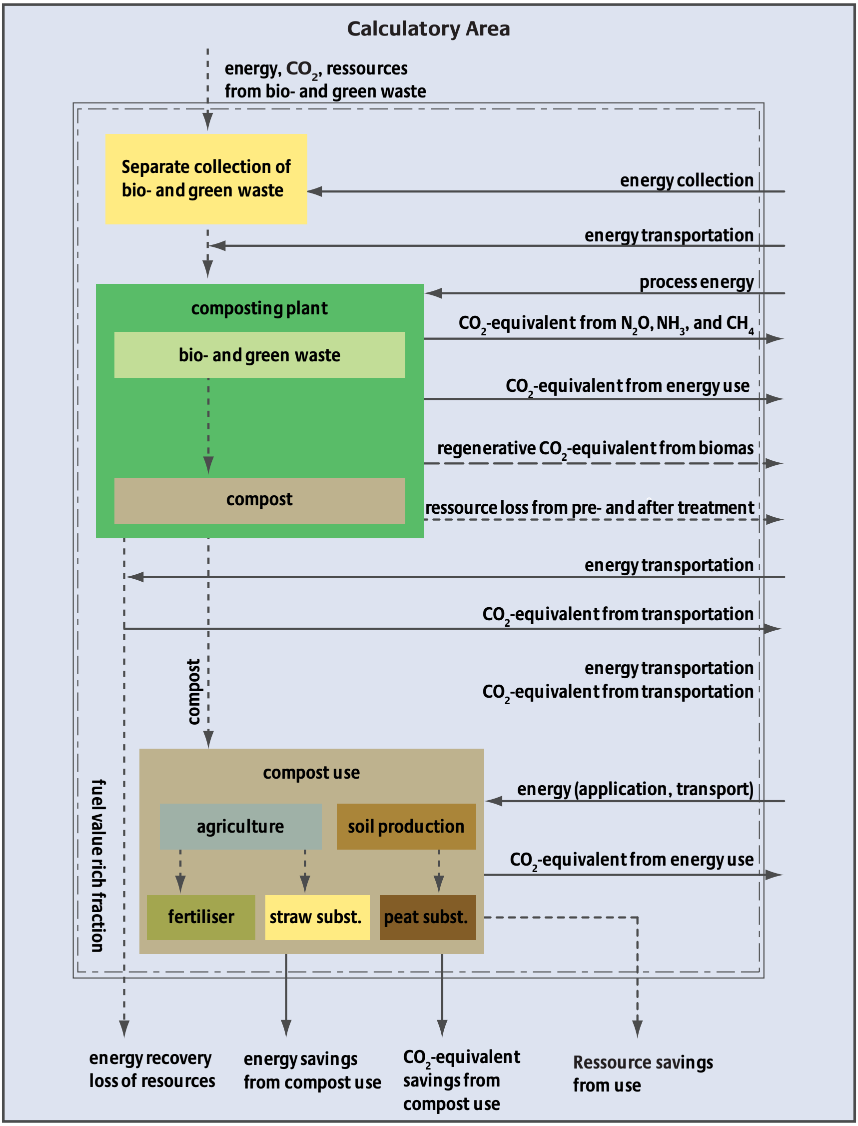
The target of the work was to compile a comprehensive energy and CO_2 balance for composting plants. Apart from the energy consumed in the composting process, the substitution potential of products and the organic primary substances as well as the production dependent emissions and energy consumption related to this was addressed. Products that are to be substituted by compost do not have to be manufactured and thus energy, finite raw material reserves and CO_2 can be saved.

Methodology

In order to illustrate the approach, the considered calculatory area is schematically depicted in the following figure (p. 172). Biowaste and other organic waste that serve as starting materials for composting or even for other waste treatment plants, have not been balanced. It is to be assumed that waste will have to be somehow treated and that the organic carbon incorporated in the waste is of a regenerative nature. Therefore, the carbon dioxide emitted during the composting process, i.e. during the degradation of the organic mass, is not newly introduced to the atmosphere but in fact originates from the atmosphere and is returned to it. The energy consumed by the composting process, as it relates to the greenhouse gases that are released, falls within the calculatory area.


Calculatory Area
energy, CO_2, ressources from bio- and green waste
Separate collection of bio- and green waste
energy collection
energy transportation
process energy
composting plant
bio- and green waste
compost
CO_2-equivalent from N_2O, NH_3, and CH_4
CO_2-equivalent from energy use
regenerative CO_2-equivalent from biomas
ressource loss from pre- and after treatment
energy transportation
CO_2-equivalent from transportation
energy transportation
CO_2-equivalent from transportation
compost
fuel value rich fraction
compost use
agriculture
soil production
fertiliser
straw subst.
peat subst.
energy (application, transport)
CO_2-equivalent from energy use
energy recovery loss of resources
energy savings from compost use
CO_2-equivalent savings from compost use
Ressource savings from use

From the input side, the boundary between the calculatory area and the non- calculatory area is factored before the separate collection and transport of bio-waste and green waste to the composting plant. The waste flow therefore develops beyond the calculatory area, as waste is a permanently incurring factor, independent of composting. Separate collection is included in the balance, as it is viewed as the pre-requisite for a product that will guarantee the quality of the compost.

Also included in the balance is the energy and C consumption of the composting plant for the decomposition process and for the compost application later on. The energy required between these steps, for transporting etc. is also taken into consideration. In addition to this, the possibility for segregating the heat value-rich fraction during the treatment (after decomposition) and feeding it in for energetic evaluation is also considered. Energy and CO_2 saving as a result of compost application and the substitution of other goods related to this, is put on the positive side of the balance. Goods that can be substituted owing to compost application are peat, mineral fertilisers and straw.

Data Compilation

Subsequently, all relevant data from the processes within the system boundary of the considered systems is compiled. The reference values are one mega gram input material as wet mass (fresh matter, FM), subsequently Mg wet mass input, one mega gram compost, also as wet mass or as dry mass (DM). The enumeration is done as energy in Joules (or MJ) and CO_2-equivalents in kilogram (kg).

Composting

According to Springer, composting plants were subdivided into 5 groups. Specifications to energy consumption and CO_2-emission are given in the following table (Springer, 2010).

Table 1: Primary energy consumption in each process according to the form of energy and total consumption

Type of composting process	Total primary energy requirement [MJ / Mg FM input]	Emission of greenhouse gases as CO_2-equivalent [kg $CO_{2\text{-eq}}$. / Mg FM input]
1 – non-aerated, wheel loader	92	65.5
2 – non- aerated, windrow turner	190	70.8
3 – BM5 low, and BM6	177	50.5
4 – capsulated plants	396	65.7
5 – BM5 high	559	77.1

Use of Compost as Substitute for Peat

Compost can be used as a substitute for peat. This has no advantages from the energetic point of view, but CO_2 stored in the peat is thus prevented from being released into the atmosphere. The amount saved depends on the factors of the peat substitute. The factors calculated by Springer (fresh compost F = 0.44 Mg peat / Mg compost and matured compost F = 0.38 Mg peat / Mg compost) show savings of 792 kg $CO_{2\text{-eq}}$ / Mg FM compost for fresh compost and 684 kg $CO_{2\text{-eq}}$ / Mg FM compost for matured compost (Springer, 2010). The basis is that 1 Mg peat would release 1.8 Mg $CO_{2\text{-eq}}$ (Springer, 2010).

Application of Compost as Fertiliser

The energy substitution potential while applying compost as organic fertiliser arises from the fact that mineral fertilisers are then not used and thus energy is saved. If the energy consumption and the $CO_{2\text{-eq}}$-emission that accompanies the production of mineral fertilisers is multiplied by the nutrients present in the compost, a value for energy and CO_2-equivalent saved through the application of compost, is obtained. The calculations are shown in the following table.

Table 2: Energy Substitution Potential through Compost Nutrients in Applying Compost as an Organic Fertiliser

	Fresh compost		Matured compost	
	Energy [MJ / Mg TM]	CO_2 – equivalent [kg CO_2 / Mg TM] Energy	Energy [MJ / Mg TM]	CO_2 – equivalent [kg CO_2 / Mg TM] Energy
Nitrogen	382	39.4	322	33.2
Phosphorus	168	8.0	134	6.4
Potassium	146	8.6	123	7.3
Calcium	100	5.7	100	5.7
Total	**796**	**61.7**	**680**	**52.6**

Utilisation of Compost as a Substitute for Straw

The possible substitution potential for compost based on primary energy and the saving of greenhouse gases is shown in the two following tables. The conversion to primary energy is done by assuming the generation of electrical energy in a straw-powered energy plant with an efficiency factor of 30 % (Kniepr, 2007, MVV, 2010). This electrical efficiency factor can be considered high based on biomass but is not a peak value. Some biomass power generating plants show efficiency factors of over 35 % (MVV, 2010, SWL, 2010). In favour of the comparability of the established values, thermal use is not taken into consideration as this is not possible at all locations.

The equivalent value for primary energy is calculated with the help of a primary energy factor of 2.61, for the German energy mix (Probas, 2009). The CO_2-equivalents are calculated with the factor 0.176 kg $CO_{2\text{-eq}}$ / MJ according to Probgas for the final electrical energy (Probgas, 2009). Surplus or loss of plant nutrients (N, P, K, Ca) is also included in the calculations. The substitution of 1.24 Mg straw through 1 Mg fresh compost and 1.05 Mg straw through 1 Mg matured-made compost is used as a basis. Summarising this a value of 14 MJ/Mg FM saved energy and about 1 Mg $CO_{2\text{-eq}}$ / Mg FM input for fresh compost is obtained on substituting compost for straw, the value obtained with matured made compost is slightly lower.

Heat Value-Rich Fraction

It is not possible to determine consistent and generally valid values for the quality and quantity of the heat value-rich fraction in bio-waste or in green waste. It can only be deduced from literature that 3M-% of bio-waste and up to 30M-% of green waste can be recycled to obtain energy. The threshold for considering thermal utilisation as reasonable is given as an Hu of 11.000 MJ / Mg FM (Meyer, 2009). The equivalent in primary energy is calculated analogous to the energy utilisation from straw, by assuming the generation of electrical energy in a biomass power generating plant having an efficiency factor of 30 % (Kniepr, 2007, MVV, 2010). Heat utilisation is not taken into consideration. The conversion of the electrical energy generated into primary energy is done with the help of a primary energy factor of 2.61, for the German energy mix (Probas, 2009). The CO_2-equivalents are calculated with the factor 0.176 kg $CO_{2\text{-eq}}$ / MJ for the final electrical energy.

Collection and Transport of Biowaste

The most current data on transport is given by Probas as 0.04 l / (Mg ·km), calculated from the data for transport with a truck for average distances and traffic conditions in Germany taking a capacity utilisation of 50 % into account. The “empty” return is therefore included in the assumption (Probas 2009). These values for transport were subsequently used by Mertens and Krumm for evaluating the collection (Mertens et Krumm 1998). Taking into consideration a distance of 5 km covered for collecting and 40 km for transport to the treatment plant and the return journey, an approximate value of 1.30 l diesel/mg is deduced for biowaste collected and transported to the plant. The value deduced for the primary energy consumed is 60 MJ/Mg waste. The resulting emission of CO_2- equivalent was calculated according to IFEU [2004] from 0.087 kg CO_2 / MJ for energy from diesel to 4.0 kg CO_2/Mg waste.

Transport of Compost to Compost Application and Utilisation

An average diesel consumption of 0.06 l/(mg ·km) is assumed as a basis (Probas 2009). This value is related to the use of a heavy tractor, state Germany 1995 – 2000, with a capacity utilisation of 100 % during the onward journey and an empty return journey. Taking an average distance of 15 km, a value of 0.9 l diesel/(Mg compost) is deduced. This is equivalent to 41 MJ/ Mg compost primary energy and a CO_2-emission of 2.8 kg CO_2-equivalent/Mg compost. No data is available in literature on the energy consumption for the application of compost. Only an extra cost of 0.32 €/dt compost-FM is mentioned (Reinhold, 2009b, LVLF, 2008).

Subsequently the additional energy required for application of the compost is calculated to an approximation. Assuming a typical amount of 10 dt / ha compost applied every three years, and a metering width of 10 m (GKRS, 2009), a distance of 1 km is deduced, that will be necessary for distributing the compost evenly over the whole area. In order to also calculate the energy required for ejecting the compost in addition to the energy required for driving on the field, a value of 1.2 l/(km · Mg) is assumed. This is the sum of 0.6 (l/km · Mg) for "transport" on the field and 0.6 l/(km · Mg) for the actual application. Thus, a primary energy consumption of 55 MJ/Mg compost and a greenhouse gas emission of 3.7 kg CO_2-equivalent/Mg compost is calculated.

Transport Straw for Energy Recovery

According to Knieper, larger straw powered plants with capacities around 50 MW are the most economical ones and have an average catchment area of 60 km (Knieper, 2007). Since the energy content of straw would enable for having a larger catchment area and would also be more economic, an average distance of 100 km is assumed for the following calculations. Taking into consideration a transport with a 23 t truck, needing 0.04 l diesel/(Mg ·km), an energy expenditure of 185 MJ/Mg straw and a greenhouse gas emission of 12.6 kg CO_2/Mg straw is deduced (Probas, 2009).

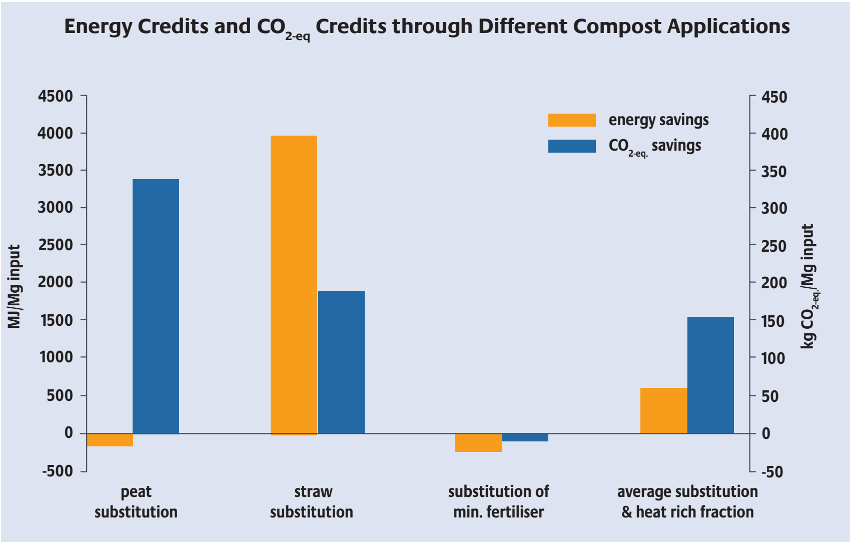
Transport Heat Value-Rich Fraction for Thermal Recovery

According to Wagner the average transport distance for waste from the free state of Saxony to a disposal plant, mainly waste combustion plants, is 101 km (Wagner, 2003). This average transport distance is taken for the heat value-rich fraction in the following as it can be assumed that the distances between the composting plant and the waste combustion plants are about the same. Considering a 23 t truck , an energy expenditure of 185 MJ/Mg HF and a greenhouse gas emission of 12.6 CO_2 / Mg HF is calculated (Probgas, 2009).

Results

In conclusion, scenarios that combine the compost plants and compost applications are created. These reference scenarios provide an insight to the real situation at present in Germany with regard to the EC-balance. For this data from data sheets of several plants are collected and balanced. Owing to the limitations specified for the paper, it was not possible to depict the results of the balancing for the reference scenarios in a comprehensive manner. Summing up it can be said that for all the plants taken into consideration, a negative energy balance (50 – 500 MJ primary energy / Mg primary energy) and a positive CO_2-balance (80 – 160 kg $CO_{2\text{-eq}}$ / Mg input of savings) was established.

Finally, the different utilisations of compost were closely investigated with the help of recycling scenarios. The main focus of the balancing was not on the actual properties any more, but on comparing the different applications of compost. The results of the compost scenario balancing are shown in the following figure (p. 179). Dark bars represent energy credits obtained by the substitution of other goods through compost, deducting the energy used for collecting and transporting the waste, for composting, applying the compost and where applicable for transporting the substitution goods. The light bars represent the savings in $CO_{2\text{-eq}}$, as the amount of CO_2 that could be avoided through the application of compost. Positive values represent positive effects, and negative values negative ones. The units are MJ primary



energy and kg $CO_{2\text{-eq}}$ per Mega gram fresh mass input material used (bio waste and green waste).

On comparing the different possibilities of application it becomes apparent that the substitution of mineral fertilisers alone is not sufficient to balance the energy requirements and CO_2-emissions in the selected operation areas. Likewise, utilisation of compost for substituting peat cannot replace the primary energy needed, but gives the highest possible CO_2-credit of ≈ 320 kg CO_2 per Mega gram of waste collected. The utilisation of straw for energy, which has not yet been established in Germany, would give an energy credit of ≈ 4000 MJ primary energy and ≈ 180 kg $CO_{2\text{-eq}}$ could be avoided if compost would substitute straw for humus production in the fields.

The last two bars represent the compost scenario with the present distribution of compost applications (40 % peat substitution, 50 % application as organic fertilisers, 10 % no substitution) with an extraction of 10 % of the input material as heat rich fraction (with Hu = 11.000 kJ / Mg) before the biology. This combination is positive in relation to both energy and the emission of greenhouse gases. About 500 MJ / Mg input material of primary energy and approximately 150 kg $CO_{2\text{-eq}}$ is saved at the same time. If this scenario is transferred to the standard scenarios, all plants would show a positive energy balance. These results agree to those of Schmidt, who writes that all the plants investigated by him were able to show a positive balance through the energetic utilisation of heat rich fraction (Schmidt, 2009).

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Hydrogen Production from Organic Waste

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Hydrogen is the energy source of the future, but only when it is produced with renewable resources. The knowledge of the limited deposit of fossil fuels and the public awareness that global warming is caused by emitting CO_2 through burning fossil fuels has led to an increase of interest in sustainable energy production.

Biomass is considered to be one of the most important renewable energy sources in the world. Theoretically, the annually accruing biomass contains enough energy to cover worldwide energy demand. Furthermore, it is the only renewable energy that can be used for energy storage without a high technical effort.

Even though energy production with a fuel cell is climate neutral, nowadays hydrogen is primarily being produced by reformation of oil or gas, wherein CO_2 is being emitted, making this process not sustainable. With the technique of anaerobic degradation a biological and CO_2 neutral option for producing hydrogen has been illustrated.

Within the biological hydrogen production field, bio photolysis and dark fermentation are two potential methods with different approaches.

Bio Photolysis: Setup and Basic Conditions

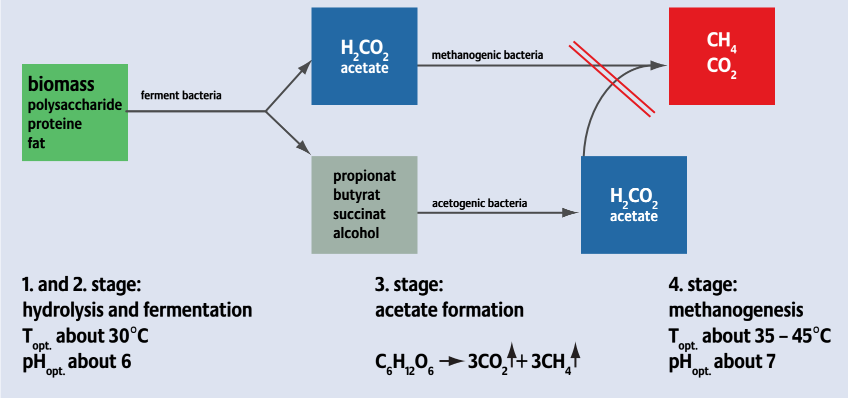
In the biological photolysis, a certain type of algae is used to produce hydrogen from water. Not all algae types are capable for this reformation. The algae need to reach a certain redoxpotential to start the reforming process. The energy source that is used for this process is light. Under natural conditions sunlight only reaches the first layers of algae and therefore low lying algae will not be supplied with enough energy, either for growing or for the water reforming process. Possible ways to avoid this problematic issue are to either enlarge the surface area or to use a light emitting diode (LED's) to conduct light into deeper layers of a reactor basin.

Furthermore, the setup of the treatment plant plays an important role. Due to the fact that algae need diverse conditions for growth and for hydrogen production, two reactors are necessary. Algae need sulphur for growth but need a sulphur free environment for hydrogen production. Beyond this, the permanent supply with light is an important cost and energy factor, making the bio-photolysis process less efficient.

Dark Fermentation: Process, Research and Results

Process

The process of dark fermentation contributes to the breakdown of organic waste into simple compounds. Therefore, three types of organisms (aerobic, anaerobic and anoxic) can be distinguished. Aerobic organisms use oxygen as an electron acceptor. Anaerobic organisms require an oxygen-free environment and anoxic medium requirements are present if inorganic hydrogen-bearing compounds are available as oxidisers. The type of oxidiser affects the decomposition of the substrate quantitatively and qualitatively, meaning that the breakdown of constituents reaches a greater or lesser degree of completion depending upon the oxidiser. The factor ultimately affects the energy conversion achieved by the organisms, which in biological systems is attributable to the redox reaction of hydrogen.

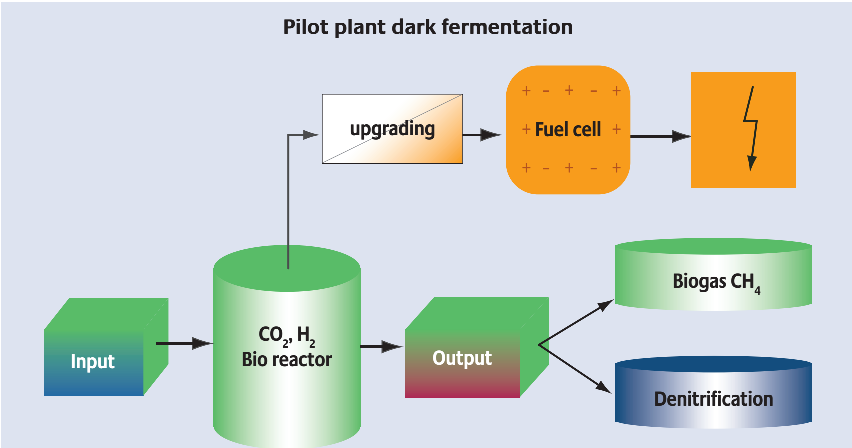


The four stages of anaerobic degradation (Krupp 2007: 7)

The process of dark fermentation takes place in the absence of light. The organic compounds are therefore used as the carbon source. The advantages of the anaerobic degradation are the high metabolic rate, the associated slow biomass growth and the incomplete conversion of the input material, which leads to the formation of methane and hydrogen (Krupp 2007:6). Anaerobic degradation occurs in four stages (hydrolysis, acidogenesis, acetogenesis and methanogenesis) (see Figure above).

In the first stage, hydrolysis, high molecular weight materials, such as proteins, fat and polysaccharides, are broken down by enzymes into lower molecular weight components. Due to the absence of oxygen, subsequent decomposition for the purpose of energy gain can only proceed as far as the formation of organic acids and alcohol. Under anaerobic conditions a bacterial population arises which completes the chemical breakdown process. The outcome of this process is carbon dioxide and methane with carbon as hydrogen acceptor.

During the four steps of anaerobic degradation, hydrogen is produced in two of them, acidogenesis and acetogenesis. When aiming for methane,



hydrogen only occurs as an intermediate product, which is then further utilised by methanogenic bacteria to form methane. Therefore, the partial pressure of hydrogen is an important factor that influences this treatment step.

In methane fermentation, an energetically favourable window is provided by acetate production and methane production, so the methanogenic bacteria are able to consume the intermediate hydrogen and gain energy. Therefore, compared to the methane production, when the aim is on producing hydrogen the environmental conditions need to be adapted and the hydrogen needs to be extracted before methanogenic bacteria can react with it.

Plant Setup

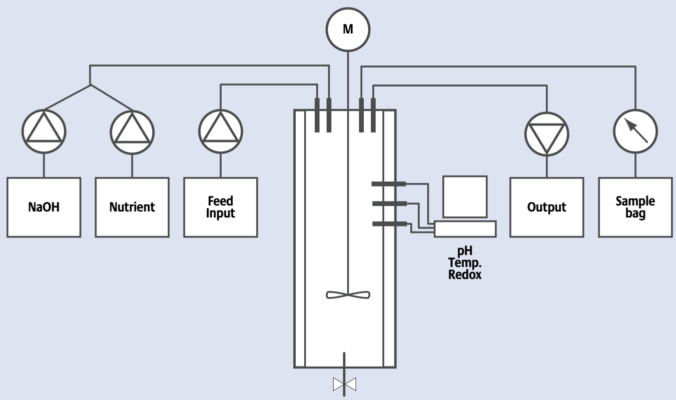
In the Figure above, a potential plant setup is displayed. Here the incoming biomass is treated in a bioreactor to form hydrogen. As a by-product carbon dioxide occurs. The produced hydrogen is then being extracted from the reactor and upgraded to increase the density of H_2 in the gaseous mixture. In a fuel cell, the hydrogen is used for energy production. The produced electricity can either be fed in the power network or used to make the treatment plant energy self-sufficient. Compared to the energy production by a Coal Handling and Preparation Plant (CHPP) using methane, the efficiency of a fuel cell is eminently higher.

The bioreactor's output can be used for different purposes. The figure on page 185 shows two options. Since the fourth step of anaerobic degradation has not been accomplished, the output can be used in a downstream bioreactor for methane production. Provided that a Waste Water Treatment Plant (WWTP) is nearby the hydrogen plant, the output can also be used as carbon source for WWTP's biological process stage.

Research and Results

At the University of Duisburg-Essen, research on anaerobic hydrogen production at diverse boundary conditions has been conducted. Herein,

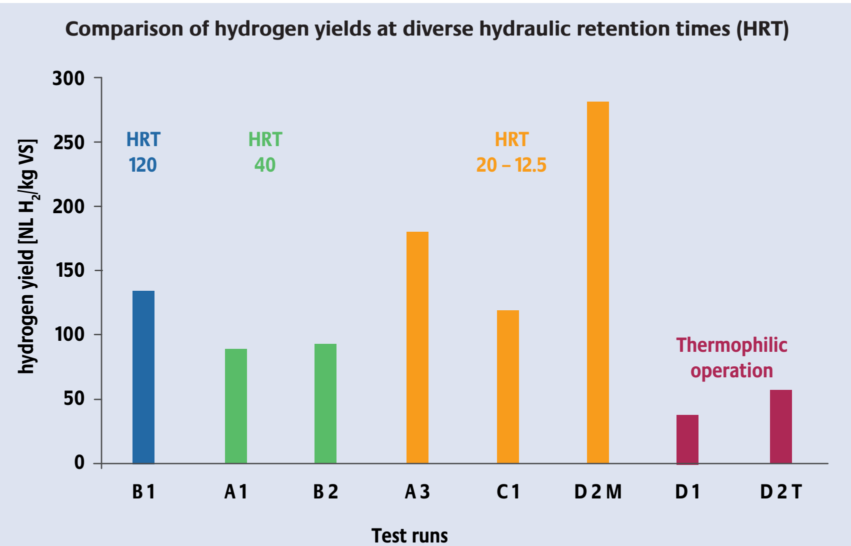
Layout of a continuous reactor for anaerobic hydrogen production



the Hydraulic Retention Time (HRT), Organic Load Rate (OLR), temperature, feeding intervals and different substrates have been varied to indicate the best conditions for anaerobic hydrogen production.

The figure on page 186 displays a lab scale setup of a continuous reactor for hydrogen production. Temperature and pH-value were monitored continuously. NaOH was used to keep the pH-value in the basin at a range of 4 – 5.5. The feeding intervals of the continuous tests were varied between 2.4 and 12 hours. The OLR was kept between 2 and 14 kg VS/m^3 · d. Substrates used for the testing series were waste sugar, juice-mix and rye flour. The HRT was reduced from 120 hours down to 12.5 hours.

The results of the research clearly identified the best conditions for hydrogen production at short hydraulic retention times between 20 and 12.5 hours. With the short HRT and an OLR of 6-14 kg VS/m^3 · d a maximal H_2-concentration of 60 % [Vol.-%] has been measured. At similar boundary



conditions hydrogen yields between 1 and 2.1 mol H_2/mol glucose input were measured whereas with the chosen input a calculative maximum of 2.5 mol H_2/mol glucose is possible.

$$4\,C_6H_{12}O_6 + 2\,H_2O \rightarrow 2CH_3COOH + 3\,CH_3(CH_2)2COOH + 10\,H_2 + 8\,CO_2$$

The figure on page 187 shows the measured hydrogen yields for three different HRT. Here it is obvious that mesophilic conditions combined with a short HRT are the most optimal conditions for anaerobic hydrogen production.

Advantages of Biological Hydrogen Production

In comparison to the biological methane production, the biological hydrogen production provides numerous advantages:

- **The treatment time is reduced extensively. Whereas methane needs several days to be produced biologically, hydrogen only needs hours;**
- **The reactor volume can be reduced to approximately 1/10 of the methane reactor volume;**
- **Through the use of fuel cells the energy production with hydrogen is more efficient;**
- **The energy efficiency of the hydrogen plant can furthermore be increased by implementing a downstream methane producing bioreactor.**

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Biogas from Waste

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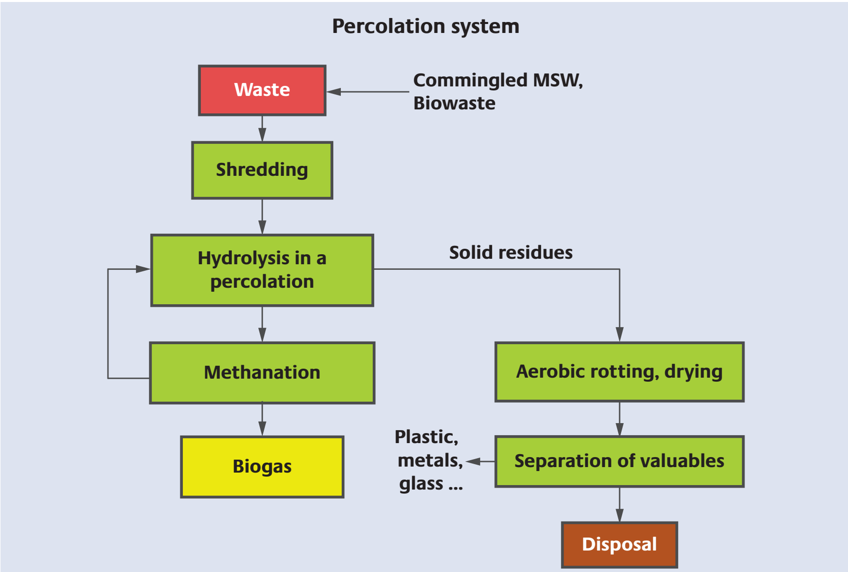
Both the controlled and optimised methane production in engineered processes for the purpose of electrical or heat energy generation and the production of made-up biogas ("bio-natural gas") have been attracting increasing attention from environmental, economic, technological and political interest groups due to the fact that energy from biomass via methane formation is considered a "green energy". Biomass is understood as any type of organic (biodegradable) waste: agricultural waste, food and restaurant waste, biowaste, municipal solid waste, slaughter waste, marc, molasses, food processing waste, and so on. Biogas production gradually replaces composting because of energetic reasons. Simultaneously, through harnessing expelled gas from landfills the uncontrolled release of methane can be avoided and hence, the capture of biogas waste contributes to a reduction in greenhouse gases.

When looking specifically at biomass, as a component within the overall Municipal Solid Waste (MSW) system, there are three main processes currently available to best utilise the biomass for energy production. These are as follows:

1. **The pulper system: First, all incoming waste is shredded and then suspended using a pulper, a machine that is well known within the waste paper recycling industry. The impurities such**



as sand, plastic, stones, glass and metals are then removed from the mixture using a combination of drum sieves, hydro cyclones, settling tanks, etc. After these cleansing steps, the liquid contains only finely dispersed or dissolved biodegradable matter, which is then exposed to single or double stage fermentation. After fermentation, the remaining solid matter is composted and can be used as compost in the non-food area.

2. Dry mechanical segregation before fermentation: The majority of the biowaste has a particle size below 60 – 80 mm. Thus, it is possible to produce a biomass-rich fraction by sieving the mixture, this done by applying a mesh with a width of approximately 70 mm to the biowaste. Biodegradable components can be enriched and concurrently, valuables can be separated. After mixing with water, heavy fractions (glass,

sand, stones, etc.) are removed through means of a settling process. Afterwards, the liquid is ready for fermenting.

3. **Hydrolysis by percolation of mixed waste: For this process, the waste needs merely to be pre-shredded and does not require a separation of the waste constituents to create a viable end product. After a maximum of 7 days, most of the biomaterial has been degraded and the remaining waste can be discharged from the percolator. Drying and/or composting prepares the material for the separation of valuables. The hydrolysate is then fed into the methanation reactor, which was designed to be as sludge bed, or fixed bed reactor.**

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Bioethanol Preparation from Municipal Solid Organic Wastes: Advanced Pre-treatment Processes for Lignocellulosic Wastes

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Substituting fossil fuels with waste biomass derived cellulosic ethanol is a promising strategy to simultaneously meet part of our energy needs, mitigate green house gas emissions, and manage municipal solid waste. Municipal solid waste is the single largest source for lignocellulosic substrates in developing countries. Urban India generates 40 million metric ton per annum (≈ 3 %) of municipal solid waste in which 50-52 % is organic/green waste, all of which could technically be used for cellulosic ethanol production. Based on compositional analysis, it has been estimated that 44.9 to 128.3 gallons ethanol /dry ton of municipal solid waste could be potentially produced. Accordingly, there is a possibility of producing 1.35-3.85 billion gallons of ethanol/year from municipal solid waste in India.

Why Pre-treatment of Lignocellulosic Substrates?

Pre-treatment of lignocellulosic biomass is a vital step to disintegrate the cell wall structure and enhance the susceptibility of cellulase enzymes. Pre-treatment alters the structure of cellulose and makes it more accessible to the enzymes that convert carbohydrate polymer into fermentable sugar

Dried cow patties are used as fuel in stoves or as bricks for construction

(Bak et al. 2009). Thus, the general idea of pre-treatment is to remove or alter hemicelluloses or lignin, decreasing the crystallinity of cellulose and increasing the surface area.

Challenges in Pre-treatment of Lignocellulosic Substrates

Until now, the overall conversion of cellulose material into glucose has been hampered by economic problems such as high cost of pre-treatment. Despite plenty of research having been carried out all over the world, inexpensive energy and efficient pre-treatment of lignocellulosic substrates for cellulosic ethanol production has yet to be demonstrated.

Conventional Pre-treatment Processes

Generally, pre-treatment methods are either physical or chemical. Some methods incorporate both effects. A number of chemical pre-treatment processes have been proposed by different workers and among them dilute acid pre-treatment has been widely studied because it is effective and inexpensive (Sun and Cheng 2005). Steam pre-treatment (with pressure) is also one of the preferred methods for lignocellulosic feedstocks. Steam pre-treatment supplies moist heat under pressure that results in substantial breakdown of the lignocellulosic structure, hydrolysis of the hemicellulosic fraction, depolymerisation of the lignin components and defibration (Ruiz et al. 2008).

Advanced Pre-treatment Processes

Among the advanced pre-treatment process technologies, microwave irradiation is very important. A microwave generates thermal energy through dielectric heating, which changes the ultra structure of cellulose, degrades lignin and hemicellulose and increases the enzymatic susceptibility of reducing sugar (Kitchaiya et al. 2003). Ultrasonication is another efficient method of lignocellulosic substrate pre-treatment. Ultrasonication can be a promising alternative to conventional hydrolysis methods (Wong et al. 2009). Ultrasonication is the act of applying ultrasound energy to agitate the particles to speed up dissolution of molecules by breaking the intermolecular interaction. Moreover, ultrasonication has the ability to degrade polymeric sequences and to extract lignin and hemicellulose from lignocellulosic materials (Sun and Tomkinson 2002).

Use of cellulose solvents is another method of advanced lignocellulosic substrates pre-treatment. Solvents that dissolve cellulose can increase the rate of conversion of cellulose to glucose and also enhance the efficiency of enzymatic hydrolysis. Alkaline H_2O_2, ozone, organosolv (uses Lewis acids, $FeCl_3$, (Al)H_2SO_4 in aqueous alcohols), glycerol, dioxane, phenol, or ethylene glycols are among solvents known to disrupt cellulose structure and promote hydrolysis. Concentrated mineral acids (H_2SO_4, HCl), ammonia-based solvents (NH_3, hydrazine), aprotic solvents (DMSO), metal complexes (ferric sodium tartrate, cadoxen, and cuoxan), and wet oxidation also reduce cellulose crystallinity and disrupt the association of lignin with cellulose, as well as dissolve hemicellulose. Although these methods are effective, they are not economically feasible considering the value of alcohol produced.

Conclusion

Extensive research is still needed for an economically feasible and industrially compatible pre-treatment process of lignocellulosic substrates including municipal solid waste and to make cellulosic ethanol a dearer commodity.

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Gasification of Solid Wastes: Opportunities in India

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India generates 40 to 45 million tons of municipal solid waste every year and it contains approximately 45 to 50 % (w/w) organic matter. Urban areas within the country are in the process of adopting modern and scientific ways of municipal solid waste management under various schemes sponsored by the government. The major thrust is given on the segregation of municipal solid waste at source, processing of organic content, and sanitary landfill for the residual municipal solid waste. Although there are many waste processing technologies such as composting and biomethanation, which are commercially available, there can be teething problems while adopting such technologies to an Indian scenario.

The major issues of concern are the extreme variations in geographical, ecological and climatic conditions on the Indian continent. Availability of non-agricultural land is another issue that pops up in the context of food security. There are several regions that are ecologically fragile and having extreme climatic conditions, where composting and incineration technologies are ruled out. Also, biomethanation technologies would have severe limitations in such areas. These are the appropriate opportunities for the gasification technologies, which need to be revisited in the Indian context.

Floating a biogas plant in South India

Municipal Solid Waste Processing: Treatment Options and Constraints

The technological options available for processing of organic fraction of the municipal solid waste fall in two major categories

- **Thermal treatment such as incineration and gasification and**
- **Bio-treatment such as biomethanation and composting.**

These major options have to be evaluated in view of the typical Indian scenario, wherein there is a lot of variation in municipal solid waste characteristics owing to dietary habits and relatively poor segregation. In addition, any technology adopted has to deal with extremely large volumes of municipal solid waste, obviously owing to the very large population.

Incineration or Mass Burning

Incineration or burning technologies are commonplace and normally oxidise the organic fraction in municipal solid waste to carbon dioxide and water. If the temperatures are properly maintained, the possibility of formation of toxic dioxin and furans can also be eliminated. The incinerators are available commercially worldwide; however, the incineration plants for municipal solid waste in India have not been successful due to segregation problems and high moisture content of municipal solid waste. This is more discouraging when incineration is linked to power generation.

Bio-Methanation

Bio-methanation technologies utilise the organic portion of municipal solid waste for producing biogas, which can be used as a fuel. There are many technologies commercially available, which incorporate many bioreactor configurations and processing sequence, some of which are patented too. Consistency of municipal solid waste characteristics and efficient segregation are the prerequisites for successful biomethanation. As mentioned earlier these are the major bottlenecks faced in the Indian municipal solid waste scenario. Toxicity due to heavy metals is another constraint. In addition, most of the biomethanation technologies operate slurry reactors, wherein maximum solids concentration allowed is seldom above 15 %. This necessitates huge water quantities for the treatment. Considering municipal solid waste generation volumes in India and water security, biomethanation becomes a limited choice.

Composting

Composting has been advocated widely in India as the most viable municipal solid waste processing option. The composting technologies are mature and practiced at many places in India. However, segregation, dewatering needs, and large area requirements are the major problems restricting the use of composting, especially in urban areas. In-vessel composting is considered as an alternative, but it has cost and capacity limitations.

Gasification of Municipal Solid Waste and its Advantages

Gasification is a well developed technology and widely used worldwide, especially during World War II and various oil crises. In due course of time, it lost its way to more economical technologies based on fossil fuels. This is quite true as far as power generation is concerned; however, there is a need to revisit the gasification technologies especially in the context of municipal solid waste processing. The major advantages of gasification as a municipal solid waste treatment option are:

- **Generation of fuel gas, which is relatively clean;**
- **Efficient segregation is not strictly required;**
- **Presence of moisture helps shift reaction;**
- **Low temperature operation;**
- **Possibility of use of other solid residues in the feed;**
- **Waste volume reduction;**
- **Possible use of pyro-char residue as adsorbent material or low cost fuel etc.**

Gasification Process

It refers to conversion of high molecular weight organic compounds to low molecular weight compounds in oxygen deficient conditions at high temperatures, usually above 400 °C. The typical end products are CO, H_2, low molecular weight organic compounds, N, and S. The end products vary according to the mode of gasification, which is broadly categorised as indirect heating, ho gasses mixing, partial oxidation, steam oxidation etc. Use of steam is common and moisture in the municipal solid waste would be advantageous.

There are a few commercialised gasification technologies available worldwide; mostly utilising circulating fluidised bed techniques. However, all such technologies have to be modified for the Indian scenario.

Data Gaps and Need for Research

There are many areas pertaining to gasification of municipal solid waste, where data gaps exist and more focused research is needed in these areas as delineated below.

- **Type of feed- RDF pellets or amorphous:**
- **Municipal solid waste feed additives- plastic, agro-residues etc.;**
- **Optimisation of operating conditions for Indian Scenario;**
- **Utilisation of product gas-as fuel or for power generation;**
- **Characterisation and utilisation of solid residue after gasification;**
- **Application to hazardous wastes.**

Probable Areas of Collaboration

Gasification technology for municipal solid waste is most suited for the hilly areas in India, especially north-east India, where availability of plane land is a major constraint. Incineration is not recommended considering the ecologically fragile nature of these areas. Availability of water is another constraint in these areas. There is a huge potential for gasification technologies in these areas and collaboration is possible.

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Waste as an Energy Source

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Europe has a wide array of plant types and sizes at present. The most common technology used for municipal solid waste incineration is the grate furnace. However, other technologies exist including fluidised bed furnaces and gasification plants.

Municipal solid waste incinerators are forms of "end of pipe" techniques where various waste categories with several characteristics have to be treated. This requires specifically designed combustors. On principle, a waste incineration plant can be divided into either the thermal main process or the flue gas cleaning system.

The cost structure of a municipal solid waste incinerator depends on many factors such as the size and age of the facility, the type of energy recovery system, the method of flue gas cleaning employed and the degree to which slag and other precipitates are utilised through the flue gas cleaning system. Therefore, the treatment prices vary greatly, ranging from between 80 and 280 €/ton (Bilitewski, 2005).

Municipal solid waste incineration plants are often a subject of controversy, usually because of their flue gas emissions. After emission limits, came into effect, and to meet these regulations, operators have had to invest large sums of money into creating flue gas treatment devices such as acid gas scrubbers, electrostatic precipitators and/or bag house filters. Due to these measures, the amount of dioxins in Germany dropped to 1/1,000 between

Okhla landfill

the years 1990 and 2000. In 1990 one third of all dioxin emission in Germany came from waste incinerator plants, by the year 2000 the contribution was less than 1 % (Stengler, 2006).

Depending on the waste composition, most household waste consists of biogenic or renewable parts ranging from 57 % to 73 % by weight. The main biogenic fractions are yard and kitchen waste, paper, cardboard and wood. It is obvious that the emission factors, as it relates to the energy content, of the waste types are clearly below that of the fossil fuels, but this does not necessarily mean that the waste incineration with energy recovery always results in a reduction of CO_2 output. The reduction potential of waste-to-energy plants depends on the type of fuel being used and the efficiency of the energy production compared to other forms of energy production, such as refuse derived fuel in power plants. The reduction of CO_2 is a comparatively cheaper alternative when compared with the use of wind and solar energy.

Power plants have the biggest potential for co-incineration of refuse derived fuel. More than 40 power plants have the authorisation to use 4.65 million tons of refuse derived fuel per year in Germany. The core reasons that the cement producing industry chooses to avoid using refuse derived fuel that has been produced from household waste are (see: Eckard, 2005).

1. **Quality specifications are not met. The examples most often cited by the industry are having very high levers of chlorine content which are too low for a heating value and too high of a metal content;**
2. **The additional investment required for storage, handling and chlorine bypass are considered by the industry to produce a low cost benefit analysis;**
3. **The ashes produced by refuse derived fuel are not considered a viable ingredient for the manufacturing of high quality cement.**

To cover the costs and risks, the cement producing industry expected and received tipping fees of 30 to 50 €/t between 2006/7.

Both technologies, the grate and the fluidised bed, are able to incinerate waste derived fuel. The fluidised bed has a higher efficiency rate and fewer problems with NO_x and volatile heavy metal than the grate system. However, the fluidised bed often has more problems with erosion. Both plant types have problems with high temperature corrosion, which depends on the amount of chlorine in the refuse derived fuel. The classic solutions for dealing with these complications are cladding of the boiler tubes, doing a flue gas recirculation and/or reducing of the steam parameters.

The new measure which has recently been put into effect requires the pre-sorting of the refuse derived fuel with near-infrared (NIR) sorting systems to identify Polyvinyl chloride (PVC) or other chlorine containing materials such as, Pentachlorophenol (PCP), Polychlorinated biphenyls (PCB) and Chlorphenol. Very often these materials, mainly plastics, also contain heavy metals in an over proportionate amount.

Nevertheless, chlorine is still a serious problem when refuse derived fuel is incinerated because the corrosion is not as highly connected with PVC as is often expected. The main corrosion is connected with the proportion of inorganic chlorine compounds such as potassium chloride (KCl), sodium chloride (NaCl) and calcium chloride ($CaCl_2$). This inorganic chlorine content of 0.414 %, which is the basis line, is not detectable with NIR. To reach the average chlorine content in the residual waste of 0.69 % in Germany (Schirmer, 2007) and has not changed over the last 15 years, 0.55 % of PVC should not be exceeded. However, to describe the corrosion properly you also need to know the sulphur, calcium, siliceous and aluminium content in the refuse derived fuel. All of them have a corrosion inhibitive effect that takes place during the incineration process (see: Schirmer, 2007).

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Landfill Technology: Construction and Operation of Landfills

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A growing population and increasing living standards all over the world require an improvement of waste disposal strategies, especially in urban areas of developing and emerging countries, due to the related growth of waste quantity and toxicity.

Environmentally sound waste management contains:

- **Waste reduction;**
- **Waste recycling;**
- **Waste pre-treatment before disposal.**

In addition to these essential elements of an integrated waste system with high recycling rates and extensive waste pre-treatment, disposal of waste on landfills is usually indispensable. In many countries, landfilling of waste will be the first essential step towards an environmentally sound waste management practice for the next 10 – 15 years.

Worldwide many disposal sites suffer from insufficient designs and missing liner and leachate collection systems. Furthermore, many of these facilities lack basic operational equipment, have poor management and oversight, and do not have treatment processes for generated emissions.

According to international definitions, disposal sites are differentiated between dumps and landfills:

- **Dumps are disposal sites used to dispose of solid waste without any barriers, management and environmental controls.**
- **Landfills are disposal sites designed, constructed and operated to minimise environmental pollution as well as nuisances to residents.**

Uncontrolled dumps without barriers and without landfill management contain risks such as:

- **Life threats and health risks for people living and working on the site;**
- **Health risks for people living in the neighbourhood;**
- **Air pollution by burning of wastes;**
- **Contamination of soils, pollution of surface water and groundwater ;**
- **Attracting and providing a breeding ground for vermin.**

Often there is more than one reason for these less suitable practices:

- **Little public awareness;**
- **No legal requirements;**
- **Insufficient financial resources ;**
- **No availability of construction materials and products;**
- **Lack of local knowledge and experience.**

In Germany, a wide range of practical know-how and scientific knowledge of landfill technology has been collected during the last thirty years and is still developing. Additionally a lot of experience was gained in international projects of cooperation in waste management and disposal in low and middle income countries.

Therefore, a group of German landfill experts, who are working on different international projects, decided to compile their know-how to provide support to colleagues in developing and emerging countries. For this purpose, two leading German scientific committees in this field have founded the joint technical committee "Landfill Technology":

- **The "Committee on Geotechnics of Landfill Engineering" of the German Geotechnical Society (DGGT);**
- **The Committee "Sanitary Landfills" of the German Association for Water, Wastewater and Waste (DWA) and the Association of Municipal Waste Management and City Cleaning (VKS in the VKU).**

The Technical Committee develops the "Toolkit Landfill Technology" for landfill design, construction, and operation, which is specifically dedicated to technical experts to assist them with advanced engineering know-how in their professional work. The central approach of the Toolkit is to describe the possibilities of a stepwise improvement of planning and practice of disposal.

For the publication of the Toolkit, the internet has been chosen to ensure a fast and reasonable dissemination. All the contributions of the members of the Technical Committee to the Toolkit were intensively discussed by the whole group, reviewed by a sub-group of experts, edited, and finally passed at an official meeting. Therefore, the individual contributions do not only reflect the experience and point of view of the authors, but also the opinion of the Technical Committee on "Landfill Technology".

Objectives of the Toolkit

In feasibility study phase when planning a landfill the question often arises, which technical standard for barrier systems, treatment plants, and equipment for landfill operation should be chosen. The same question comes up when national authorities in developing and emerging countries develop national standards for landfills.

Appropriate technical standards for landfills should consider:

- **The hydrological and climatic conditions;**
- **The ecological requirements and effectiveness;**
- **The economic resources;**
- **The availability of construction materials and technology.**

Unfortunately, there are only few technical guidelines or recommendations, which can give assistance to landfill professionals in developing and emerging countries. In many European countries and in North America guidelines and handbooks for design and construction of sanitary landfills that focus on the situation in industrialised countries exist, but do not meet the particular regional requirements and frame conditions in developing and emerging countries. Only a few publications deal with landfill technology in developing countries in particular, and most of them are written for decision makers or give a comprehensive overview but without detailed engineering advice.

The "Toolkit Landfill Technology" has been developed to close this gap and will compile the methodical approach and detailed knowledge for:

- **Landfill design;**
- **Landfill construction;**
- **Landfill operation.**

The main objective of the Toolkit is to present the engineering methodology in order to enable colleagues in other regions to develop environmentally sound and cost-effective solutions that consider the socio-cultural, climatic and economic circumstances in their countries.

The “Toolkit Landfill Technology” focuses on the landfilling of municipal solid waste, but many methodologies discussed are not limited to this purpose and can be adapted to landfills for industrial and hazardous wastes and sludge deposits.

The scientific level of the Toolkit corresponds to the guidelines of the cooperating scientific-technical societies DGGT and DWA/VKS. In particular, the Technical Recommendations on Geotechnics of Landfills of the DGGT have been considered.

The proposals for technical solutions provide both minimum requirements and standards for advanced sanitary landfills.

Scope of the Toolkit

The “Toolkit Landfill Technology” consists of three parts:

- **Part I: Fundamentals;**
- **Part II: Regional Experience;**
- **Part III: Examples.**

In Part I, all the basic knowledge for landfill design, operation, closure and aftercare is subdivided into six main chapters:

- **Principles of sanitary landfilling;**
- **Siting and bottom liner systems;**
- **Collection and treatment of leachate and landfill gas;**
- **Landfill operation;**
- **Landfill closure and restoration;**
- **Landfill aftercare.**

Each of the main chapters consists of six or more papers, which explain detailed engineering background information of design principles, methods of calculation, constructional methods, and operating advice for the related issues. The final chapter of Part I describes economic calculations and instruments of finance.

In Part II, the present state of regional experience shall be reflected. International experts – cooperating with the Technical Committee – will describe the present situation, upcoming legal requirements, standard solutions and pilot projects in their countries.

This part is seen as an eminent part of the Toolkit, because regional procedures and knowledge of suitable solutions are made accessible in other regions by this way. This might be helpful in particular for decision makers to choose an adequate level of technology.

In Part III – the "treasury" for planning engineers - examples will be shown of:

- **Controlled dumps;**
- **Engineered landfills;**
- **Sanitary landfills;**
- **Interesting constructional solutions;**
- **Important details;**
- **Operating experience.**

The focus will be on cost effective and sustainable solutions, which are implemented or are seen to be useful in developing and emerging countries.
A bibliography, design tools for calculation, and internet links complete the toolkit.

Invitation for Participation

The "Toolkit Landfill Technology" shall be a "growing" and dynamic documentation of proper methodologies and solutions. Therefore, landfill experts from all over the world are invited to present additional experiences and examples.

A serious gap in landfill design in many developing and emerging countries is the limited knowledge of the quantity and quality of landfill emissions under arid and under very humid climates. This is especially the case if the disposed waste has a different composition compared to waste from industrialised countries.

For this reason, more data is necessary on:

- **Leachate quantity and quality;**
- **Landfill gas generation;**
- **Long-term performance of barrier systems.**

This data is the base for the design of treatment plants and barriers.
In addition to this data, progress reports of cost effective methods for treatment of leachate and landfill gas are welcome to amend the methods proposed in Part I of the Toolkit.

Apart from this question, especially case studies and examples of controlled dumps and landfills are helpful to demonstrate:

- **Successful design of controlled dumps and landfills;**
- **Liner constructions with a wide range of liner materials;**
- **Landfill operation under different climatic conditions.**

Finally, interesting construction solutions and details are welcome to help assist in spreading this technical information.The case studies and examples can become components of Part II "Regional Experience" and in particular of Part III "Examples" of the toolkit. Interested colleagues are welcome to contact the chairman of the Technical Committee.

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Waste Management in Low Income and Emerging Countries with Particular Attention to Energy Efficiency of Material Recycling and Energy Recovery of Selected Waste Fractions

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The strategic approach to sustainable utilisation of natural resources, according to the European Commission, ought to lead to better resource efficiency and resource productivity while at the same time reducing the negative ecological consequences of resource utilisation (anon., 2005). Accordingly, waste management measures must be investigated critically.

Following this approach, the instruments of waste management are also to be subject to a critical examination – this applies to highly developed countries as well as to developing countries to the same extent. In this document, classifications of various waste management instruments are planned with respect to a sustainable use of resources. In addition, consequences for waste management measures in developing and emerging countries are being explored.

Methods of Recycling

A high degree of importance is to be awarded to the judgment of principally applied recycling with respect to sustainable use of resources.

Fundamentally, according to European nomenclature, two forms of recycling can be defined: material recycling and energy recovery.

Material recycling means the substitution of raw materials by recovering substances from waste (secondary raw materials) and the utilisation of the material properties of the waste for their original purpose, or for other purposes, except for direct energy recovery. The main purpose of this measure is the utilisation of waste and not the elimination of its pollution potential. Under this, we subsume biological recycling with composting (aerobic process) and fermentation (anaerobic process).

The main purpose of energy recovery from waste must be the utilisation of the waste, however, not the elimination of its pollution potential as applicable to thermal treatment. Here, as a general rule, and in contrast to thermal treatment, waste materials are used whose combustion qualities were improved by prior mechanical processing leading to higher calorific values and a lower pollutant content. Method and degree of treatment may vary considerably. Neither treatment nor the product "refuse derived fuel" are defined by law. Both methods are using the energy content of the waste. In this article, we subsume thermal treatment under the category of energy recovery.

Assessment Approach

To assess resource efficiency, one needs to consider not only the immediate resource consumption and yields of the different recycling methods, i.e. the necessary data acquisition. One also needs to consider possible resource savings by making use of substance and energy recycling. The cumulated energy demand (CED) required for the manufacture of a product, from cradle to grave, is of crucial relevance for the evaluation of the energy consumption.

An important initial parameter in this context is therefore, the cumulated energy demand for waste relevant products, which are differentiated according to their production from primary or secondary raw materials. The lower calorific value of the considered product group and the energy efficiency of the employed thermal plants are also relevant for the evaluation approaches below. The energy efficiencies currently reached in waste incineration plants within Germany apply. These vary between a minimum of 21 % and a maximum of 76 %, creating an average of 45 %. The energy efficiency of straw combustion, relevant for biowaste, achieves approximately (≈) 21-29 % for pure electricity generation. Values of up to 92 % are reached for pure heat utilisation.

Energy Efficiency of Selected Waste Fractions

Whether material recycling or energy recovery is the most energy efficient solution is a question of particular relevance with regard to the following waste fractions: paper and cardboard, plastics, biowaste and also indirectly metals.

Paper, Cardboard and Plastics

The cumulated energy demand for the production of e. g. photocopying paper made of fibers gained from primary raw materials (cellulose pulp) of northern origin amounts to ≈ 39 MJ/kg (IFEU, 2006). According to the

latest data from the paper industry, the energy demand could meanwhile be reduced to 35 MJ/kg (IFEU, verbal communication 2009). The cumulated energy demand for the production of equivalent paper made of fibers gained from waste paper amounts to ≈ 15 MJ/kg. The net calorific value is ≈ 13.2 MJ/Kg. The net calorific value for waste paper and cardboard products is slightly lower due to moisture absorption during use, compared to "new products" (Fricke et al., 2008).

The cumulated energy demand necessary for the manufacture of plastic granules shows a large range for the different polymers. The same applies to the lower calorific value (Kindler and Nikles, 1979; Patel, 1999; BUWAL, 1991 and 1995).

Polyethylene:	CED 65–85	MJ/kg	Calorific value:	≈ 43	MJ/kg
Polyvinylchloride:	CED 51–55	MJ/kg	Calorific value:	18–20	MJ/kg
Polystyrene:	CED 72–89	MJ/kg	Calorific value:	≈ 40	MJ/kg

For the production of e. g. polyethylene granules from secondary raw materials, the cumulated energy demand amounts to ≈ 15 MJ/kg (HTP and IFEU, 2001; IFEU, 2004, own data).

This comparison demonstrates that material recycling, compared to energy recovery, offers higher energy efficiency for both considered waste fractions, even at high efficiencies of the combustibles (see table 1). Both, increasing differences between the cumulated energy demand, if production is based on primary raw materials or secondary raw materials, and the lower calorific value compared to the cumulated energy demand favor material recycling. At the same time, the limits of energy recovery are indicated.

Various studies basically reach the same conclusions (HTP and IFEU, 2001; IFEU 2006; UBA, 2000). Thus, energy recovery constitutes the most sensible form of disposal for waste paper and waste plastics, which are inapplicable for further material recovery, e. g. small, soiled components or composite elements.

Table 1: Cumulated energy demand for the production of paper made of fresh fibers and polymers on the basis of primary and secondary raw materials, as well as energy savings and provision for material recycling and energy recovery.

CED production from primary raw materials	CED production from secondary raw materials	Energy savings Using secondary vs. primary raw materials	Net calorific value	Energy savings Fuel efficiency 76 %	Energy savings Fuel efficiency 45 %	Energy savings Fuel efficiency 21 %
Copying paper	Copying paper	Copying paper	Waste paper			
35 MJ/kg	15 MJ/kg	20 MJ/kg	13.2 MJ/kg	10.0 MJ/kg	5.9 MJ/kg	2.8 MJ/kg
PE-polymer [)]	PE-polymer	PE-polymer	PE-polymer			
68 MJ/kg	up to 15 MJ/kg	53 MJ/kg	43 MJ/kg	32.7 MJ/kg	19.4 MJ/kg	9.0 MJ/kg

[1)] excl. energy demand for processing into finished product

In accordance with an improved energy efficiency of material recycling vs. energy recovery, the climatic effects of substance-related recycling are also considered less harmful. The results of various life cycle assessments confirm this statement (HTP and IFEU, 2001; IFEU, 2004); IFEU, 2006; UBA, 2000).

Biowaste

Due to its high water content, frequently above 60 %, biowaste has a very low net calorific value of ≈ 2–3.6 MJ/kg. Separate collection of biowaste is only sensible, if recycling products like compost are used in agriculture or horticulture, as is done in Germany, and if the prevalent high demand for product quality is met. Energy recovery would be accomplished in combination with residual waste. To assess energy efficiency the above-mentioned efficiencies of waste incineration plants must be considered.

In Germany, straw is one of the most important substances employed for balancing humus in farmland. If compost is used to substitute straw for the purpose of humus regeneration, the substituted straw could be utilised as a regenerative energy source in biomass power plants. On the basis of the nutrient contents and considering the loss of mass during the composting process, a substitution equivalent factor of 0.44 ensues for biowaste compared to straw, i.e. 1 Mg biowaste corresponds to 0.44 Mg of straw (Fricke et al. 2010).

Material recycling of biowaste into compost and energy recovery from the substituted straw, leads to higher energy efficiency compared to direct energy recovery of biowaste (cp. Table 2). The integration of anaerobic digestion increases the energy efficiency of material recycling even further.

Table 2: Energy provision for energy recovery of biowaste and straw as biowaste-straw equivalent with different fuel efficiencies

	Energy provision	Energy provision	Energy provision
Calorific values	Fuel efficiency 76 %	Fuel efficiency 45 %	Fuel efficiency 21 %
Biowaste 3.2 MJ/kg	2.43 MJ/kg	1.44 MJ/kg	0.67 MJ/kg
	Fuel efficiency 92 %[1]	Not specified	Fuel efficiency 21 %[1]
Straw 14.4 MJ/kg			
Biowaste-straw-equivalent 6.34 MJ/kg	5.83 MJ/kg	Not specified	1.33 MJ/kg
Net provision[2]	5.13 MJ/kg		0.63 MJ/kg
Net provision with utilisation of biogas[3]	5.63 MJ/kg		1.13 MJ/kg

[1]Fuel efficiency straw-biomass power plant;

[2]Taking into account the energy demand for transport of biowaste and straw, as well as composting with a total of 0.7 MJ/kg;

[3]100m^3-biogas/Mg fresh matter, 60 % CH_4-content, 35 % – 80 % efficiency, 0.75 – 1.72 MJ/kg, less additional excess energy demand during anaerobic phase 0.70 MJ/kg. (0.5 MJ/kg)

Metals

In order to assess which method of recycling should be applied to metals, one needs to consider the following questions; if, and in what quantity and quality, can waste metals deriving from specific waste streams (e. g. separately collected metals, lightweight packaging, raw waste and slag) be separated and brought into the recycling process. Steel, aluminum and copper are the principal metals of urban waste being considered here.

With regard to household and commercial waste, the waste fraction of metals demonstrates the highest specific potential for energy savings and environmental protection (see Table 3).

For ferrous metals, state separation performance rates in German sorting plants of up to 98 %; for nonferrous separation (Al) of up to 84.7 % (HTP and IFEU 2001). According to the authors, these ferrous and nonferrous separation performance rates are overstated. Own assessments of mechanical processing steps of MBT and secondary fuel production plants showed performance rates of up to 86 % for ferrous separation (Fricke et al., 2003). For nonferrous metals separation performance rates of up to 75 % are effectively reached.

Table 3: Comparison of CEDs for the production of selected metals from primary and secondary raw materials

Metal	Energy demand for steel production		Energy savings due to recycling
	Primary raw materials	Secondary raw materials	
Crude steel [1]	16.2 MJ/kg	6.1 MJ/kg (scrap car recycling)	62 %
Oxygen steel [1]	20.4 MJ/kg	6.5 MJ/kg (packaging)	68 %
Aluminum [2]	211.8 MJ/kg	15.3 MJ/kg (scrap car recycling)	93 %
		16.4 MJ/kg (packaging)	94 %
Copper [3]	Pipes 32.1 MJ/kg	3.4–9.2 MJ/kg	80–92 %
	Wire 50.4 MJ/kg		
	Sheets 31.8 MJ/kg		

[1] ISI, 2004; Mutz, 2001; [2] ISI, 2004; Krone, 2000; [3] DKI, 2000 and 2005

Meaningful data about the efficiency of ferrous and nonferrous separation from slag are scarce.

According to Prof. Dr.-Ing. Arnd I. Urban from the University of Kassel (verbal communication, 2008), tin plate and aluminum foils are crushed during the incineration process and in form of fine grains are sintered with the slag. Furthermore, it can be assumed that proportions of the nonferrous metals, depending on the thickness of the foil, are oxidised during the incineration process. Separation via the eddy current method is therefore only possible to a limited extent. IFEU (2007) states efficiency rates of ≈ 66 % for the separation of ferrous metals from slag in waste incineration plants.

Separate collection and/or sorting of raw waste streams results in higher recovery rates than slag processing. In general, the authors conclude that the separation efficiencies for ferrous metals and nonferrous metals in particular show great potential for optimisation.

Consequences for Waste Management in Developing Countries

With regard to energy efficiency, substance-related recycling of specified waste fractions like paper, cardboard, plastics, biowaste and metals has clear advantages compared to energy recovery. Which conclusions can be drawn from these facts for waste management?

Therefore, material recycling should be intensified for the above-mentioned material categories.

Step 1: Material Recycling

- **Separate collection using curbside and drop-off systems,**
- **Sorting from a mixture of materials and total waste and**
- **Intensification of anaerobic technologies for recycling of biowaste.**

Step 2: Energy Recovery

- **Thermal treatment or energy recovery of the remaining non-recyclable waste, with or without prior treatment in mechanical or mechanical-biological treatment plants and**
- **Optimisation of energy efficiency of these plants in order to maximise the effective energy gain.**

Intensifying Separate Collection

Despite the good economic conditions for separate collections and existing, adapted collection and transport systems, these are only practiced on a low scale by the informal sector and are therefore often badly organised, irregular and selective. The collection rate achieved, thus only reached values between 5 and 8 %. A well-organised municipal or private separate collection system does not exist, or only exists on a small scale. This is to be traced back to different factors, e. g. the shortage of specific information for stakeholders and among the technical experts regarding:

- **The market for secondary resources e. g. revenues, quality requirements and demand;**
- **Waste quantities and qualities;**
- **Appropriate technologies for collection and transport, efficiency of existing collection systems;**
- **Instruments for economic modelling of the various available waste management instruments;**
- **Knowledge of the acceptance by the population for participating in separate collecting systems.**

To increase separate collections, these important gaps must be closed.

Following comparative studies and experience from developing countries, which have primarily occurred in urban areas, the following measures are to be classified as suitable, under economically favourable conditions high rates of collecting and recovering are to be realised:

- **Supporting the informal sector including long term guarantees of revenue, making collecting equipment available, training;**
- **Integrating the informal sector into the total system of waste management;**
- **Setting up systems of drop off points for paper and cardboard, glass, metals, plastics;**
- **Setting up systems of curbside collection (bins and/or bags) for biowaste.**

Establishing Assorting Facilities

Sorting the remaining recyclable material is done in sorting plants, which are preferably integrated into or used prior to plants for waste treatment before disposal, such as, mechanical-biological pre-treatment (MBT) and thermal waste treatment (IP). The target fractions are paper and cardboard, plastics, glass, metals and wood.

Against the background of low personnel, costs and the generally prevailing labour policy goal of creating jobs, waste processing and sorting plants are to be adapted to correspond to these conditions. Personnel intensive sorting concepts are to be preferred to automatic process technologies. Other propositions ought to be in line with appropriate issue of health care and occupational safety.

As it is also the case for separate collecting, the informal sector is to be integrated, i.e. as sorting staff. Flat bunkers are to be preferred for deliveries. This delivery concept offers the possibility of storing specific qualities of waste temporarily in special bunker sections, in order to add them to the waste stream in an intended manner or to be able to supply special sectors of the sorting plant. Separation of impurities, contaminants and harmful substances as well as large pieces of recyclable material manually and by using loading devices is also possible. The transfer of the material to the processing and sorting stage can be done by wheel loaders or mobile excavators with polyp gribber. In most simple plants with small processing capacities, a manual approach (shovel/pitch fork) is also practical. Before being handled on the sorting belt the mixture of material ought to be processed with an aggregate for opening bags and agglomerates (bag opener) and a device to separate material (screening stage with sieving section of ≈ 80 to 100 mm). The coarse grain, mainly waste packaging, is placed on the sorting belt and sorted manually. The fine grain and the remnants of the coarse grain are processed by biological residual waste treatment.

Summary and Conclusion

At present, developing and emerging market countries are increasing their efforts to handle waste management and waste disposal issues. A number of measures are available and have been pointed out, starting from source separated collection up to more climate friendly waste treatment and disposal methods.

Out of the described material categories, material recycling has clear advantages compared to energy recovery. In accordance with the improved energy efficiency of substance versus energy recovery, the climatic effects of substance-related recycling are also considered less hazardous. Therefore, material recycling should be intensified for the above-mentioned waste fractions.

For the recyclable fractions paper and cardboard, plastics, biowaste and metals it becomes apparent, that intensification of the separate collection systems in combination with a more intensive use of sorting technologies can increase the extent of material recycling. Collection and sorting systems must be coordinated. The objective of the overall system must be to achieve an optimum between the highest possible recovery rates and a high quality of recyclables.

Material recycling is the most reasonable activity due to booming markets for secondary resources. However, it should be noted that markets for recyclables are volatile and may be subject to quick changes.

The reuse techniques for the recyclables are subject to future developments increasing material reuse aiming on significant savings of primary energy. This progress may increase the attraction of advanced recycling technologies. Regardless to what extent the recycling activities may be improved residual waste needs to be disposed of.

As a consequence of intensified material recycling, the fraction of high calorific value and the net calorific value of the remaining waste will decrease significantly in the medium term. In Germany, this process has already started due to intensified paper and cardboard collection.

In the medium term, one can expect costs for primary raw materials to rise significantly. This development in turn will stimulate the proceeds situation for secondary raw materials. The current price development of crude oil and various metals substantiates this assumption. Paper and cardboard, in addition to metals, will no doubt be the first fractions to reach the status of self-supporting resource management financed through proceeds. Considering the expected market development for secondary plastics, this process will in the medium term be brought about also for this material category.

In order to build up a more sustainable waste management, a change of consciousness is needed with regard to the importance of resource protection. One of the biggest obstacles is still the stigmatisation of secondary raw material waste – resulting in inadequate proceeds. However, developments in climate protection seem to indicate that before long the vital importance of the problem of resource shortages will be recognised and be classified by all social classes as one of the most important challenges of the years to come.

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Occupational Safety and Health Risk Assessment of Workers in Solid Waste Management - Experiences from Addis Ababa, Ethiopia

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The research project "IGNIS – Income Generation and Climate Protection by Valorising Municipal Solid Wastes in a Sustainable Way in Emerging Megacities – exemplarily for the City of Addis Ababa, Ethiopia", funded by the German Ministry of Education and Research (BMBF), strives to develop a new concept for the improvement of waste management and the local environment while generating new workplaces, increasing general welfare and reducing greenhouse gas emissions. The project consortium is comprised of public institutions, universities and NGOs from both Germany and Addis Ababa, Ethiopia. The Federal Institute for Occupational Safety and Health, Germany is one of the project partners. One focus of the project is the improvement of the occupational safety and health of waste workers in the informal and semi-formal waste management sectors.

Occupational Safety and Health in the Informal Waste Management Sector

Health is a human right. Therefore, the prevention of health impairments has to take priority over treatment. In IGNIS, pilot projects in the field of waste collection and recycling are set into effect, scientifically evaluated

and adjusted. We focus on the informal or semi-formal waste management sector since it provides the best income generation opportunities for many labourers with low levels of education. As a consequence, low-scale, inexpensive technologies which require foremost manual labour are implemented. These might be associated with elevated safety and health risks which might not be treated adequately due to limited access to health care facilities. In this environment, the worker's health is his/her greatest asset and a precondition for the sustainable generation of income.

Some examples for the waste management activities surveyed and analysed within the project are:

- **Door-to-door collection of mixed waste:**
  Groups of collectors transfer waste from any kind of container into wheat sacks or directly into a pushcart. These collectors must then travel over rough, unpaved or cobbled, often inclined roads to a collection site, where the waste is manually emptied into a container or truck.

- **Door-to-door collection of recyclables:**
  Individuals walk from house to house and buy metal, glass and plastics. These materials are then transferred into their wheat sacks and often these heavy loads

are carried over long distances to the marketplace where the items are sold to intermediate buyers.

- **Small scale composting:**
  Groups sort the waste and create windrows on a concrete floor under a roof. The windrows are then turned manually.
  Recycling of inorganic materials: Procedures depend on the input material but involve only basic tools.

Risk Assessment

The activities listed above are associated with a wide variety of safety and health risks. Handling mixed wastes with a high percentage of ashes and organic materials during collection and composting involves inhalation exposure to airborne organic dusts covered with microorganisms. Exposure to hazardous substances of unspecified origin is to be expected and musculoskeletal disorders caused by the handling of heavy loads prevail.

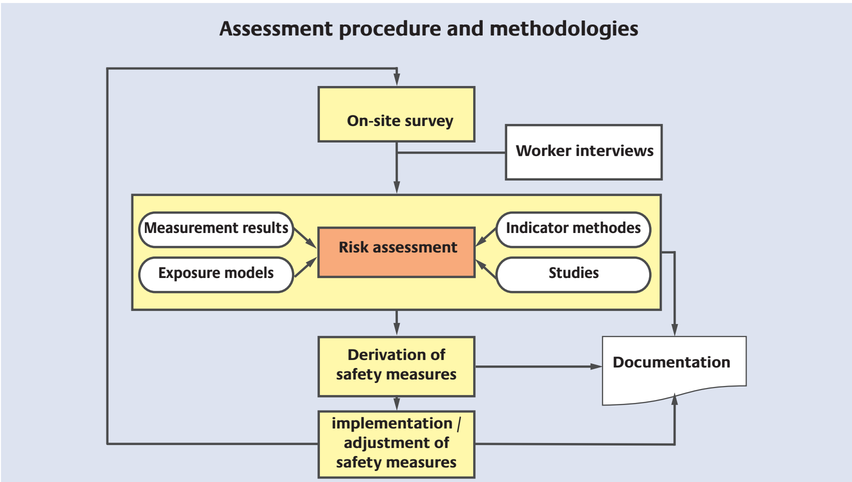

Table 1: Allocation of risk scores to risk ranges and resulting demand for interventions

Risk range	Risk score	Description
1	< 10	Low load situation, physical overload unlikely to appear.
2	10 – <25	Increased load situation, physical overload is possible for less resilient persons. For that group redesign of workplace is helpful.
3	25 – <50	Highly increased load situation, physical overload also possible for normally resilient persons. Redesign of workplace is recommended.
4	> 50	High load situation, physical overload is likely to appear. Workplace redesign is necessary.
Working procedures with a risk range of four have to be improved immediately.		

Thus, a high variety of potential health and safety risks can be observed. In the next step, a detailed risk assessment has to be performed in order to find out if this potential risk is high enough to cause adverse health effects and to derive appropriate counteractive measures.

For risk evaluation, a variety of methods can be applied. Health risks during lifting procedures, for example, can be assessed with the Key Indicator Method by the Federal Institute for Occupational Safety and Health. Relevant risk parameters are recorded and assigned to rating points. Time rating points are then derived, depending on the number of lifting procedures, the holding duration or the carrying distance during one workday. In a second step, rating points for the load handled during the lifting/holding/carrying activity, the body posture assumed during the procedure and the working conditions are determined and summarised. The result is multiplied with the time rating points to obtain a risk score, which is allotted to a risk range between one and four.

Challenges

If existing methods, e. g. indicator methods, are chosen for risk evaluation, it has to be taken into consideration that these were developed based on studies on the physiology of the Central-European population and for the industrial context. Therefore the actual working conditions and procedures in the informal waste management sector in developing countries are not fully assessable against these methods and effects of inexpensive, low-level measures might not be sufficiently discernible.

According to European legislation, all risks with high scores have to be reduced. Although this should be the final goal for every workplace, reality within the informal sector might demand different prioritisation due to technical and financial constraints. In this case, a priority list has to be developed to indicate which of several risk factors should be addressed first.

However, this proves to be challenging since the assessment of different risk factors (e. g. mechanical risks, exposure to hazardous substance and risk of musculoskeletal disorders) requires different methods with different kinds of results. In some cases, a three-level hierarchy is used while in other cases, as in the example above, the results are assigned to a four-level hierarchy or measurements are compared with threshold limit values – which are either exceeded or not. For some risk factors, no such evaluation methodologies exist and the risk is described as “dangerous” or “not dangerous” by the safety expert. The development of such a priority list is work in progress within IGNIS.

Safety Interventions

For the derivation of safety interventions the following, acknowledged hierarchy of measures based on their efficiency can also be applied in the informal waste management sector.

1. **S Substitution of hazardous process or material**
2. **T Technical measures**
3. **O Organisational measures**
4. **P Personal protective equipment**
5. **P Personal behaviour**

Lifting device – “Balance stick”

Measures found on top half of the hierarchical chart are most efficient. However, in developing countries, occupational safety and health intervention is often associated with personal protective equipment, one of the least effective measures. The ineffectiveness is in large part due to the demand for correct application, insufficient supply as well as inadequate materials of some of the available equipment.

The following pictures show that simple, efficient technical measures, also called “engineering control devices” in the industrial context, can be developed even for very basic workplaces.

Alleviation of musculoskeletal strains during weighing procedures: a wooden stick is placed across the shoulders of two people, thereby transferring the weight vertically onto the spine. Two screws inserted in the middle of the stick prevent the balance from sliding in one direction.

Reduction of airborne dust particles by covering the process with inexpensive plastic foil held beneath the respiratory tract of the workers.

Encapsulation of dust-generating procedures

Summary / Key points

- **Prevention is a priority;**
- **Detailed risk assessment is obligatory to derive adequate safety measures;**
- **Existing methods need critical evaluation/adaptation when applied in a low-tech context in developing countries;**
- **Low-scale and inexpensive measures in accordance with the hierarchical guidelines are feasible;**
- **Further research regarding baseline data and tools for risk assessment in the informal sector is recommended.**

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Occupational Health Hazards in Municipal Solid Waste Management

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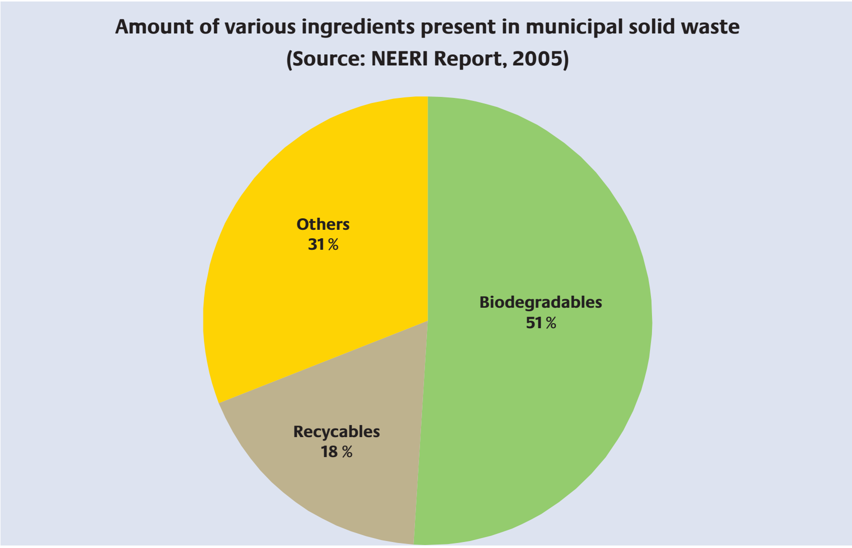
Municipal solid waste management involves various types of activities, e. g. collection, storage, transportation, treatment and disposal. In India, the community bin system has been adopted for collection of municipal solid waste. In this system, a resident is supposed to deposit waste in nearby community bins. In a few areas, house to house collection has also been adopted. In most of the cities in India, sanitary landfill is not available. Waste is dumped in specific low-lying areas.

Municipal corporations are responsible for management of municipal solid waste. In India, solid waste management activities are mostly manpower oriented. Staff is employed to carry out various activities. Thus, the staff is often directly exposed to the waste while performing their duties, which cause adverse impacts on their health. Health status of municipal solid waste workers is discussed in this paper.

Characteristics of Municipal Solid Waste

Municipal solid waste contains various constituents of multiple characteristics. Biodegradables like fruits, vegetables, kitchen waste etc. are present in substantial amounts. Recyclables like paper, plastics, metals and glass are also present in the waste. The following figure (p 234) represents the amount of various ingredients present in the municipal solid waste in India.



Salient Features of Health Status of Municipal Solid Waste

Categories of staff involved in municipal solid waste management are as follows

- **Collection staff;**
- **Drivers;**
- **Loaders;**
- **Disposal staff.**

Collection staff is usually involved in the collection of domestic waste as well as the cleaning of roads. The staff normally uses handcarts and wheel barrows to collect the waste and then transfers the waste to the community bins. Drivers are engaged in driving the bigger vehicles for waste transference from the collection points to the disposal site. Loaders are engaged in loading the community bins onto the vehicles. Disposal staff

Table 1: Unhygienic Practices in Municipal Solid Waste Management

Sr. No.	Activities	Non-Hygienic Practices
1	Collection and storage of waste	Non-use of protection gear
		Delay in removal of biodegradable matter
		Use of short-handled broom in road sweeping
		Bins/containers without lid
		Mixing of industrial and biomedical waste with municipal solid waste
2	Transportation of waste	Non-use of protective gear
		Carrying uncovered waste in vehicles
		Use of old vehicles
		Manual loading
		Smoke nuisance caused by vehicles
3	Segregation of waste	Non-use of protective gear
		Open burning of waste
		Spreading of the waste
4	Treatment of waste	Non-use of protective gear
		Windrow composting in unlined floor/Uncovered space
5	Disposal of waste	Non-use of protective gears
		No application of soil cover
		Disposal in unlined landfill
		No compaction of waste
		Poor drainage and leachate collection system
		No recovery of landfill gas

is employed at the disposal site for unloading the vehicles and management of waste at the site. In addition to this, waste pickers from the informal sector are involved in segregation of recyclables. Both males and females are involved in these activities. Unhygienic practices usually observed in municipal solid waste management are presented in Table 1.

Health studies carried out in an Indian city revealed that almost all categories of staff, more or less, are suffering from health disorders.

In India, open waste water and sewers often run along the same paths.

A large fraction of the staff was found to be suffering from chest and abdomen pain, musculoskeletal movement restrictions, abnormalities in blood pressure and respiratory problems. Abnormalities have been observed in pulmonary function tests of many workers. Pathological testing of blood samples showed an increase in C-reactive protein and an increased erythrocyte sedimentation rate (ESR) which indicates signs of inflammation. Some major reasons for these health disorders are a lack in proper waste management and non-use of protective gear; open dumping of waste, an absence of sanitary landfills and improper design of collection implements. Proper source segregation is also not carried out. As a result, biomedical and industrial waste also sometimes reaches landfill sites and community bins.

Preventive Measures

It is necessary to provide protective gear to municipal solid waste workers, such as goggles, hats, masks and gumboots. Regular health check ups, provision of nutritious food and the use of properly designed collection implements are also some of the other major preventive measures. It is also necessary to have strict supervision so that industrial waste and biomedical waste do not get mixed with municipal solid waste.

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Acronyms and Abbreviations

3P	Concept of People, Planet and Profit
ADB	Asian Development Bank
ASP	Activated Sludge Process
ASP	Active Server Pages
AST	Activated Sludge Tank
AtCo	Atmospheric Water Condensation
AusAID	Australian Government´s overseas aid program
AVSWAT	Hydrological Model with an ArcView GIS Interface
BAuA	Federal Institute for Occupational Safety and Health
BMBF	German Federal Ministry of Education and Research
BOD	Biochemical Oxygen Demand
$CaCl_2$	Calcium Chloride
CARL	Current Annual Real Losses
CE	Communauté Européenne
CED	Cumulated Energy Demand

CFD	Computational Fluid Dynamics
CHP	Combined Heat and Power
CHPP	Coal Handling and Preparation Plant
COD	Chemical Oxygen Demand
CO_2	Carbon Dioxide
CPCB	Central Pollution Control Board
CPD	Construction Products Directive
CPSP	Country Policy Support Programme
DEM	Digital Elevation Model
DeSal	Desalination
DLR	German Aerospace Centre
DM	Dry Mass
DMF	Dual Media Filter
DMSO	Dimethyl Sulfoxide
DST	Department of Science and Technology
EBRD	European Bank for Reconstruction and Development
EF	Environmental Flow
EFA	Environmental Flow Assessment

EFR	Environmental Flow Requirement
EIA	Environmental Impact Assessment
ESR	Erythrocyte Sedimentation Rate
EU	European Union
EZ	Development Cooperation (Entwicklungszusammenarbeit)
FAO	Food and Agriculture Organization of the United Nations
FC	Fuel Cell
FDC	Flow Duration Curve
FM	Fresh Matter
FONA	Research for Sustainability
FZ	Financial Cooperation (Finanzielle Zusammenarbeit)
GAP-1	Ganga Action Plan Phase I
GHG	Greenhouse Gas
GIS	Geographic Information System
GIV	Gross Intrinsic Value
GTZ	German Society for Technical Cooperation
GUI	Graphical User Interface
GWFA	Global Water Franchise Agency

GWP	German Water Partnership
Ha	Hectare
HadRM2	Hadley Centre Regional Climate Model 2
HadRM3	Hadley Centre Regional Climate Model 3
HEX	Highly Exothermic
HIGEE	High Gravity Process
HRT	Hydraulic Retention Times
ICID	International Commission on Irrigation and Drainage
ICT	Information and Communication Technology
IEA	International Energy Agency
IEEM	Institute of Environmental Engineering and Management
IFIM	In-Stream Flow Incremental Methodology
IGNIS	Income Generation and Climate Protection by Valorizing Municipal Solid Wastes in a Sustainable Way in Emerging Megacities
IIT	Indian Institutes of Technology
IITM	Indian Institute of Tropical Meteorology
INRES	Institute of Crop Science and Resource Conservation
INRM	Integrated Natural Resource Management

IPCC	Intergovernmental Panel on Climate Change
IPH	Irrigation and Public Health
ISCST	Industrial Source Complex Short Term
IUCN	International Union for Conservation of Nature
IWA	International Water Association
IWMI	International Water Management Institute
IWRM	Integrated Water Resources Management
KCl	Potassium Chloride
KfW	Credit Institute for Reconstruction
LandGEM	Landfill Gas Emission Model
LCS	Lignocellulosic Substrates
LED	Light Emitting Diode
LIT	Laxminarayan Institute of Technology
MAE	Maharashtra Academy of Engineering
MBT	Mechanical Biological Treatment
MFA	Material Flow Analysis
MFN	Minimum Flow Need
MMTPA	Million Metric Tonne per Annum

MONERIS	Modelling Nutrient Emissions in River Systems
MS	Member State
MSW	Municipal Solid Waste
NaCl	Sodium Chloride
NaOH	Sodium Hydroxide
NEERI	National Environmental Engineering Research Institute
NIR	Near-Infrared Sorting Systems
NRW	Non-Revenue Water
ODA	Official Development Assistance
OECD	Organization for Economic Cooperation and Development
OFR	Oscillatory Flow Reactor
OLR	Organic Load Rate
O&M Cost	Organization and Management Cost
OSH	Occupational Safety and Health
PCB	Polychlorinated Biphenyls
PCP	Pentachlorophenol
pH	pH-Value
PI	Process Intensification

PRV	Pressure Reducing Valves
PVC	Polyvinyl Chloride
RAP	River Action Plan
RCM	Regional Climate Model
RCP	Retention Cum Polishing
RDF	Refuse Derived Fuel
RSF	Rapid Sand Filter
SBR	Sequential Batch Reactor
SDR	Spinning Disk Reactor
SME	Small and Middle Sized Enterprises
STP	Sewage Treatment Plant
SWAT	Soil and Water Assessment Tool
TMR	Total Material Requirement
TZ	Technical Cooperation
UARL	Unavoidable Annual Real Losses
UASB	Upflow Anaerobic Sludge Blanket
UICT	University Institute of Chemical Technology
UNEP	United Nations Environment Program

UNFCCC	United Nations Framework Convention on Climate Change
UNU	United Nations University
USAID	United States Agency for International Development
UV	Ultraviolet
VOC	Volatile Organic Compound
VNIT	Visvesvaraya National Institute of Technology
WB	World Bank
WEEE	Waste Electric and Electronic Equipment
WHO	World Health Organization
WISDOM	Water Related Information System for the Sustainable Development of the Mekong Delta
WMO	World Meteorological Organization
WMS	Waste Management System
WSP	Waste Stabilisation Pond
WWTP	Waste Water Treatment Plant

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